SHOWCASING SPACE

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Artefacts series: studies in the history of science and technology

In growing numbers, historians are using technological artefacts in the study and interpretation of the recent past. Their work is still largely pioneering, as they investigate approaches and modes of presentation. But the consequences are already richly rewarding. To encourage this enterprise, three of the world's greatest repositories of the material heritage of science and technology: the Deutsches Museum, the Science Museum and the Smithsonian Institution, are collaborating on this book series. Each volume treats a particular subject area, using objects to explore a wide range of issues related to science, technology and medicine and their place in society.

Edited by Robert Bud, Science Museum, London
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Contents

Notes on contributors

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Series preface

With the rise of formal academic programmes in the history of science and technology over the last half century, the hope was occasionally expressed that these new scholars, as they developed new traditions, would turn to artefacts, carefully preserved in both public and private museums, as fodder for their research appetites. With some notable exceptions, this has not proven to be the case. Even those scholars who entered museums as curators have produced only a modest number of publications where historical conclusions depend on analysis of the collections.

The situation was aggravated as museums changed in the late twentieth century. Some responded to calls for improvement in science education, turning themselves wholly or partly into science/ technology 'centres'. Others responded to trends in the academic community, developing exhibits that placed science and technology in broader social contexts. In the former case, if they were used at all, objects appeared as symbols or icons. In the latter case the pressure to develop social-history approaches has too frequently meant that museum curators look to academia not only for theoretical structures but also for suggestions on where to find supporting evidence, and objects end up as illustrations for the text rather than as fundamental sources.

It was in this environment that the first 'Artefacts' conference took place in 1996. Representatives from the Science Museum, the Deutsches Museum and the Smithsonian met with colleagues from other museums and from academia. We hoped that through formal presentations and through discussion we might begin to develop models for how objects can be used effectively in historical studies. The results would appear in book-length publications (stimulated by the meetings, but not formulated as 'proceedings'). Each meeting, and each volume, would focus on a particular topic.

Now, ten years later, volumes on the topics of medicine, electronics, transport, images and the military have already been published. Space is therefore the sixth topic to be covered.

In the decade since the enterprise began, its context has changed for the better. Museums have come to work more often with the academic history of science, technology and medicine to interpret together the symbolic and the instrumental qualities of artefacts. It has become clear that engagement with artefacts can stimulate new stories as well as unearthing new facts. In many of the papers published through this series, the problem rather than just the solution has been raised by the history or even the presence of a single relic. Nurturing the trend to such a rich and varied use of artefacts in the histories of science, technology and medicine is the challenge taken up by this series.

Each volume also contains a section treating museums that feature the subject being considered. This indicates the wealth of material that has been preserved in collections, and the extent to which it is being used for various levels of interpretation in exhibits. While typically discussion of exhibitions has emphasised design and communication, we hope that these contributions will stimulate debate too on the intellectual underpinning of the use of material culture in museums.

Martin Collins

Introduction

What stories might space artefacts tell? Do they speak for themselves? Or do they, in David Noble's oft-referenced turn of phrase, represent 'frozen history' – a dense sediment of human agency, culture and technology?[1] And, more particularly, as products originating (primarily) in Cold War culture, do space artefacts pose historiographic questions and issues different from those posed by artefacts with other histories?

Within the history of science and technology, the questions above reflect a long-standing concern with the artefact as a theoretical problem – as a focal point for creating models of technical change and, more broadly, for creating models that provide a comprehensive framework for understanding the intersection of technical and cultural change. History of science and technology, of course, are not the only disciplines with an interest in the artefact as a site of inquiry.[2] For traditional anthropology and material culture studies, the artefact has long been an entrée into exploring the meanings and practices associated with particular cultures. Artefacts may illuminate a culture through the details of their creation and use (materials, craft skills, exchanges, rituals) as well as through their associated symbolism. History of science and technology have drawn on these methodologies, but with the addition of a unique concern: to investigate how over the last 500 years science and technology have become the pre-eminent means for understanding and controlling nature, and thus a crucial form of social power. From this vantage, scientific–technical objects – from laboratory instruments to nuclear reactors and rockets – stand as important markers, evidence and enablers of this profound transformation.[3] In the 1970s, science and technology studies used this insight to cast the artefact in a specific, critical theoretical role – as the nexus through which one could comprehend both technical and cultural change. These methodologies offered a kind of unified theory of micro- and macro-history, of the details of the 'act of invention' in the laboratory or technical project and the larger frame of culture. Superficially, this historiographic turn seemed a kind of alliance between internalist and externalist perspectives of the 1950s and 1960s. Yet it started from a distinct assumption: that science, and by extension technology, through their methods of producing knowledge, not only generated claims about what the world is and how it works but were forms of social power as fundamental as politics, religion or economics in understanding the making and changing of culture. In short, explaining scientific, technical and cultural change were fundamentally related tasks. Science, technology and culture were 'co-produced', taking shape together through the artefact, none the simple effect of the other's cause.[4]

How might space artefacts – as museum objects, as focuses of historical inquiry – fit into this evolving historiographic discussion? They are, for the most part, products of a particular milieu – the Second World War, the Cold War and the emergence of state-sponsored big science and technology projects.[5] In recent years, private markets and corporations have established a new (but overlapping with the state-based model) context for creating space technologies. In either context, situated within the complex institutional and technical environment of a 'big' project, space artefacts pose interesting challenges: What is the relationship between a given artefact and the larger project? What are the possible ways in which artefacts, projects and culture intersect? Does the artefact in and of itself offer the opportunity for insights into technical or social change that other interpretative angles might not?

Two features of big technology that are particularly true of space efforts complicate the status of the artefact. One is the strategies of project management that have been central to missile and space-technology undertakings. The creation of technologies in this context pertains not only to a confluence of problem definition, design, research, development, testing and production, but also to a highly-structured, detailed system of managerial control and documentation that coordinates and describes these activities. This project-management culture is an inseparable part of the structure of big technology projects – indeed, it too can be conceived as a technology – and may be regarded as organically part of the artefacts produced through a project. Posed another way, this circumstance raises the question of what counts as 'an' artefact within the context of the project and in what fashion might the historian define and relate a project's components.[6]

Another closely-related feature of big technology that complicates the meaning of space artefacts is the *idea* of the project. As a Cold War construct, the project is a conceptual and practical instrument – a means for the state or a group of states to organise resources that are dispersed geographically and institutionally and to focus them on the solution of particular problems. A range of government entities, of corporations acting as prime and subcontractors, and universities may channel expertise in and through a project. To reach its specific objective (whether a missile, satellite, instrument or subsystem) the project alters social boundaries and tends to de-centre the work and contributions of individual teams or research sites. The assumption of the older historiography was that the act of invention was a local phenomenon, a concentration of problem, inventor and material culture at a given site. The Cold War-style project raises questions of how to characterise the actors and places through which artefacts are created and how these relationships may be reflected in the artefact.[7] These questions take on added significance as the US-developed project template was adapted, for example, in the multinational programmes created in Europe and as the market rather than the state began to organise big-technology space projects at the end of the Cold War.

In addition to these structural and conceptual features, Cold War big-technology artefacts also represent a distinctive relationship among science and engineering expertise, innovation and problem-solving. As research and development initiatives (another Cold War conceptual category), space artefacts often never were fully settled entities in a design or material sense. Typically, projects posed technical problems that required extensions in the state of the art (say, in the creation of or processing of materials) or in how scientific principles applied to understanding design or performance of an artefact (say, the behaviour of electronics in space). In many cases, artefacts proceeded through iterations of design, development and test, with the artefacts undergoing constant revision – the creation of stable, settled technologies was more the exception than the rule. This circumstance was intimately connected with the larger political culture of the project: state sponsors placed a high value on innovation and state-of-the-art performance. This contingent, fluid situation at the working level bears more scrutiny – as a means to understand the context and details of innovation and their connection to the Cold War culture.

The importance of governmental political acts in creating and sustaining big technology projects has made the programme history seem the natural and key methodological approach to explicating the Cold War fusion of technology and state interests. In this genre, the artefacts and the specifics of innovation are subsidiary to politics and management. Recent historiographic perspectives that see the artefact as a uniquely crucial site for exploring the co-production of culture and technology implicitly shift the emphasis of the programme history away from high-level politics and toward the multifaceted terrain of 'ground-level' engineers and managers. But as the points above on big technology and artefacts suggest, this methodology, too, faces challenges in comprehending the Cold War experience and space artefacts.[8]

These historiographic issues cycle back to the museum in several ways. Might artefacts created through the contexts of big technology or the Cold War serve as evidence in studying the interaction of technology and culture in the twentieth century? If they do, given the above observations, then in what ways? And do different national contexts, international frameworks of collaboration and the turn to the market offer distinctive insights on the workings of space-oriented big technology? From the curatorial perspective, are the detailed historiographic analyses of artefacts associated with big technology compatible with contemporary museum presentation standards – standards that favour concision and simplicity over elaborate explanation? If not, then in what ways do museums and academic history collaborate in developing histories of the signature developments and contexts of technology over the last several decades?

There is one area of technology and culture in which museums and academia have a significant common interest – the ways in which artefacts become identified with cultural values and ideas. Notions of progress and national prestige, and ideals associated with exploration and the frontier, are often integral to the cultural framework through which space artefacts are produced and through which they are perceived by a variety of publics. Indeed, identifying artefacts such as rockets as space rather than military artefacts is a way to invoke one set of cultural associations and submerge another. Museums are bound up in this terrain of cultural interpretations in ways that academia is not. As civic institutions, technology museums often seek to embody and reflect the cultural assumptions of their publics, as well as occasionally engage in the academic task of subjecting these assumptions to critical reflection. For this reason, in recent scholarship, the museum itself increasingly has become an object of study to understand its social role in linking technology with particular values and ideas.[9]

The essays in this volume are grouped into two sections. The first highlights the artefact in its historical dimension, as a crossroad between scholarship and museum purpose. The second shifts the focus to give priority to issues of display, of exhibition as a dynamic expression of professional practice and the cultural values of museum personnel, audiences, patrons and nations. Both sets of essays map onto the historiographic discussion above in different ways.

In the artefacts essays, the transnational landscape of the Cold War takes centre stage as the material and conceptual framework that establishes the history and meaning history of two artefacts – Astris and Black Arrow R4 – and a historic site, the Woomera Test Range. The US advantage in space technology, the importance of that technology in the Cold War and in international relations, and the intention of Europe and the British Commonwealth to compete as well as cooperate with the US were essential context for these artefacts. Astris, the third-stage rocket for the ELDO A launcher, in Helmuth Trischler's account, reveals the complex ways in which West Germany, between the 1950s and 1970s, used state-sponsored technology as a signature means to link innovation policy and practices, notions of European multistate cooperation, US relations, and to interrelate concepts of the market, the civilian and the military. Doug Millard explores similar terrain in Great Britain's development of the Black Arrow R4 rocket, giving special emphasis to the artefact as a site for understanding the overlapping and diverging of British and US interests. Kerry Dougherty draws Australia into this complex cultural Cold War geography, examining the Woomera Test Range's role in launching British, European and US rockets. Each highlights the importance of national context in drawing out historical meaning.

Select aspects of the US and USSR experience, from the Cold War to its aftermath, are represented in essays by Philip Scranton, Asif Siddiqi and myself. Scranton's contribution on the Mercury spacecraft explores a defining element of the US pursuit of technological innovation in the Cold War – state sponsorship of the 'cutting edge' through contract to industry – but with specific attention to the organisational and engineering environments thus created at local sites. The result was a specific Cold War style of innovation and engineering practice – chaotic, fluid and constantly experimental. For the USSR, Siddiqi's essay shifts the focus to the post-Cold War era, as loosened state controls gave rise to a social and political competition to shape perceptions of the history of Soviet space achievement. Museums, artefacts, publications (especially memoirs of participants) and auctions in the West served as flashpoints in defining past and present. The transition to the post-Cold War era also is the focus of my own essay. I examine the move to market-based big technology initiatives in the emerging era of globalism, as seen through the Iridium venture, a system of satellites providing a worldwide cellular telephone service.

All of these essays highlight the challenges of distilling complex artefactual histories in ways that meet the practical limitations of display as well as integrate with the museum as multipurpose cultural institution. Historical meaning and explanation vie, often unsuccessfully, with the museum's role in presenting narratives of progress, national celebration and in reinforcing symbols of national identity. Judging from the essays, such narratives are a deep and common aspect of presentations in national museums and prevail across differences in culture and social context.

The exhibition chapters in the volume delve further into this problem. Cathy Lewis's essay offers comparative insight on space artefacts as cultural symbols in the US and USSR in the 1960s, tracing the two nations' active promotion of their respective space accomplishments in international fairs and expositions, as well as their efforts to secure the recognition of such accomplishments in museums. (Her essay should be read as a complement to Siddiqi's account.) David DeVorkin turns the focus from the international to the personal, as he provides insight into the curatorial work of planning and executing a major exhibition, 'Explore the Universe', at the Smithsonian's National Air and Space Museum. Professional commitments to his subject matter, history of astronomy, jockeyed with a variety of constraints – practical, organisational, political (themes that are also touched upon in Doug Millard's Black Arrow essay). Anthropologist Brian Durrans reminds us of the rich cultural associations of 'space' – including the divine and popular media concepts – that visitors overlay on space displays and challenges museum professionals to attend to this cultural interplay and re-examine the inclination to emphasise the technological. Finally, the volume concludes with a select international list, compiled by Brian Nicklas, of museums that feature space exhibitions – a schematic of the state of the art.

This volume seeks to explore the meaning of space artefacts – as products of particular historical milieus, national and international, and as windows on the historiographic challenges of understanding artefacts and technological and cultural change. It also seeks to examine the distinct vantages of museums and academic history in explicating and presenting space artefacts. The goal of the essays is to see these challenges through a range of cases that highlight differences and commonalities across technologies, institutions, professional communities, projects and national contexts.

Notes and references

1 Noble, D, *Forces of Production: A Social History of Industrial Automation* (New York: Knopf, 1984)

2 Material objects and artefacts still remain active sites of scholarly inquiry. Recent examples include Brown, B, *Things* (Chicago, IL: University of Chicago Press, 2004), Daston, L, *Things That Talk: Object Lessons from Art and Science* (New York: Zone Books, 2004), and Baird, D, *Thing Knowledge: A Philosophy of Scientific Instruments* (Berkeley, CA: University of California Press, 2004).

3 For a sampling of anthropological, material-culture and history-of-technology perspectives on the study of artefacts, see Kingery, W D (ed.), *Learning from Things: Method and Theory of Material Culture Studies* (Washington DC: Smithsonian Institution Press, 1996).

4 A classic expression of these points is contained in Latour, B, 'Give me a laboratory and I will raise the world', in Knorr-Cetina, K and Mulkay, M (eds), *Science Observed* (London: Sage Publications, 1983), pp141–70. Good and comprehensive reviews of the positions and implications of the science and technology studies literature are Golinski, J, *Making Knowledge Natural: Constructivism and the History of Science* (Cambridge/New York: Cambridge University Press, 1998); Jasanoff, S (ed.), *States of Knowledge: The Co-production of Science and Social Order* (London: Routledge, 2004); and Pestre, D, 'Thirty years of science studies: knowledge, society and the political', *History and Technology*, 20 (2004), pp351–69.

5 Not insignificantly, the shifts in historiography noted above occurred nearly contemporaneously with these developments, reflecting an increased scholarly interest in articulating the relationship between politics and scientific and technical knowledge production.

6 The issues raised here parallel in part the concept of system advanced by Thomas Hughes in his study of electrical networks in the late nineteenth and early twentieth centuries. Cold War big technology projects through their development of new managerial methods of control and description raise deeper questions about the relationships between specific artefacts and the large social-technical structures of which they are a part.

7 As with the related point in note 6, this characteristic of big technology is not unique or without precedent. It is an important feature in the rise of large firms in the nineteenth century and common to most contemporary technologies. The Cold War did, it may be argued, intensify and push experimentation with this kind of social organisation for technology.

8 An important example of this tension between programme- and artefact-centred history is MacKenzie, D, *Inventing Accuracy: An Historical Sociology of Nuclear Missile Guidance* (Cambridge, MA: MIT Press, 1990).

9 For an important review of the intersection of history and museum studies, see Starn, R, 'A historian's brief guide to new museum studies', *American Historical Review*, 110 (2005), pp68–98.

Helmuth Trischler

A talkative artefact: Germany and the development of a European launcher in the 1960s

Artefacts as talkative things

When was Europe 'invented', what constitutes European identities, and what is Europe as a political and cultural entity? These questions have occupied the minds of numerous historians and political scientists, in particular since the end of the Cold War and the fall of the Berlin Wall, when the physical barrier that for several decades had symbolised the division of Europe into two opposing blocks was dismantled. The answers to these questions are manifold and controversial – and often revisionist in that they challenge the master narrative of European integration as a linear process leading to the constantly-expanding Europe of the European Union as an integrated political, economic and societal body.[1]

In contrast to the rapidly-growing stock of literature on European integration as a political, economic and cultural process, surprisingly little attention has been paid to Europe as an entity shaped by material networks, scientific knowledge and technical artefacts. Only recently has a research network of European and American scholars started to study the linking and de-linking of (transnational) infrastructures and the circulation and appropriation of knowledge, artefacts and systems in order to make visible the 'hidden integration' as well as the 'hidden fragmentation' in modern Europe.[2] From this perspective, the history of Europe in the twentieth century must include big scientific and technological projects, within and beyond the nation state. Such projects have often surpassed their obvious function as scientific artefacts or technical systems, and have generated a variety of symbolic meanings, economic and cultural impacts, and political consequences.[3]

Big science and big technology are close cousins. Big science means modern science carried out in an almost industrial manner. Big science requires elaborate technological systems which often include large and expensive instruments. Big science is based on substantial financial and human resources, on industrial organisation, and often on strong state support. Big science manifests in military contexts such as the Peenemünde project to build the V-2 rocket and the Manhattan project to construct the first atomic bomb, or in civilian contexts such as the CERN facilities for nuclear and high-energy physics near Geneva and the Human Genome Project.[4] As with big science, big technologies are usually government-sponsored, and traditional commercial considerations are of secondary importance. In most cases, they protect national industries. This protection 'is enhanced, at least in Europe, by international programmes where governments together make long term engagements which are extremely difficult to break. They can thus find themselves locked into major programmes whose costs often spiral dramatically and whose benefits become increasingly difficult to see.'[5] In historiography, the boundaries between big science and big technology are rather ill defined, and often purposefully so as a consequence of the amalgamation of science and technology into techno-science in (post)modern societies.

The project to build a European launcher carried out by a number of leading western European countries in the 1960s fits largely within this characterisation of big technology (and big science), as we will see. In 1962, six European nations signed the agreement to form the European Space Vehicle Launcher Development Organisation (ELDO). This big technological project resulted from the will of European scientists and political decision-makers to contest the two superpowers' dominance in space. The political rationale was to keep Europe independent from the superpowers in general and from the United States in particular. The project, which has been described as an example of 'Euro-Gaullism', extended national interests into the European arena.[6]

From a slightly different angle, the project can be seen as an example of technological failure and failed innovation.[7] In high-performance technological systems such as astronautics, technical failures can be seen as the norm, and the history of American space activities in fact points to the ubiquity of failures.[8] But in the case of ELDO, technical failures led to the final demise of the overall institution. Technical problems combined with poor project management caused a series of misfortunes. Between 1964 and 1970, when the participating nations began to disband ELDO, the patient European public witnessed a full dozen test flights intended to launch the European flag into space, which in a few cases resulted in very limited operational successes but in most cases were technical failures. The German third stage, Astris, was particularly troublesome. Test flights that aimed at demonstrating its operability ended in disastrous explosions.

This case study of the launcher ELDO A or Europa I in general, and its German contribution Astris in particular, shows the importance of big technologies in the formation of Western Europe as a political entity in the age of the superpowers. It also demonstrates the complex effects of technological failures in (post)modern societies. Furthermore, and more importantly in the context of this book, it exemplifies the talkativeness of specific objects. Objects can be described as 'nodes at which matter and meaning intersect'.[9] Material objects, more than ideas alone, can embody multiple and often contradictory cultural viewpoints. It is this multiplicity that gives specific objects their talkativeness, their complex narratives. Objects in museums, artefacts, are often talkative objects per se. In the semi-public space of a museum, artefacts generate dialogue with visitors. The character of this dialogue depends on a variety of constituting factors: the place of a given artefact within an exhibition, its conceptual contextualisation, its materiality, its authenticity and its historic uniqueness, the intensity of the cultural charge, and so on.

This introductory section is followed by a brief technical portrait of Astris. The third section shows the talkativeness of our artefact by outlining a number of stories that are embedded in it. The fourth section explains the fate of Astris as a technological failure resulting from its character as a political artefact, and a brief conclusion discusses the role of talkative artefacts in museums of science and technology.

Astris: a technical portrait

The Deutsches Museum displays Astris, the third stage of the European launcher ELDO A or Europa I, in two different settings: firstly in the space gallery of the main museum in central Munich, where it is shown primarily in a technical context as part of a historical narrative leading from the rocket projects of the interwar period to the most recent spacecraft technology, expressed in artefacts such as the gigantic motor of the latest European launcher, Ariane V; secondly in the branch museum Flugwerft Schleissheim, some 16 km outside the city of Munich, as an integral part of the complete four-stage Europa I launcher. Here it tells the story of the ultimate failure of ELDO as a first attempt by Europe to join forces in order to challenge the monopoly of the two superpowers in space. One might go so far as to say that the museum has fallen in love with this artefact, as its repositories hold two more copies of Astris (Colour plates 1 and 2).

Astris was named after the first liquid-propellant rocket in Europe. In March 1931, at the culmination of the Weimar enthusiasm for space, Johannes Winkler, a former engineer of the Junkers company, had successfully launched Astris from the *Raketenflugplatz* (rocket launch pad) in Berlin.[10] Referring to this climax of seemingly-apolitical rocket research in the Weimar era should demonstrate that German rocket history had developed a second, civil tradition of generating sophisticated hi-tech artefacts, alongside the development of the devastating V-2 rocket in Peenemünde under the Nazi regime. Even in the 1960s, German scientists and policy-makers still acted in the long shadow of Peenemünde, which forced them to be mindful of a sensitive national and international public. After the total ban on rocket technology imposed by the Allied Powers from 1945/46 to 1955, rocketry and space flight in West Germany had to be cautiously reinterpreted as a peaceful and therefore positive goal of human endeavour.

Astris was conceptualised as a research-intensive innovation in rocketry. The project aimed at cutting-edge technologies. By mastering this scientific and technical challenge, West German space industry hoped to prove its international competitiveness. Part of this challenge was the move from medium-energy to high-energy fuels. From the beginning of the project, the German experts had specified cryogenic fuels, but their partners in Great Britain and France had opted against this leapfrog in rocket technology.[11] Increasingly, the Germans were forced to search for every opportunity to save weight. The pursuit of weight-saving solutions led the Astris team to a number of technical innovations, which were most visible in two components: the corrugated sheet-metal structure of the skin and the fuel tanks.

On their way to the space gallery, visitors to the Deutsches Museum cross the aviation gallery. Two iconic artefacts in this gallery are the Junkers F-11 and Ju-52 aircraft, both characterised by bodies and wings consisting of corrugated sheet metal. On reaching the space gallery, visitors may perceive Astris to be a result of the same material and production technology, which was developed by Hugo Junkers during the First World War and widely used by aircraft designers in the interwar period. A closer inspection of the artefact shows a very different technical concept. The cylindrical main bulkhead of Astris consists of a corrugated sheet-metal structure made from titanium sheet 0.1 mm thick. The industrial contractors had to develop novel technologies to produce such sophisticated materials, and their search for innovation led to manufacturing techniques that were completely novel in German industry.

The overall design of Astris was based on the concept of a single spherical titanium container with a diameter of 2 metres (Figure 1). The tank was separated by an intermediate bulkhead to store Aerozin 50 as fuel in the upper part and nitrogen tetroxide as oxidiser in the lower part. The container was suspended by means of diagonal titanium ribs which were glued to the container and whose ends were spot-welded to the main bulkhead. The tubular framework with a satellite platform was attached to the upper end of the main bulkhead. The high-performance low-thrust main engine and the two vernier engines, as well as the two ultra-light high-pressure containers, were mounted at the lower end of the main bulkhead. The two oval tanks of 135 litres each were constructed of spun-fibreglass-reinforced plastic to store helium at an operating pressure of about 300 atmospheres and a bursting pressure of 580 atmospheres.[12]

The engineers in charge thought that the most critical part of Astris would be its spherical titanium container. In its final design, the tank was specified as having a wall thickness of 0.8 mm. In order to

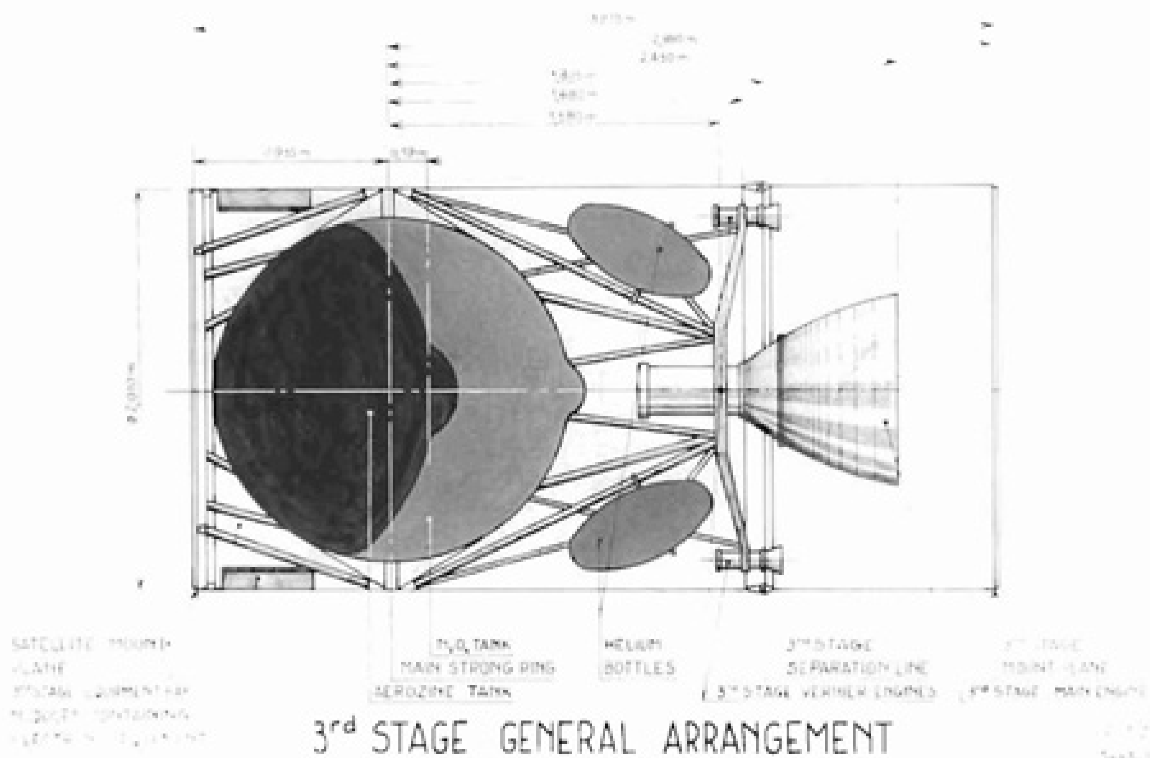


Figure 1 Schematic diagram of Astris. (Archives of the Deutsches Museum)

reach his goal, the engineers had to combine two highly-sophisticated manufacturing modes: the techniques of explosive forming and of electronic-beam welding in a vacuum (Figure 2). Explosive forming as a novel production technique had been developed in the United States to solve the problem of fabricating the gigantic boosters of the Saturn rockets for the Apollo programme.[13] In a final step, the wall thickness was reduced by chemical milling.

But the problems didn't arise where they were expected. The critical part of Astris proved to be its electronics, the less visible component of the artefact. Fixed at the upper end of the inner side of the main bulkhead, some small black units carried the devices for guidance, control and telemetry. For the German scientists and engineers, these black units were literally 'black boxes'. They also contained the computers to guide and control the first stage of the launcher. As the contractor responsible for the electronics of the whole launcher, the British company Hawker Siddeley had built an impenetrable information barrier around these modules. The German engineers were willing to accept this boundary. Furthermore, they showed 'a refusal to attend acceptance or bench integration tests, a lack of cooperation in defining strict working procedures, a total refusal of responsibilities'.[14]

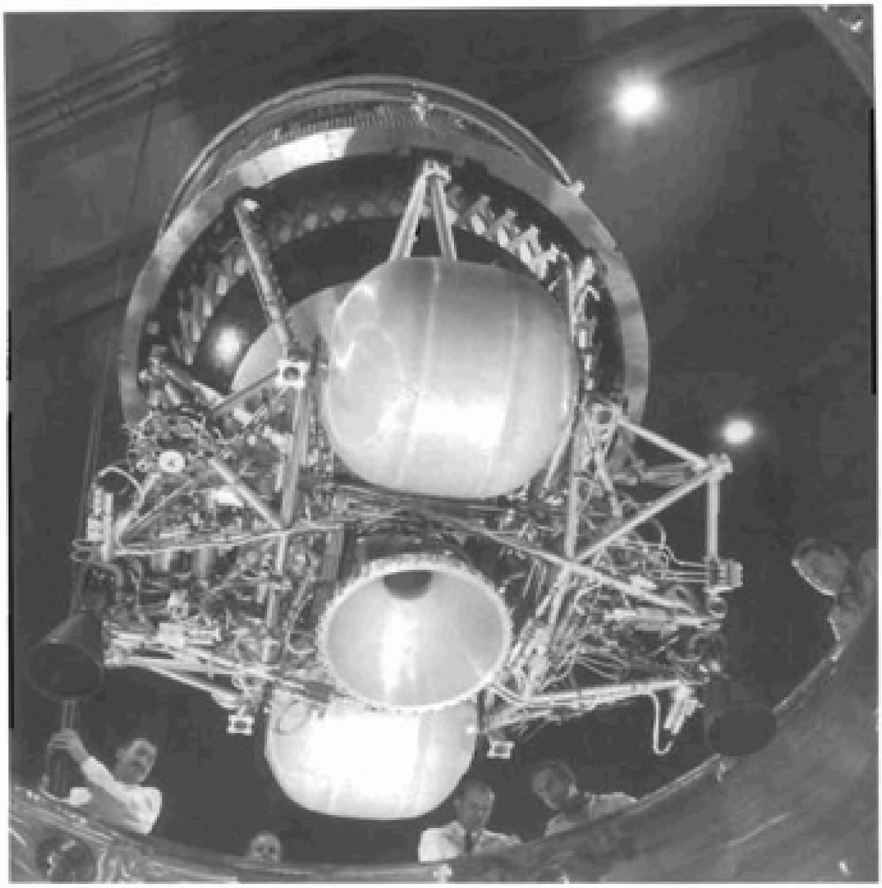


Figure 2 Participating in the ELDO launcher project meant a big technological challenge for German industry: here, engineers of Bölkow AG place a test model of Astris into the vacuum chambers of the corporate testing facilities at Ottobrunn, near Munich. (Archives of the Deutsches Museum)

Not surprisingly, Astris performed poorly. In flights F7 (December 1968) and F8 (July 1969), which aimed to test the operability of the third stage, Astris exploded shortly after separation. In contrast to their expectations, the investigators found that the explosions resulted not from the propulsion system of Astris but rather from an electrical failure between the third stage and the test satellite under Italian responsibility. Fixing the electrical problems did not prevent Astris from malfunctioning on the next test flight, the final flight of Europa I in June 1970. Firstly, an electrical connector disconnected prematurely and prevented the separation of Astris from the satellite test vehicle; and, secondly, the propulsion feed system of Astris failed. This latest disaster convinced the ELDO Council of the necessity to create a Quality Assurance Association, 'but due to a lack of staff, it could not cover all sites and processes'.[15]

ELDO planned to give Astris its major public launch on 5 November 1971. On this seminal day in European space history, the modified Europa II started from the new European launching area, Kourou in French Guiana (Figure 3). The launcher included all three stages plus a new 'perigee–apogee' stage. For a short while, flight F11 seemed to be

Figure 3 Europa II, ready for test flight F11, mounted on its launch base in Kourou, French Guiana. (Archives of the Deutsches Museum)

successful (Figure 4). But after 104 seconds the computer of the British inertia navigation system, which was fixed to the German third stage, failed. After a further 46 seconds the vehicle began to break up and was destroyed by the range officer.[16]

At the next meeting of the ELDO Council some weeks later, the participants were fully aware that the demise of ELDO was imminent. The Council set up an investigation committee of senior engineers and executives from government and industry in Europe and the United States, led by Robert Aubinière, the French Secretary-General of ELDO. The committee report, dating from 30 May 1972, was a devastating proof of ELDO's poor organisation and its massive management and communication problems. In December 1972, after having successfully mastered two 'package deals', the ELDO member states finally agreed to close down the ELDO launcher programme and found a new, much more integrated and powerful joint space organisation: the European Space Agency (ESA). ELDO was finally dissolved in May 1975.[17]

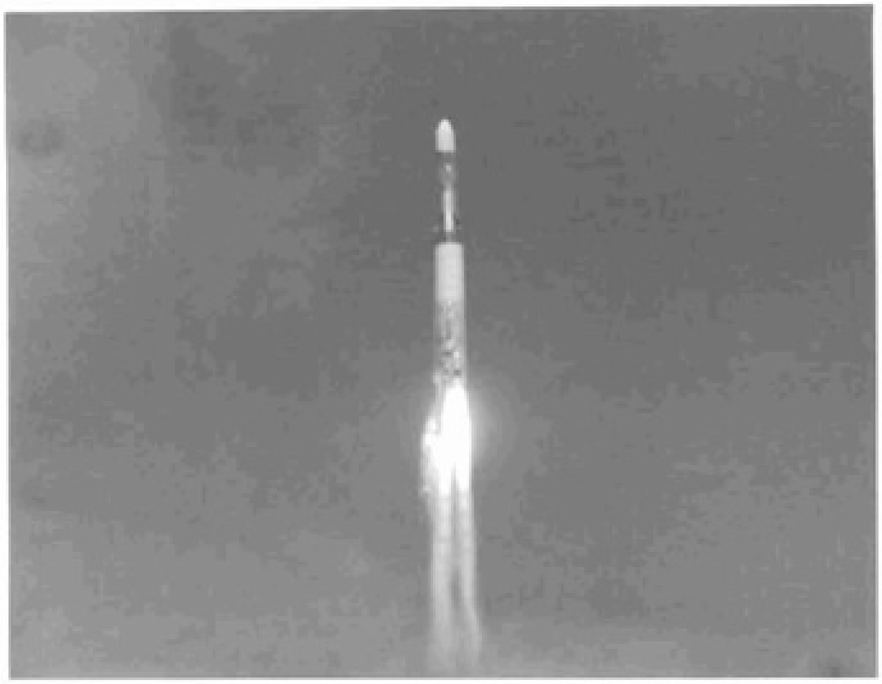


Figure 4 A technical disaster precipitated the end of ELDO: Europa II after its start from Kourou on 5 November 1971. Poorly-designed British, French and German electronic modules caused the break-up of the vehicle. (Archives of the Deutsches Museum)

Astris: a talkative artefact

At the beginning of the twenty-first century, space travel in Europe has become a truly transnational business. Europe as a space-faring actor is even larger than Europe as a political entity: the participation of Switzerland, Austria (before it became an EU member) and even Canada means that ESA involves countries outside the European Union. With Arianespace and EADS as leading enterprises, the space industry has succeeded in developing a refined European structure that is way ahead of the efforts in the fields of politics and society by the European Union. The master narrative of Europe in space is a history of growing transnational integration, initiated by scientists and engineers and based on the strong will to cooperate despite political barriers.[18]

Historians view the history of Europe in space as a history of Europe shaped by tensions, as a dichotomy between integration and disintegration, coupling and decoupling. The long-lasting tensions of Europe in the twentieth century were evident as multinational space programmes developed after the 1950s: individual national rationales often conflicted with the publicly-stated will to cooperate on the basis of mutual understanding and equality of status.

Astris is the perfect artefact to communicate this story, as will be shown. As a talkative artefact, it not only tells the stories of the importance of big technologies as a catalyst of European integration and technological failure, but it also relates to a number of other meaningful historical contexts:

1. Astris points to the importance of the national catch-up effort in science and technology. The history of the relations between the US and Europe throughout the twentieth century is the history of a dense transatlantic discourse and process of mutual orientation.
2. Astris expresses the constituting problem of modern societies in coping with the complexity of big science and big technologies.
3. Astris characterises the dialectics of historical continuities and discontinuities beyond 1945 as a key date in twentieth-century German history, and it points to the limited room for manoeuvre in West German politics resulting from the legacy of the Nazi period.
4. Astris exemplifies the strong persistence of national innovation systems and cultures in transnational innovation processes.
5. Astris highlights the importance of international collaboration for the scientific, political and economic legitimisation of resource-intensive projects in national contexts.

The following section will touch on some of these narrative strands, but focuses first on the ubiquity of politics in European space activities. More than most other fields of science and technology, space is dominated by political interests and state actors. Until very recently government has been not only the sole sponsor of innovation activities in space, but also the only customer for the resulting products, and to a large extent this is still true today. In contrast to most other technologies, in space business market forces and the 'consumption junction' (Ruth Schwartz Cowan) between producers and users of innovations have been less important than actors in the political realm. Whereas modern knowledge societies in general are sought to be characterised by the 'triple helix' of academic research, industry and the state, a collaboration which is driven by economic competition and market forces, in space the 'triple helix' of science, economy and politics has been dominated by the latter.[19]

This is especially true of German space activities, where the ubiquity of politics derived not least from the legacy of history. The historical burden of Peenemünde, the birthplace of rocket technology under the Nazi system, for a long time forced decision-makers to avoid any attempt that could be interpreted as being continuous with this dark period of German history. As a consequence, in German space history, the collaborative network of science, industry and politics shows a clear political bias.[20]

The ubiquity of politics leads to the second focal point: the tension between national and international orientation in German space activities. Again, due to the historical burden of the Third Reich in general and Peenemünde in particular, Germany became the prime advocate for European cooperation. German policy-makers tended to favour international space projects and joint efforts with partners in Europe and the US. In contrast, scientists and industrial actors were keen on upholding a vigorous national programme. They advocated a strong national platform of scientific knowledge and technical expertise, which would act as an essential basis and then allow German science and industry to cooperate in international projects on an equal footing. The tension between national and international orientation affected German space research and space technology on all levels, and this tension is vividly manifested in the artefact Astris.

Early Cold War years and the interlude of the 1950s

In the period immediately after the end of the Second World War in Europe, the Allied countries used the instrument of 'exploitation and plunder' to profit from the progress of German science and technology during the war.[21] This transfer of knowledge from Germany to the United States is part of the long-lasting transatlantic discourse on the problem of how science and technology should be organised to perform at their best. Viewed in this way, the transfer of von Braun's core team from Peenemünde to Fort Bliss in Texas, and later to the 'Redstone Arsenal' near Huntsville, Alabama, can be seen as part of the long history of learning from the excellence of German science. Huntsville was the resurrection of Peenemünde-Ost, the Nazi development centre for the V-2. Americans and Germans quickly began calling the place 'Peenemünde-South'. A significant reason for Huntsville's success was that it followed the organisational principle established at Peenemünde of 'everything under one roof'. This meant that the coordination of the different areas and branches of science, technology and production lay in the 'firm' hand of those in Peenemünde, now working in Huntsville.[22]

During the 1950s the pendulum swung back. The German scientific community was oriented towards and learned from the United States. But at the very beginning of the post-war period the conditions for the rise of a new community of scientists and engineers interested in rocketry were very poor. Rocket technology had been totally banned by the Allied powers. The term 'rocket' was identified with Nazi crimes and devastating warfare; the idea of space flight suffered from the legacy of Peenemünde. Given these unfavourable conditions, it is rather surprising that a number of space activities started in the 1950s, even during the period of Allied restrictions (1945–55). Three events that later allowed West Germany to participate in the European cooperation in ELDO and ESRO (European Space Research Organisation) should be mentioned here.

Firstly, a number of space societies paved the way for a reinterpretation of space flight as a peaceful human endeavour. Institutionalised as *eingetragene Vereine* (registered associations), these civil, self-organised institutions did not break the Allied restrictions.

Former Peenemünde scientists and engineers successfully created a new space-flight community in the grey area between legal and illegal activities, consisting of a mix of professionals and amateurs. As early as 1947, for example, a group of space-flight enthusiasts emerged at the Technical University Stuttgart, which one year later was officially institutionalised as the Gesellschaft für Weltraumforschung (GfW, Society for Space Research). To comply with the Allied restrictions, the society tried to internationalise. In 1949 it approached a number of sister societies in other countries and proposed the idea of organising joint international conferences and founding an international federation. The internationally highly-respected British Interplanetary Society embraced these ideas and in 1951 the International Astronautical Federation (IAF) was founded.[23]

The main goal of the German society was to establish a space research institute in Germany, and this leads us to the second precondition of the later German participation in European space cooperation: the forming of networks of scientists in space sciences and rocketry. The GfW succeeded in using the international platform of the IAF to develop this aim further. IAF's first president was Eugen Sänger, a well-known expert in rocket and ramjet technology. Sänger had already established, in 1936/37, a research laboratory in the remote village of Trauen in Lüneburger Heide, which in the 1960s was developed into a rocket research centre working for ELDO. With enormous financial support from the Air Force, Sänger had built huge testing facilities for rocket and ramjet engines. In the early 1940s, he and Irene Bredt, who later became his wife, had drafted the concept for a visionary supersonic spacecraft, *Silver Bird*, an early version of the 'shuttle' idea. But more importantly for the Air Force, they also worked on a long-range bomber.[24] In July 1954 the GfW succeeded in officially establishing the Forschungsinstitut für Physik der Strahlantriebe (Research Institute for the Physics of Jet Propulsion) with Sänger as director, who returned from France, where he had worked after 1945. German companies such as Daimler-Benz were involved in the institute, but the bulk of research contracts came from US industry. German government too served as a stakeholder. The Federal Ministry of Transportation provided the basic funding for the institute. Minister Friedrich Seebohm thus tried to gain control over this new and promising field of transport technology.

The GfW also lobbied successfully for the foundation of a chair for rocket and combustion research at the Technical University of Stuttgart, which came into being in 1954. Like Sänger, a considerable number of other German rocket specialists, who had worked for the Allies after 1945, returned to the Federal Republic in the second half of the 1950s, among them Günter Bock and August Wilhelm Quick, who later became key figures in the West German space programme. Both held chairs at technical universities, and both also had leading positions in institutes of the rapidly-multiplying non-academic aeronautical research centres, which in the late 1950s gradually expanded their activities into space research.[25]

Parallel to the formation of a community of scientists interested in rocketry and spacecraft, a community of scholars interested in questions of astronomy, astrophysics and related fields – which later merged into space sciences – was also established. For example there was the Institute of Astrophysics of the Max Planck Society (MPE); its director was the astrophysicist Ludwig Biermann, who became known as the first to find evidence for the solar wind. In the early 1950s Biermann had already tested the 'possibility of creating a comet artificially by injecting suitable material into interplanetary space'.[26]

A third precondition enabling the later West German contribution to ELDO and ESRO was the creation of industrial competence. Recent historiography has shown that West German business had already started rocket development projects during the era of Allied restrictions. After the Korean War the Americans were keen to use West German industrial capacity for joint defence in the framework of NATO. In late 1953 the young company set up by Ludwig Bölkow, who in the Third Reich had done sophisticated design work for Messerschmitt, was awarded the contract for developing an antitank missile. The project was funded by the Dienststelle Blanck, predecessor of the Federal Ministry of Defence, which procured West Germany's armaments. This project gave a head start to the Ludwig Bölkow AG, which became the leading German aerospace and defence company, outflanking the older generation of well-known industrial firms such as Messerschmitt, Junkers and Heinkel. Bölkow's success was due to the constant support of Franz Josef Strauss, the Federal Defence Minister. He developed the concept of a state-supported industrial policy aimed at creating innovative high technologies as a counterbalance to Ludwig Erhard, whose reigning economic doctrine of 'Soziale Marktwirtschaft' favoured the market and kept the state out of business. Strauss's industrial philosophy of state interventionism favoured the aerospace sector especially, which was seen as a key technology stimulating the overall performance of any advanced national innovation system. Not by chance, the closely interlinked aerospace and defence industries became more and more concentrated in Bavaria's capital, Munich, Strauss's political base. And it was again Strauss who in 1961 enabled Bölkow to create a large complex of industrial research laboratories for the aerospace industry, the Industrieanlagen-Betriebsgesellschaft, next to Bölkow's production facilities to the south of Munich.[27]

Thus, when Sputnik was launched, provoking the United States to enter the space race at full speed, and European nations began to reflect on joining forces to further their own participation in the conquest of space, West Germany was at least partly becoming a competent partner. Actors in all parts of the triple helix – science, economy and the state – had resumed their own activities in the business of space. But these activities were not interlinked and coordinated. Space as a well-defined and politically-structured field did not yet exist, and it needed the European challenge to achieve this.

The formative period of West German space policy

When in the late 1950s the already well-established research institutes for aeronautics began to actively expand their scientific programmes into space research, state actors agreed that neither new institutional structures nor new scientific paradigms and methods were needed. Space was seen as a continuation of aeronautics at higher altitudes. When Germany's largest centre for aeronautical research, the Deutsche Versuchsanstalt für Luftfahrt (DVL), publicly announced the foundation of a new department for space research in 1959, it was again Defence Minister Strauss who strongly supported the proposal. He asked the DVL to coordinate all German activities in astronautics. Strauss advocated close cooperation with the United States, enabling German science and industry to catch up and gradually draw level with the cutting edge in this field of science and technology. In early 1959 Edoardo Amaldi formulated his famous memo 'Space research in Europe' and quickly gained support from other eminent European scientists such as Pierre Auger and Harrie Massey, but he opted for an alternative to transatlantic cooperation. The European and transatlantic options which were now on the agenda of political decision-making each met the interests of conflicting groups in the German government, categorised as the 'Gaullists' and 'Atlanticists', who constantly competed for dominance in foreign policy.[28]

But to begin with, the German government was not at all prepared to play its part in the emerging European cooperation. This was clearly shown when all countries participating in the Geneva conference of 28 November to 1 December 1960 signed the agreement to set up COPERS, except West Germany. This didn't mean that Germany was reluctant to support the foundation of ESRO, but members of the government had failed to work sufficiently closely to clarify their position. This became even more embarrassing when the British Minister of Defence, Peter Thorneycroft, visited Bonn in January 1961. Speaking with four ministers of Adenauer's cabinet, he was confronted with four different positions. This led to negative comments in the German press and the demand for a clear statement from the chancellor.[29]

In January 1962, when the whole of Europe was looking towards Bonn, Adenauer gave his final word. He added responsibility for space to the remit of the Federal Ministry of Atomic Energy, which consequently was renamed the Federal Ministry of Scientific Research one year later. But this was only a half-hearted decision, because he also installed an inter-ministerial coordination committee, which led to a complex and time-consuming decision-making process. It is not surprising that industry heavily criticised this complicated political construction, especially as German space policy in the following years showed – and continues to show even today – a scientific bias that often disregarded the opportunities for an active industrial policy.

The decision also had a long-lasting effect on how space programmes were managed. In 1962, using the American example of non-profit corporations and trying to adopt the management procedures that had been developed in the US in the meantime, the Federal Research Ministry established the Gesellschaft für Weltraumforschung as an independent administrative body. But the ministerial bureaucracy kept this institution under firm control and never granted it the autonomy it would have needed to manage large-scale space programmes efficiently. This was only the first link in a long chain of mistakes in managing space projects.

During the crucial year of 1961 it was not at all clear whether the Federal Republic would finally join ELDO. When the government asked a group of distinguished experts to comment on the British–French proposal to build a launcher based on the British Blue Streak as first stage and the French Coralie as second stage, the response was negative. The experts criticised the technological backwardness of the projected launcher Europa I in comparison with the American launchers. They came to the conclusion that neither science nor industry in Germany would profit from the project (Figure 5).

It was purely for political reasons that government remained involved. Firstly, the European venture legitimised Germany's re-entry into the field of rocketry, which still suffered from the historical burden of Peenemünde. Secondly, as prime mover of European unification, West Germany was forced to consider seriously any initiative that would strengthen Europe, particularly if the initiative was co-launched by the most reluctant partner, Great Britain. The German government thus declared it was interested in the Europa I project, but with two conditions attached: firstly, there must be close cooperation between Europe and NASA and, secondly, there must be a careful re-examination of the scientific, technical and financial conception of the project by teams of experts from Britain, France and Germany. When the teams met in late April 1961, the British and French delegates presented well-prepared papers with a much more transparent breakdown of costs than had been seen before and a long list of benefits resulting from the joint effort. Günter Bock, the head of the German delegation, was so impressed that he and his colleagues changed their minds – and so did the formerly more sceptical politicians. Even the Federal Defence Ministry was now in favour of a joint European effort, particularly as in the meantime the US government had shown its unwillingness for open bilateral cooperation on an equal footing.

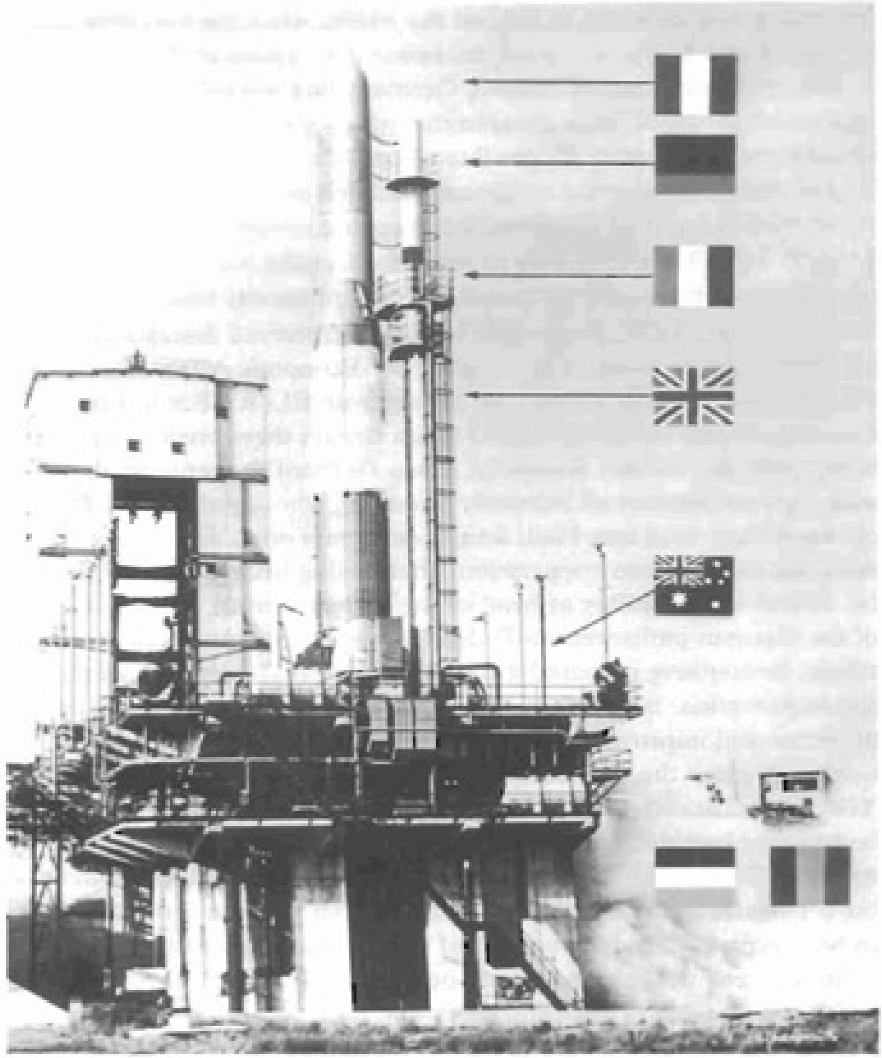


Figure 5 The share of work in European space activities: the flags and arrows show the responsibilities of the various nations participating in Europa I, which originally was planned to have its first launch in 1966 from the Australian launch site at Woomera. (Archives of the Deutsches Museum)

The German scientific experts had accompanied their vote for the Europa I project with the warning that only a forceful national programme would allow the German space community to be an equal partner of France and Great Britain. The aerospace industry gave the national programme even more priority. When in July 1961 science and industry joined forces to found the Kommission für Raumfahrttechnik (Commission for Space Technology), they were driven by the fear that the resources provided by the German government would only go to international institutions and have little effect on the home country. Ludwig Bölkow demanded that the national programme should be 'at least twice as large as the expected German contribution to the Blue-Streak-project'.[30] Here, Bölkow formulated a relationship between nationalism and internationalism which developed into a set of guidelines for the aerospace industry for the following decades.

But reality was different, at least in the 1960s, when the contributions to ELDO and ESRO exceeded the national programme.[31]

From the early days of ELDO, Germany had strongly favoured a more sophisticated future programme, which would meet the needs of the emerging market for satellite communications. During the ELDO intergovernmental conference in Paris on 19–21 January 1965, the French delegation suggested leapfrogging straight to ELDO B, because ELDO A was unable to meet the Gaullist aim of breaking the American monopoly of launchers for commercial satellites. In Germany, the ELDO crisis again led to controversial discussions on the French proposal. The Ministry for Economic Affairs, for example, voted for an immediate retreat from ELDO. But it was Germany which stabilised ELDO when Britain threatened to withdraw completely in 1965/66. Ironically, it was Gerhard Stoltenberg, the new Federal Minister of Scientific Research, who saved ELDO. He changed from Saul into Paul, from a deliberate critic to a strong advocate of European cooperation, after having been promoted from his former responsibility as head of the budget control committee of the German parliament to Federal Minister responsible for space affairs. Stoltenberg prepared a compromise to find a way out of the immediate crisis. Based on the ongoing programme, a substantially modified and improved rocket, ELDO B/Europa II, which would be able to place the ESRO and CETS (Conférence Européenne des Télécommunications par Satellites) satellites into high orbits, should be built for launch from Kourou. One week in advance of the decisive meeting of the ELDO Council, Stoltenberg succeeded in convincing his colleagues in the German government that this compromise had to be accepted, despite a number of good arguments against it from scientific, technical and economic perspectives.

On the first day of the conference that took place in Paris on 26–28 April 1966, the ELDO Council agreed on Stoltenberg's compromise. Germany had to pay a considerable price for this political success: the German share of the ELDO budget rose from 22.01 per cent to 27 per cent, whereas the British financial load was reduced from 38.79 per cent to 27 per cent. The German intervention came nowhere near to ending the almost constant crisis of ELDO, as Great Britain's reluctance to engage further in European launcher development showed.[32] But Germany had again convincingly demonstrated its role as a motor of European space cooperation.

Astris: a political artefact

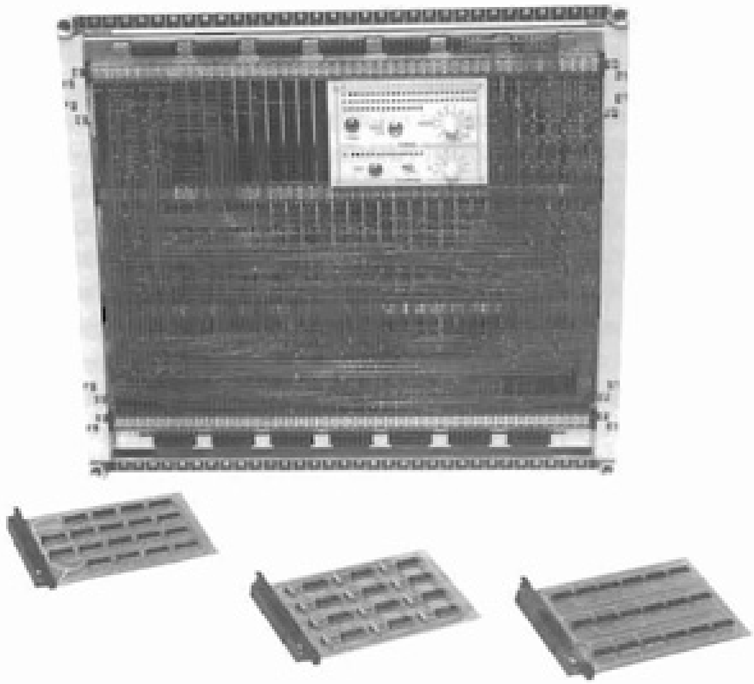
During the 1960s, the Federal Republic of Germany convincingly demonstrated its role as motor and catalyst of European unification in general and as an actor in space in particular. This role was reliant on German taxpayers and the neglect of other fields of science and technology policy, but in the long run it kept open the door to a

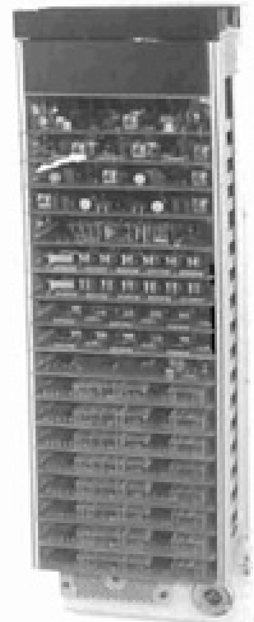
Europe in which scientific knowledge and technology capabilities served as cognitive and material bases for growing societal integration.

Thus, the domination of space research activities by political factors was an important prerequisite in establishing Europe as a powerful force in space. With its family of Ariane rockets, ESA, the institutional successor of ELDO, developed a highly-competitive and technically-reliable system of launchers that succeeded in the rapidly-expanding market for research and communication satellites. Ariane became a political icon of successful cooperation and integration in Europe.[33]

But the learning curve Europe had to climb was steep, and achieving this success was painful and costly. As we have seen, ELDO is a classic example of the failure of a big technological project. When in May 1972 the Aubinière commission published its report on the disastrous explosion of Europa II on test flight F11, it became evident that ELDO had failed because of its political character. The report vividly criticised the inadequate organisation of ELDO and its poor management structure. It emphasised the weak position of the ELDO secretariat, which had no say in the central task of contracting. How contracts were awarded for their respective parts of the joint launcher was the *arcanum imperii*, the prerogative of politics. The national governments jealously controlled their financial investments in ELDO so that these were returned as contracts for their national research laboratories and industries. This policy of *juste retour* (fair return) was identified early on as a key misconception of European 'cooperation' in space.[34] Rather than fostering transnational collaboration from the bottom up, the member states sought to acquire as much knowledge and resources produced in the joint undertakings as possible, in order to strengthen their economic positions in the international markets.

The supranational body of ELDO continued to organise its institutional structure in a way that reflected the concept of the nation state which had dominated European history for many centuries. This orientation resulted in a fatal technical problem that manifested most significantly in Astris. The disastrous performance of Astris on test flights F7 to F11 resulted from the poor communication between the British contractor Marconi and its German corporate counterparts. But it also resulted from communication barriers within the German industrial partnership. Lack of coordination led to a technical design which obeyed 'none of the elementary rules concerning separation of high and low level signals, separation of signals and electrical power supply, screening, earthing, bonding, etc.'[35] Eventually, none of the participating firms was willing to bear responsibility for these failures, not even the Arbeitsgemeinschaft Satellitenträger (ASAT), which was created by the German government specifically for the task of coordinating the work of Messerschmitt-Bölkow-Blohm (MBB) and Entwicklungsring Nord (ERNO) on Astris. Eventually, the small company ASAT could not bridge the traditional tensions between





MBB und ERNO and so become freed from government control (Figures 6 and 7).[36]

The strong coupling of science and politics which marked German project management found its continuation at the next level of space administration. In August 1962, the Federal Research Ministry's Gesellschaft für Weltraumforschung, which had been deliberately established that year as an independent body to be in charge of overall space project management in West Germany, was unable to free itself from political authority and interference. Despite all efforts to reform the institution, in the eyes of industry it remained a body which was controlled by government and worked alongside political actors.[37] In 1972, the German government reacted to the Europa II disaster by integrating the project management authority into the National Laboratory of Aeronautics and Space Research, Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt. This proved to be no more appropriate as a way of ensuring efficient project management. In the mid-1980s, the federal government was again forced to reform the institutions to take account of fierce criticisms from industry. In 1987, the government founded the Deutsche Agentur für Raumfahrtangelegenheiten to be in charge of space management, without really decoupling space science and space politics. The political administration's withdrawal from interfering was only half-hearted, which meant that project management for space activities remained a major issue on the national agenda into the 1990s. In 2000, the government returned to the solution of integrating

Figures 6 and 7 Large-scale technological projects often fail at the level of small-scale artefacts. A rubber ring that began to leak at low temperatures led to the Challenger *Space Shuttle catastrophe, and malfunctioning electronic devices, such as the ones here, caused the disastrous test flights of Europa I and II. But eventually the demise of ELDO resulted from its inadequate transnational organisation and its poor management structure. (Archives of the Deutsches Museum)* the space management authority into the National Laboratory for Aeronautics and Space, which in the meantime had been renamed the Deutsches Zentrum für Luft- und Raumfahrt.[38]

Astris reflects the strong bond between science and politics which is said to characterise knowledge societies since their early beginnings in the scientific revolution of the early modern period.[39] Moreover, Astris, as a political artefact, reflects the tendency of (post)modern knowledge societies to undermine the status of science as the unique method for gaining truth. For science and politics are said to have acquired equal epistemological standing as preferred sources of truth.[40] Last but not least, Astris reflects a decisive element of innovation processes in advanced innovation systems, as the cost of Germany's participation in ELDO to produce the artefact Astris had to be covered by German taxpayers. In high-risk big technological projects it is the state which is forced to bear political and financial responsibility, while corporations come on board late in the day at comparatively low risk.

Finally, to close the loop, this chapter has to return to the idea of talkativeness as a conceptual tool for analysing material objects in general and museums' artefacts in particular. As shown, the talkativeness of a specific object manifests in the multiple cultural narratives which it offers to its observers. And in fact, a closer look at Astris' material and cultural performance has identified a multiplicity of narrative strands of which only one, if not the most significant one, has been outlined here in depth: its character as an artefact resulting form a big technological project which was shaped by political forces and political actors.

Conclusion

Historians and cultural scientists have begun to acquire the methodological ability to listen to talkative artefacts and to cope with the multiplicity of their narratives. Museum curators have started to develop sophisticated methods of using talkative artefacts, which often are overcharged with myth and cultural meaning, to convey such interpretations of history to visitors.[41] But what do we know about the scientific, technical and cultural literacy of an average museum visitor, what about the ability of various visitor groups to listen to talkative artefacts? Can talkative artefacts generate dialogue and what are the constituting factors to foster such a dialogue between unequal partners: the place of a given artefact, within an exhibition, its conceptual contextualisation, its materiality?

In fact, these are open questions on which museums need to reflect further. Such concerns are all the more important, as museums perceive their material heritage, their artefacts, to be powerful conveyers of not only scientific and technical expertise, but also historical and cultural knowledge.

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Douglas Millard

Black Arrow R4: a candidate for materialising the history of technology

Introduction

On 28 October 1971, a Black Arrow rocket launched the X3 satellite into orbit. It was the fourth Black Arrow to be built; the first three had been used on development flights. The fifth vehicle, R4, should have launched the next satellite in the X series, but, with the Black Arrow programme already cancelled, it was acquired in 1972 by the Science Museum instead. For almost 15 years the rocket was kept in the Museum's storage facility. In 1986 it was put on display in the museum's new 'Exploration of Space' gallery and in 2000 redisplayed there in a partial refurbishment of the gallery. Black Arrow R4 has now been on museum inventory for over 30 years. How have the museum's practices of collecting and exhibiting artefacts of this kind assisted in our understanding of the Black Arrow programme? How does this understanding compare with that we might obtain from the historical literature? Can the respective objectives of the museum curator and historian find common ground through the artefact? These are the questions addressed in this chapter.

I start with a review of R4's museum 'life' and outline the types of historical interpretation of it the museum has offered to the visitor during this time. I move on to compare this display 'historiography' and its shortcomings with that found in the literature for Black Arrow. The study then dips into the museum's collection of primary, printed UK rocketry source material in an attempt to reveal some of the many factors, unacknowledged in both the Black Arrow literature and in R4's displays, that contributed to the shaping of this artefact. Finally, I offer some reasoned speculation about the power of new electronic interpretative technologies, already in use in some museums and galleries, to address the shortcomings in the historical interpretation of technological exhibits. I argue that this renewed approach to material culture will improve not just the historical interpretation in museums of artefacts such as R4, but also, ironically, help counter any latent technological determinism still prevalent in the literature on the history of rocket technology .

Let us first review the object's 30-year museum history.

Storage

While in storage, the Black Arrow R4 rocket was almost completely inaccessible to the general public. It was kept in an industrial warehouse, some miles west of London, alongside many thousands more objects from the museum's reserve collections. Visits were possible by appointment, but, as the storage facility's existence was not publicised, they were almost non-existent. Further, R4's accessibility within the store building was limited by the nature of the storage: object density was high and visibility of individual objects such as R4 correspondingly low. Examination of such artefacts rarely progressed beyond the routine stock-check or inspection carried out by curators and store staff. There was no museological interpretation of the rocket as it lay in store. There were no labels or diagrams or pictures attached to the artefact. Black Arrow R4 was being kept, preserved, cared for – yes, but held back. Public display of R4 in the museum galleries was an aspiration, something for the future, as the curator responsible made clear in his justification for the rocket's acquisition: 'it is an example of a conventional three-stage launch vehicle and therefore will be a good technical exhibit'.[1] But there was no timetable for such an exhibition. It had a future, but no present. Indeed, this deferral to posterity, whatever form that might take, seemed to be an acceptable end in itself: '[Black Arrow] will in time become an historic relic of this country's space technology programme.'[2]

First display

In 1986 R4 was taken out of storage and put on display in the Science Museum's new 'Exploration of Space' gallery (Colour plate 3 and Figure 1). The rocket was floor-mounted horizontally and in its complete configuration, although the third-stage apogee motor and flight-spare satellite were separated and included in a neighbouring part of the display. The display gave a pedagogic interpretation of the artefact, and there were no physical barriers to it, allowing museum visitors to inspect the prostrate rocket closely.[3] The rocket was located in a section called 'Britain in Space', an area tracing the nation's rocketry and space activities from the 1930s until the present, an apparently historical theme for the display. A large desktop-mounted graphic comprising text, illustrations and specifications ran alongside the rocket; but the panel's information contained a paucity of historical narrative, despite R4's situation in a part of the gallery that looked back at Britain's space activities. The only nods to a historical perspective were to the Black Arrow programme's origins in 'proven Black Knight technology' (an earlier rocket design), its launch-record dates and an explanation for R4's presence in the museum gallery with wording little different from that offered in this chapter's opening paragraph. The display interpretation did not even begin to attempt an explanation of why this rocket was built, by far the most interesting

Figure 1 Black Arrow R4's Gamma Type 8 engine as displayed in the 'Exploration of Space' gallery, 1986–2000. This floor-mounted artefact was popular with young visitors, who could touch a 'real rocket', and film crews, who used it as a photographic backdrop. (Science & Society Picture Library)

question to ask, given that the political climate during the mid to late 1960s was hostile to many costly 'big' aerospace programmes.[4] The display panel provided little more than a basic technical description of the rocket, perhaps, indeed, as the curator who had acquired the artefact had originally intended.

It is instructive to look at the stated objectives of the new 'Exploration of Space' gallery in order to explain the form of R4's display interpretation. They reveal that any apparent intellectual tradition of interpretation (historical, in this instance), any style or flavour of display within the new exhibition, was secondary to the greater objectives of the new gallery:

> 1. Using our prime collection of historic space science and technology artefacts, we wish: a) to communicate the excitement of space exploration; b) to explain what rockets and satellites are, how they work, and what they do in space technology; c) to show how the use of satellites is affecting our way of life now, and how it will become more powerful in the future.
> 2. We also aim: a) to show why space research is useful, and b) to show the challenges and complexities of living and working in space. Top level: Intelligent 12+, with extra technical information where appropriate.[5]

In other words, any historical function of the display was but one interpretative tool of several that were geared largely to visitors' presumed interests in contemporary space exploration. Thus, Black Arrow R4 was displayed with very little pedagogical historical narrative of the type that might have been expected for the general visitor and with still less of that which might have been expected for the historian of science and technology.

Second display

In 2000, R4 was redisplayed in a refurbishment of the 'Exploration of Space' gallery (Colour plate 4). The rocket was suspended horizontally from the ceiling, its stages separated to mimic the sequence of actual launch events. The apogee motor of the third stage and the flight spare satellite (Figure 2) were now added, while the fairings that enclosed the latter were opened in the manner of Gemini 9's 'angry alligator'.[6] This display's interpretation was similar in scope to the previous one – mainly technical with cursory historical reference, but far more discreet: one graphic panel was used on a nearby gallery pillar. The intention was to raise the display's level of

Figure 2 The X3 satellite flight spare as displayed in the 'Space' gallery, 2000 to present. The satellite comprises eight three-faced modules, with an interface or 'fillet' between each pair. This large surface area was covered with solar cells and experiments. (Science & Society Picture Library)

spectacle and diminish the pedagogic element.[7] An artefact's history, once again, was downplayed.

Black Arrow historiography

How then does this paucity of historical analysis within the Science Museum's display of R4 compare with that found in the historical literature? When 'Exploration of Space', with R4 a starring exhibit, opened in 1986, there were virtually no accounts of Black Arrow in print. The nearest R4 and the entire Black Arrow programme came to being historically represented was in popular directories of space exploration such as Jane's.[8] Here, the treatment was largely one of technological description and brief chronology – not unlike that of the Science Museum's displays. The literature improved greatly with Peter Morton's extensive account of the Anglo-Australian Joint Project in which Black Arrow featured prominently.[9] But, despite the breadth of narrative, Morton's account was still largely descriptive and allusory. There was little analysis of the Black Arrow programme and its inception. Some of the interesting issues that he raised and which are worthy of deeper analysis were glossed over, although this was, perhaps, unavoidable, given the sheer scope of his book.[10] For example, of Black Arrow's inception Morton reported that, 'Harold Robinson [...] was officially encouraged to pursue an earlier idea which had emerged from the success of Black Knight.'[11] Robinson was a divisional head in the UK's Royal Aircraft Establishment (RAE), the government institution that acted as design authority for a ballistic missile test vehicle called Black Knight. Morton's citation was intriguing yet frustrating. What did 'official encouragement' mean? From whom was it received and in what form? What were the factors that prompted it? Robinson himself made similar, tantalising reference to this mysterious process elsewhere: 'thus, Satellite Launcher Division found itself actively encouraged to continue, in greater depth, its small satellite launcher studies – now given the name "Black Arrow".'[12] And Robinson's RAE colleague Ian Peattie followed suit: 'Black Arrow [...] was regarded as an urgent UK requirement to further research into both satellite and launch vehicle technology.'[13] Who considered it an 'urgent' requirement and why? Neither Robinson nor Peattie elucidated further and their subsequent histories of Black Arrow strayed little from technologically-determinist sets of justifications and explanations: Black Arrow's precursor, the Black Knight test vehicle, could be converted, relatively easily, into a satellite launching vehicle by extending this part, strengthening that, adding another, upgrading that, and so on. And it is this tradition that is maintained throughout almost all the accounts of Black Arrow.[14]

To date, the historical literature, like the Science Museum's displays of R4, has not added greatly to our understanding of how the Black Arrow programme began. Both forms of interpretation – the museological and the literary – have told us how Black Arrow worked; neither has told us how Black Arrow was *allowed* to work.

An interesting exception, albeit fleetingly so, can be found in Albert Tagg's and Ray Wheeler's history of Saunders-Roe (SARO),[15] the long-established marine and aeronautical engineering company that built the Black Arrow and Black Knight vehicles. Leading copious technical descriptions of 'Fighters, Helicopters and Rockets', the fourteenth chapter opens with, 'The cessation in the demand for marine aircraft resulted in the company spreading its activities into other aspects of aviation and also into space vehicles.'[16] Although the statement is in itself highly utilitarian – the slump in demand for one type of company product 'resulted' in it focusing on another, but there are no details of exactly *how* it resulted – it does at least move the account away from the purely technological towards a rationale for that technology from the wider context in which the technological sits, namely, the world of business and commerce. Tagg and Wheeler's statement, brief as it is, hints at a motive for their company's proactive involvement in the rocket programmes of the 1950s and 1960s which included Black Arrow. This is, perhaps, a banality – of course a privately owned company such as SARO exists to do business in its specialised field and thereby generate financial profit. Nevertheless, it is a perspective that, while pursued in some other histories of space technologies,[17] is almost entirely missing from the Black Arrow historiography. What role did those companies that were involved in the building of the Black Arrow rockets have in the *inception* of the Black Arrow programme? Let us look briefly at these companies' pre-Black Arrow activities.

SARO, and Bristol Siddeley Engines (BSE),[18] the makers of Black Arrow's first- and second-stage Gamma engines, had collaborated on rocketry programmes since 1955. The companies were the principal contractors for the detailed design and manufacture of the Black Knight test missiles.[19] There were three variants of the Black Knight design as the requirements of the missile programme altered. Each variant increased the mass of payload that could be lifted off the ground. The first, a single-staged version, first flew in September 1958. The second, a two-staged variant, was launched for the first time in May 1960. The third, a derivative of the original two-staged version but with an uprated first-stage engine, took to the air in August of 1962. A fourth variant would have doubled the thrust of the first-stage engine. Through the RAE, the Ministry of Aviation was contracting these companies, and BSE especially, to develop and improve the rocket technology in order to meet specific missile research requirements. The Black Knight vehicle was being made more powerful: it would be able to accelerate to still greater velocities. Its capability would now be such that with relatively little further modification it could accelerate payloads to orbital velocity. It would not be unreasonable to presume an inclination on the part of SARO and BSE, with their Black Knight teams and manufacturing machinery in place, to propose new programmes, including one for the design of a satellite launch vehicle to exploit (financially) these assets further. This would certainly be consistent with the sentiments of Tagg and Wheeler as they described SARO 'spreading its activities into other aspects of aviation and also into space vehicles'.[20] What, though, of role of the RAE in the inception of Black Arrow?

The Science Museum's RAE papers

The RAE was the government's design authority for the Black Arrow vehicle, as it had been for Black Knight. The Establishment was one of several in the Ministry of Aviation, formerly the Ministry of Supply, involved in the design and procurement of equipment for the UK's armed services. It offered both a controlling and a *supporting* role for those industries manufacturing the equipment. The supporting brief extended to the long term: it would be in the Establishment's interest to help maintain the stability and potential of industry so that both would be better placed to develop and deliver the technologies for future defence requirements. Put another way, the RAE would be tacitly anxious to assist SARO and BSE in meeting their (commercial) objectives, as this would help it meet its own supply objectives. Can we therefore gather more evidence suggesting a mutual push by the RAE and its collaborating industries to develop a satellite launch vehicle based around the increasingly powerful Black Knight vehicles then in production? Let us examine some of the RAE papers acquired by the Science Museum shortly after its acquisition of the R4 artefact.

These papers indicate there was a precedent for such joint RAE/industry aspirations based around the adaptation of the UK's cancelled Blue Streak missile. A May 1960 SARO brochure presented, in the words of D J (Joe) Lyons, Head of the RAE's Guided Weapons Department's Ballistic Missiles Group, 'an interim statement [...] on the design studies which are jointly being made by RAE and SARO Ltd. on Black Prince, the proposed launching system for earth satellites'.[21] Black Prince would be a three-staged satellite launching vehicle utilising a newly-designed BSE third stage but with modified Blue Streak and Black Knight vehicles for its first and second stages respectively. In his statement to parliament announcing that Blue Streak had been cancelled, the Minister of Defence, Harold Watkinson, had said that, 'The government will now consider with the firms and other interests concerned, as a matter of urgency, whether the Blue Streak programme could be adapted for the development of a launcher for space satellites.'[22] Macmillan's government then touted the Black Prince design around the British Commonwealth and then to France in an attempt to bring partners on board and so help defray the development costs. Commonwealth countries were not interested and within a year Black Prince had metamorphosed into an Anglo-French proposal that replaced the Black Knight second stage with a more powerful French design.[23] The opportunity to develop an orbital-capable Black Knight derivative appeared to have gone – or had it?

In November of 1961 the Director of the RAE stated, during an address to its soon-to-be-restructured guided weapons and armaments departments, that 'Black Knight is a [...] rocket programme which we are determined to continue', and the programme was duly moved to the newly-created RAE Space Department.[24] At this time Black Knight was still being used in follow-on trials to its original re-entry research programme for the original Blue Streak missile. A basic understanding of this programme is important in understanding the role of Black Knight in Black Arrow's prehistory and we should now pause to review it. A list of the various rocket programmes developed in the UK, and the engines used, is given in Table 1.

Table 1 Rocket programmes and engines

Programmes	
Black Arrow	Satellite launch vehicle
Black Knight	Test ballistic missile
Black Prince	Satellite launch vehicle (proposed)
Blue Streak	Medium-range ballistic missile
Crusade	Re-entry vehicle research (proposed)
Dazzle	Re-entry vehicle research
Europa	Blue Streak satellite launch vehicle
Gaslight	Re-entry vehicle research
Engines/motors	
Black Knight first-stage engines	
Gamma 201	
Gamma 301	
Gamma 303	
Gamma 304 (proposed)	
Black Knight second-stage motors	
Cuckoo	
Kestrel (proposed)	
Black Arrow first-stage engine	
Gamma 401 (Type 8)	

The Black Knight re-entry physics programme

The Black Knight trials began in 1958 as means of 'investigating the aerodynamic heating levels at hypersonic speeds and the behaviour in them of candidate heat shield materials in support of Blue Streak'.[25] These objectives were swiftly achieved and the Black Knight programme diverted, with collaboration from the United States and continued work with Australia, towards the investigation of other atmospheric re-entry phenomena. This research necessitated the launching of heavier payloads and that in turn required the use of a more powerful Black Knight engine: BSE's Gamma 301. BSE then designed and developed a still more powerful engine, the Gamma 303 – subsequently improved as the 304 – as part of a proposed extension of this collaborative re-entry-physics research programme. However, a meeting was held in the RAE's Space Department in November 1962 to which representatives from other government defence research establishments were invited, to discuss the possible future uses of Black Knight, including and in addition to the proposed continuation of the Anglo-US-Australian re-entry physics research programme. The discussions ranged between the possible use of the rocket to help meet the needs of the RAE Aero Department in investigating very-high-Mach-number aircraft, the RAE Weapons Department in working on the (soon to be cancelled) Skybolt missile (the replacement delivery system for Blue Streak), antiballistic missile systems and antisatellite weapons, and the RAE Space Department and its studies on a new type of upper stage fuelled by liquid hydrogen. It is worth noting this last in detail:

> 5.3 Liquid Hydrogen Test Bed. If there should be a definite requirement for a liquid hydrogen/oxygen upper stage development for satellite launching systems then this would have to be coupled with Black Knight

> as the only test bed available. The proposed development of Black Knight [as part of the re-entry physics programme] is compatible with further improvements which could follow to make the combination with a liquid hydrogen stage suitable for satellite launching. Such improvements would probably take the form of increasing the number of chambers to 8 thereby doubling the thrust with some other vehicle modifications to increase the tankage available.[26]

In other words, the Space Department was making clear that, should another talked-about programme (developing a liquid-hydrogen upper stage, possibly for use on the proposed uprated version of the European Blue Streak-based satellite launch vehicle) materialise, then the capabilities gained in completing such a programme would also enable new options to be considered, especially the development of a smaller satellite launching vehicle based on Black Knight. That said, it is interesting to note that there was no stated justification at this meeting for pursuing such an option: why would it be desirable to build a satellite launch vehicle; what sort of satellites would be launched; what functions would they perform, and so on?

However, closer inspection of the RAE papers makes it clear that these thoughts of a Black Knight-based satellite launch vehicle utilising a liquid hydrogen/oxygen (cryogenic) upper stage were not new and appear to be the latest in a sequence of aspirations linking Black Knight to such a role. On 12 December 1961, Harold Robinson, Head of the Satellite Launcher Division of the shortly-to-be-replaced Guided Weapons Department at the RAE, issued 'an advance indication of the studies in progress [in his division] on the design of a second stage for Black Knight, using the Liquid Hydrogen/ Liquid Oxygen high energy propellant combination'.[27] The interesting element of this proposal is the ranking of its stated objectives. It lists seven aims, with the gaining of knowledge about hydrogen/oxygen systems ranked top, minimal costings for the concept ranked last and 'The capability to launch payload into earth orbits should be aimed at'[28] immediately preceding. In other words, according to this listing the development of an orbital capability was low down the list and so, presumably, not a high priority. But this is not the impression carried in the preceding three pages of notes. They relate almost exclusively to the development of just such a capability. Furthermore, the sole attached hand-drawn sketch of two Black Knight-derived three-staged rocket vehicles is entitled 'Black Knight Satellite Launching Vehicle'.[29]

And such RAE investigations into an orbit-capable Black Knight can be traced back still further to a Guided Weapons Department memo dated 18 January 1961. This was just ten days before the meeting between De Gaulle and Prime Minister Macmillan at which the French president agreed to join the British in developing a satellite launch vehicle based around Blue Streak, which became ELDO's

Europa, but with a French alternative to the initially-proposed Black Knight second stage. The memo states that Black Knight as it stood had only 'marginal' potential as the basis for a satellite launch vehicle, although, 'It may be worth-while considering a project to develop a small liquid hydrogen engine. With a few modifications Black Knight could then be used as a cheap launcher of small satellites.'[30] This statement is notable because it reflects the RAE giving attention to the utilisation of Black Knight in a satellite-launch-vehicle design even while its significant role in a Blue Streak conversion proposal was still possible, if increasingly unlikely (the Anglo-French proposal[31] for a Blue Streak-based satellite launch vehicle is dated February 1961, but would clearly have involved preparatory studies carried out by the technical teams in the UK and in France).

The above references suggest that there was a relatively long-standing objective, albeit low-key and a little guarded, among those Black Knight players at RAE and in industry to develop, aside from Blue Streak-based studies, an exclusively Black Knight-based satellite launching vehicle.

Figure 3 An early Black Knight re-entry head, sectioned for display. This artefact was used at the Royal Aircraft Establishment for research and instruction during and after the Black Knight programme. (Science & Society Picture Library)

Let us, however, return to the Anglo-US-Australian[32] re-entry physics programme to which Black Knight was being directed in the early 1960s. It was this programme of actual Black Knight trials that formed an important part of Black Arrow's immediate prehistory.

Once the initial Black Knight launches (part of the Blue Streak re-entry vehicle design programme) had begun, it became clear that the descending re-entry heads (Figure 3) were generating some unexpectedly extreme atmospheric re-entry phenomena. This was of great interest to US and UK military thinking with respect to the development of both defensive measures – detecting and thence intercepting Soviet missile launches – and offensive ones – improving the invulnerability of US and UK missiles. Black Knight provided a ready opportunity to examine these effects further via a series of ballistic atmospheric re-entry investigations over a land range, a facility not then readily available to the US. The US duly transferred Gaslight optical and infrared tracking equipment from its Atlantic Missile Range at Cape Canaveral to the Australian Weapons Research Establishment (WRE) test range at Woomera, South Australia, home of the Anglo-Australian Joint Project and launch site for the Black Knight vehicles (Figure 4). Such was the urgency surrounding this type of research at this time that, even as Gaslight was under way, plans had been made for Dazzle, a more demanding follow-on re-entry physics programme, this time employing a new US radar detection system developed by the Stanford Research Institute for the Advanced Research Projects Agency (ARPA) and more complex re-entry head on-board instrumentation. It was the Dazzle trials that would require the launching of heavier payloads and would therefore require BSE's more powerful Gamma 301 rocket engine.

Figure 4 Black Knight 13 (foreground) and 14 (background) at Woomera in 1961. This was the only 'in-tandem' preparation of Black Knight vehicles; the programme lacked the resources to maintain this level of activity. (© Crown Copyright/ MOD)

After two successful proving launches in 1962, Dazzle was started in 1964. And as Dazzle began, the RAE was devising final planning details for yet another follow-on re-entry research programme, Crusade. Crusade would use a still more powerful Black Knight first-stage engine, the Gamma 303, as well as a new second-stage solid-propellant motor called Kestrel (this replacing the Cuckoo motor used during Gaslight). Crusade would be able to boost the heads to near intercontinental ballistic missile re-entry velocity – a research capability of particular interest to the US. But the proposed Crusade project, which would have started around 1966 when Dazzle had finished, was cancelled in September 1964. The reasons for this are still unclear, although one can speculate: it is possible that the quantity, frequency and specificity of the data that would be produced by Crusade were not considered of sufficient strategic value to justify the extra funding that the UK's Ministry of Aviation would need to seek for this programme. What is clear, however, is that this cancellation freed up funds for those putative Black Knight-based satellite-launch-vehicle designs that elements within RAE and industry had been ruminating on for several years. The RAE's Space Department had worked on two launch-vehicle-programme proposals – one for another re-entry-physics research programme, the other for launching satellites, but both employing and/or adapting Black Knight technology – in parallel during 1963 and much of 1964. It funded these studies from the existing Ministry of Aviation funds allocated to the RAE. Neither programme, however, could be started while Dazzle was still in progress: the additional funds would not be forthcoming from the Treasury, and this, if nothing else, suggests that only one of these follow-on programmes for Black Knight was ever likely to be given the eventual go-ahead.

The situation was more complex, of course, and, with further reference to the Science Museum's collection of RAE papers, we can seek to develop a more comprehensive picture. It is the complexity of forces that shape technologies that is so often ignored in museum displays and, in this case, the historical literature too.

The following extended excerpt from the fourth meeting of the Re-entry Physics Co-ordination Panel, in July 1963, serves the point. It is reproduced almost in its entirety, as it illustrates how parts of the decision-making process that shaped Black Knight's fate (and hence Black Arrow's inception) differed widely. The Re-entry Physics Co-ordination Panel comprised some 20 representatives from various parts of the Ministry of Aviation, including the aero, space, maths and radio departments of the RAE, the Royal Radar Establishment (RRE), the Royal Armament Research and Development Establishment (RARDE), the Ministry's London Headquarters and one secondee from the Australian WRE. Under agenda item 3.2, 'B.K Round Status and Schedule', one of the RRE scientists expressed concern over the frequency of Black Knight launches. His point draws a sequence of responses from others around the table that illustrates the complexity of the programme's interrelationships:

> Dr. Smith [RRE] asked whether the dates of the next five Dazzle rounds could be brought closer together. He made four points initially. (1) The data was [sic] of considerable significance from the point of view of the defence of the country. This lent a sense of urgency to the programme. (2) Politically, a willingness to speed up the programme, which has slipped considerably whoever might be to blame, would count a lot in bargaining power with the USA and Australia. There was a danger that the data would be obtained too late to be of interest anywhere except in the UK. (3) The overall efficiency of the programme, ie. Cost of the data, should be considered not the cost per firing. Delay in obtaining important information was expensive. (4) Dazzle 1 was a 'package deal', an example of a programme that needs to have all the results put together to be of value. It will be almost impossible to plan something new into Dazzle 2 [Crusade] until all the Dazzle 1 results are available and partially digested. If all goes well at the present rate this could hardly be before mid-1965. Thus the proposed Dazzle 2 is becoming only an extension of the current experiments and is to the same philosophy.
>
> Dr. Smith emphasised that either the programme was wanted and the results required with some urgency or it was not and could be stopped on the grounds of expense. Wg./Cdr Morris [Ministry Headquarters] stated

that the Treasury were not very happy on the return for money spent at present. Mr. Montgomery [WRE] said that the delays at the Australian end were due to the Australian Defence Department. They had been warned about the value of the work within the present time scale and had been greatly concerned at the apparent falling away of the programme after 1964. Australia would probably look favourably at a speed up of the proposed programme.

Mr. Gait [RAE Space Department and Chair] said that there had been some contraction of the programme and the original completion date was being held. He thought that some time needed to be allowed to assess each trial before the next e.g. to consider the merits of altering the pulse coding [of the monitoring radar]. Dr. Smith countered by saying that each round was different; a round such as the P.T.F.E. [polytetrafluoroethylene] would be of little use in planning for the Durestos [asbestos set in a phenolic resin matrix] one. It had to be assumed that the pulse coding proposed by S.R.I. [Stanford Research Institute, developer of the Dazzle radar] would be near optimum for these trials.

Mr. Parkin [RAE Space Department] said that there were practical difficulties in speeding up the programme which after all was being compressed from 13 to 9 months. (For two of the months saved, the range would have been closed down anyhow). It was possible to produce the vehicles for a faster programme but there [would] need to be a speed up on the engine manufacturing side which would cost money. Saunders Roe could produce the main stages but this would probably cost money. There was a limitation on the number of staff available in Space Department to accompany trials. More staff would cost money. However, the most serious snag was in the de Havilland firing team [the de Havilland company was responsible for running the Black Knight launch programme]. The team would have to be expanded and assuming the right men were available and could be trained this could add, say, 20% to the bill. To fire more than one a month seemed impossible because it would require the launching of two vehicles within a fortnight (the length of a moonless phase) and would need two preparations teams to ready the two vehicles in parallel. Wg./Cdr. Morris said that the de Havilland firing team seemed to be the major bottleneck. Originally de Havilland's estimates for the firing team had been lush and H.Q. ['Joe Lyons' written in pencil in the margin] had forced them to prune their team to the minimum needed for one firing every two months. The team is not completely independent of the Blue Streak team because, for economy, it relies on the same supporting staff, eg. stores and clerks. The personal problems involved in keeping the team continuously at Woomera for a period like six months also had to be considered. [...]

Dr. Smith said that two things for concern were: (a) When the U.S.A. were first involved with Black Knight it had several unique features. These are now becoming rapidly less unique with the development of comparable U.S.A. programmes. (b) The time to feed back data into the programme was far too long.

> Many of the panel felt that there was some case to accelerate the next five firings and if support from D.P.R.C. [Defence Policy Research Committee, responsible for advising on the prioritising of defence programmes] was very strong then there would be a very good case for pressing the matter. It was clear that a distinction had to be made between policy for the next five rounds and for the succeeding programme. The question had to be settled whether the overall efficiency of gathering data was best served by a steady, albeit slow, rate of firing or by alternating bursts of activity and quiescence on the range. It was thought that it might be more efficient to increase the firing rate by increasing the number of firings but keeping the rate steady as costs were primarily determined by the peak levels of activity involved. The essential questions were agreed to be: (a) Can the next phase be contracted two months? (b) can the de Havilland bottleneck be overcome? Mr. Simmons [Ministry Headquarters] said that it would have to be a very good case to obtain approval for the increased expenditure that would be involved.[33]

What factors affecting Black Knight (and thence Black Arrow) are evident in the passage above? There is the international dimension: clear concern to keep the United States on board the re-entry physics programme. One panel member expressed the fear that the uniqueness of the Black Knight programme was evaporating as the US caught up with its own re-entry physics research. An earlier reference suggests a reason: 'This continued U.S. interest is very important for without it, and the use of their costly ground instrumentation after the five remaining DAZZLE rounds, our national re-entry physics programme could not afford similar equipment. It is desirable, therefore, to secure further U.S. participation in this programme.'[34] There were the 'practicalities' of speeding up the Black Knight Dazzle launch schedule: a higher frequency of launches would require larger teams from industry in order to build engines and vehicles more quickly. It would also require bigger teams in RAE's Space Department and, crucially in the minds of the assembled, for the launching teams in Australia. There would be 'personal' problems associated with keeping UK workers in Australia for extended lengths of time. Attending to all of these 'practicalities' would mean spending more money. Even the phasing of the Moon played a role: launching more than one rocket a month would mean having to do so within a fortnight – the duration of the moonless phase during which all Black Knight re-entry trials had to be launched. Especially interesting is the concern expressed by Dr Smith over the nature of the science that could be done with the proposed Crusade programme. It was necessary, according to Smith, to raise the frequency of data generation in Dazzle because only when all of these data were 'available and partially digested' would it be possible to plan the experiments for Crusade.

Costs, international dimensions, the science... The fate of Black Knight as a launching vehicle for the next generation of re-entry physics experiments was intimately linked to these and other forces. And it was some such combination that eventually cancelled Crusade and allowed Black Arrow through. Let us turn to those studies that became Black Arrow.

The Black Knight satellite launching vehicle (Black Arrow)

Following the years of aspiration, into what specific form did these prospective plans for a Black Knight-based satellite launch vehicle now settle? And what other factors had an effect on that form, in the same way that other factors had influenced Black Knight in Crusade?

The minutes of the Re-entry Physics Co-ordination Panel of November 1962, which discussed future uses of Black Knight, record a passing reference to 'increasing the number of [rocket engine] chambers to 8 thereby doubling the thrust'.[35] It is now clear that, as of June of that year, the BSE and SARO teams had been working on just such a design at the request of the Ministry of Aviation. Westland's technical report SP 598 of September 1962 detailed an eight-chambered 50,000 lb-thrust rocket engine motor bay as the first stage of 'a multi-stage vehicle for launching a satellite'.[36] This vehicle was based around the 54"-diameter Black Knight that SARO was, concurrently, designing for the Crusade re-entry physics programme. The eight-chambered Gamma 401 engine for the satellite-launching-vehicle design would be a (relatively) simple doubling-up of the Dazzle Black Knight's Gamma 303. This reference, indeed, provides a good preview of the Gamma Type 8 engine, as the 401 later became known – the engine that was actually used on the first stage of the Black Arrow vehicle. There is one important difference, however. SARO's 1962 design was for a 54" (4' 6", 1.37-metre) diameter vehicle. Black Arrow's eventual diameter was 6' 6.74" – 2 metres.[37] This increase in size had been adopted 'to conform with possible future applications [...] as a second stage on Blue Streak',[38] thereby producing a far larger satellite launch vehicle – one comparable to the Blue Steak-based vehicle which the European Launcher Development Organisation (ELDO) was then working on. A later design proposal followed this principle and suggested that a 30-per-cent improvement on the ELDO vehicle's payload capability could be achieved.[39] In other words, Black Arrow's raw size, the width of this rocket – so evident to visitors gazing up at the Science Museum's R4 – also had everything to do with another, far larger, rocket – one quite invisible to the museum's display.

Materialising the history of technology

So, what has this study accomplished so far? It has reviewed the history of an artefact – the R4 Black Arrow rocket, during its museum life. It has demonstrated that its public displays were accompanied by little more than listings of its technical specifications and launch dates. There was little historical interpretation in these displays, but this deficit is consistent with that in the literature, which similarly offers little if any historical analysis of R4 and the Black Arrow programme. The chapter then dipped into primary source material held by the Science Museum and in association with R4 to discover more of the origins of the Black Arrow programme. This exploration revealed a range of social factors – a context to the Black Arrow programme. This background consisted of both long-term, well-established aspirations to adapt Black Knight into a satellite launching vehicle, as well as forces – technical, political, organisational, financial, industrial, military – that were shaping and eventually halting the preceding Black Knight programme.

This social hinterland of an artefact is of a sort well known in the history of technology. Many kinds of historians have employed a range of linguistic, metaphorical and rhetorical tools to expound upon it. Social constructivists such as Pinch and Bijker speak of the social construction of both technological objects and facts and the means by which they reach their final form: the role of 'social groups', the existence of 'interpretative flexibility' and the mechanisms by which technologies reach 'closure'.[40] MacKenzie walks a similar path, noting that 'technological change is simultaneously economic, political, organizational, cultural, and legal change, to enumerate just some of "the social"'.[41] Noble critiques historical narratives that seek to shield our comprehension of the 'social relations which bind and divide [people], with the shared dreams and delusions which inspire and blind them. For this is the substrate from which all of our technology emerges.'[42] His philosophy might be extended to the (far from atypical) museum technology exhibit as exemplified by the Science Museum's R4. 'Because of its very concreteness, people tend to confront technology as an irreducible brute fact, a given, a first cause, rather than as a hardened history, frozen fragments of human and social endeavor.'[43] Noble is concerned with the grand and high-level effects of such misperception: the way in which 'technology has served at once as convenient scapegoat and universal panacea – a deterministic device of our own making with which to disarm critics, divert attention, depoliticize debate, and dismiss discussion of the fundamental antagonisms and inequities that continue to haunt America.'[44]

My objectives for this essay are less overtly sociopolitical than, for example, Noble's – although it would be interesting to pursue such extrapolations from this investigation.[45] Rather, I am anxious simply to discern more of a specific artefact's origins and in particular any ways in which a museum's preservation of its final form can assist in this analysis. It could be argued that the artefact in question, Black Arrow R4, provided none of that additional background – the social context that tells us more of the nature and manner of the artefact's

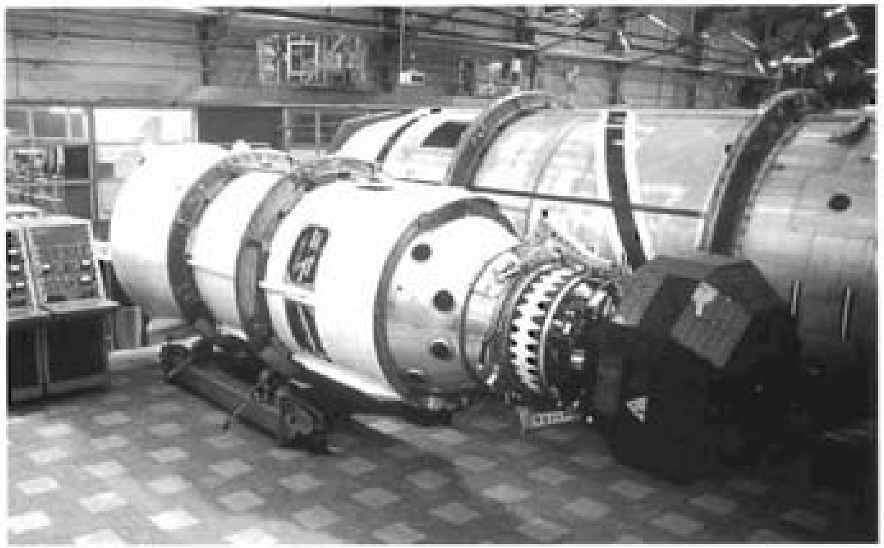

Figure 5 Black Arrow R4 at SARO, Cowes, Isle of Wight, prior to transfer to the Science Museum. The second stage (foreground) has the Waxwing apogee motor and X3 engineering model attached. (Science Museum)

inception. The main sources of primary evidence used in support of my arguments were, after all, conventional documents – the Science Museum's collection of RAE papers spanning that institution's rocketry activities undertaken with industry and (domestic and foreign) government. But this would be to neglect the role of the artefact in helping me – the author and curator, via its existence, its presence, its physicality – appreciate the worth of these papers.

Although I had been aware of R4 for many years – it would be difficult not to be aware of such a physically-prominent and substantively-significant museum object (the last of its kind) – it had not featured strongly in my curatorial interests and priorities. This changed when R4 became a problem, or rather a challenge, for the Science Museum; an obstacle to the successful redisplay of the museum gallery it occupied. It did not lend itself easily to the redesigned gallery and there were thoughts of moving it into store or loaning it to the new space centre at Leicester, then at its planning stage. I was anxious, however, not to lose any more authentic artefacts from display than was necessary, especially one as visually dramatic as Black Arrow R4. Furthermore, it was a rare example of a large indigenous UK space technology. My concerns reopened conversations with some of the original SARO industrial team that had both built the original Black Arrow rockets and prepared this one,[46] R4, for transfer to and initial display at the museum (Figure 5). This proximity with artefact and artisan stimulated my interest in R4 and, when a successful redisplay had been effected, I continued to investigate the Black Arrow programme and in particular those other objects in the Science Museum's collections that related both directly and indirectly to it. The main result was a small book, a history of Black Arrow told from the perspective of the evolution of its engines from an original German type. The publication was a simple ploy to catalogue many other engines and components in the Science Museum's space technology collection: artefacts that were mostly in store and so otherwise virtually invisible to the public.[47] Contact with the rocket's engineers and designers encouraged further and extended conversation and recollection in the shape of a witness seminar marking the 30th anniversary of R3's orbiting of the Prospero satellite. The proceedings were recorded and are being transcribed, and will form another resource for the interested historian.[48]

Such outputs satisfy one of the key rationales Finn enunciates in his defence of the artefact: its ability to stimulate interest in its actual and associated histories.[49] Further, Boon cites Jules Prown in alerting us to the way in which we can engage with artefacts, 'not with our minds, the seat of our cultural biases, but with our senses'.[50] Yes, there are other roles for the artefact – the archaeometric, for example, where the object's physical entity 'provides better testimony data than extensive written material', and Boon re-emphasises Schlereth's citation of Merrit Roe Smith's study of surviving Whitney muskets to show that 'interchangeability of parts was more of an aspiration than an actuality'.[51]

But it is Finn's stimulatory function that is worth emphasising here, not least because it applies both to the professional historian and to the casual museum visitor. Both types of individual have the same set of physiological tools with which to sense the artefact. They will, of course, respond in entirely different ways according to their own specific interests, predilections and, indeed, intellectual abilities. But the exchange will be essentially similar: the interrogation of a material artefact by a person and the potential of the object – by way of its physicality, its size, its beauty, even its smell – to trigger some sort of meaningful response in the person via a broad spectrum of sensations. For the professional historian the interrogation of the artefact does not replace the intellectual interrogation of non-artefactual evidence, but it may stimulate or enhance it. This is what happened in my case.

Perhaps this scenario could now be embedded in the design of more museum displays on space technology and made available to more prospective historians, be they professional or casual, by way of new interpretative technologies. These will pass far more of the interpretative responsibility to the visitor through local and remote electronic access to quantities and types of information. The museum's other primary sources, besides the artefact, could in principle be made available electronically. So too could those held elsewhere by other organisations. For R4, the Science Museum's associated RAE papers could be electronically accessible, along with equivalent and complementary ones from the UK's National Archives, industry and academia. The vast Australian archival resource could be tapped. Primary audio and video media could be accessed from these centres and from the broadcasting industry. Personal testimonies would be available. Witness transcripts could be used. Relevant histories could be presented alongside this primary material. Bibliographies and historiographies, for different audiences, could be included. The visitor to the artefact would be presented with more choice. Could this choice be provided away from the physical artefact – in libraries, universities and, indeed, on an individual's computer? No: the material evidence would have been excluded. Just as a choice that excluded any video evidence, say, would be exclusive, so too would be one that ignored the surviving material evidence of the artefact.

Museums can now, by way of their collections of artefacts, play a more active role in the pursuit of historical enquiry, be it for the casual or for the professional visitor. They can make available, alongside representatives or representations of conventional sources, a form of primary source – the artefact – that has been largely ignored by historians. Other institutions might aspire to do the same, but to rival the capabilities of museums they would in effect need to turn themselves into museums. Museum curators are used to dealing with artefacts and can now, by way of new, interpretative technologies, more than ever before, draw upon the traditions and techniques of those other history professionals in presenting as comprehensive a set of historical contexts to the material culture they hold as possible. Displayed space artefacts such as Black Arrow R4 need no longer be exercises in and manifestations of the sort of technological determinism so abhorred by David Noble. They will become less *explanans*, more *explanandum*. In the future we should be able to return to Noble's claim that our culture 'objectifies technology and sets it apart and above human affairs' and through recourse to the very concreteness he criticises use the artefact as an attractor for truth.

Notes and references

1 Lacey, G W B, Keeper of the Department of Land Transport and Aeronautics, Science Museum, minute to the Director, 8 February 1972, 270A, Department of Trade and Industry Space Administration, etc.

2 Lacey, G W B, note 1

3 'The fact that it is possible to touch [...] [Black Arrow] is excellent as is the ability to view the workmanship at close quarters. When you can see the individual welds, screws and rivets, these fantastic machines lose some of their fantasy and become monuments to the skill of [...] the engineer and technician.' Statement by gallery reviewer.

4 The first Labour government of Harold Wilson cancelled two major military aircraft projects – the TSR2 and P.1154 – within months of each other in 1965.

5 'Aims of the Exploration of Space Gallery', attachment to covering letter from Jane Insley, Exploration of Space Gallery Project Co-ordinator, to gallery reviewers, 9 March 1987

6 The 'angry alligator' was a US Agena target spacecraft whose fairings had failed to open properly and had remained stuck in the manner of an alligator with its jaws open. This meant the nearby Gemini 9 spacecraft was unable to dock with the Agena and rehearse procedures essential for the Apollo missions to the Moon.

7 The emphasis on spectacle was partly intentional, but also heavily contingent on the constraints facing the gallery project. R4 was displayed in the only available location left and this (suspension from the ceiling) just happened to confer spectacle on the display. Furthermore, the personnel, funding and time available to this redisplay project were strictly rationed and the resources available for the interpretation of R4 accordingly lean.

8 Turnhill, R (ed.), *Jane's Spaceflight Directory* (London: Jane's, 1984), pp27–9

9 Morton, P, 'Black Arrow: Britain's own satellite launcher', in *Fire Across the Desert: Woomera and the Anglo-Australian Joint Project 1946–1980* (Canberra: Australian Government Publishing Service, 1989), pp497–528

10 Morton, P, note 9 extends to 575 liberally illustrated pages, covering 40 years of a project in which a vast array of weapons, technologies and international politics were focused on the arid South Australian outback.

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12 Robinson, H G R, 'The genesis of Black Arrow', *Journal of the British Interplanetary Society*, 45/4 (April 1992), p149

13 Peattie, I W, 'The Black Arrow launch vehicle development programme', *Journal of the British Interplanetary Society*, 45/4 (April 1992), p155

14 Another former RAE employee, Brian Day, focuses his narrative on the satellites, actual and proposed, that the Black Arrow rockets would launch. Day, B P, 'The Black Arrow satellites', *Journal of the British Interplanetary Society*, 45/4 (April 1992), pp173–8. For a concise technical description of Black Arrow, see Gould, R D and Harlow, J, 'Black Arrow: the first British satellite launcher', *History of Rocketry and Astronautics*, 20 (1997), pp257–73. For a history of Black Arrow told via the technological evolution of its engines, see Millard, D, *The Black Arrow Rocket: A History of a Satellite Launch Vehicle and Its Engines* (London: Science Museum, 2001).

15 Saunders-Roe became part of the Westland Aircraft group in 1959 and then a division of the British Hovercraft Corporation in 1966. Its Isle of Wight site became part of the GKN Group of companies.

16 Tagg, A E and Wheeler, R L, *From Sea to Air: the Heritage of Sam Saunders* (Newport, Isle of Wight: Crossprint, 1989), p209

17 See, for example, Kelly, T J, *Moon Lander: How We Developed the Apollo Lunar Module*, (Washington DC/London: Smithsonian Institution Press, 2001), for a first-hand account of a prime industrial contractor's role in a space-technology project.

18 As with SARO, the BSE company metamorphosed in name with the consolidation of the UK aviation-based industries in the 1960s. BSE was formed from the amalgamation of the Bristol Aircraft Company and Armstrong-Siddeley Motors before being absorbed into Rolls-Royce.

19 The Black Knight vehicles' initial role was to launch development re-entry heads for the Blue Streak missile in steep trajectories high above the Earth's atmosphere. Their performance during re-entry would be studied and an optimum design for the head effected.

20 Tagg, A E and Wheeler, R L, note 16

21 Typed memo, personally signed by Lyons and taped to the inside cover of *Black Prince: A Launching Vehicle for an Earth Satellite*, Technical Publication No. 435 (Osborne, East Cowes, Isle of Wight: Saunders-Roe, May 1960).

22 'Blue Streak, Statement by the Rt. Hon. Harold Watkinson, M.P., Minister of Defence in the House of Commons on Wednesday, April 13th 1960', Ministry of Defence, London, reproduced in Martin, C H, *De Havilland Blue Streak: An Illustrated Story* (London: British Interplanetary Society, 2002), p207

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24 'Formation of weapons and space departments', Technical Memorandum No. DIR 9 (Royal Aircraft Establishment, Farnborough), Ministry of Aviation, London, January 1962, p5

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26 Minutes of the second meeting of the Re-entry Physics Co-ordination Panel, 5 November 1962, p4, RAE papers, Science Museum. © Crown Copyright/MOD. Reproduced with the permission of the Controller of Her Majesty's Stationery Office.
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28 Robinson, H G R, note 27
29 Robinson, H G R, note 27
30 Waterfall, A P, 'Black Knight as a satellite launcher', loose memo, 18 January 1961, p4, RAE papers, Science Museum
31 Note 23
32 Canada was also involved via its own hypersonic facilities.
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37 'A small satellite launcher based on Black Knight technology', Space Department, Royal Aircraft Establishment, April 1964
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43 Noble, D F, note 42
44 Noble, D F, note 42
45 David Edgerton, for example, reminds us of the need to counterbalance the number of micro-studies of science and technology with those that incorporate 'macro politics, economics, nations'. Edgerton, D, *Warfare State*, Chapter 8 (forthcoming).
46 SARO made R4 ready for acquisition by the museum: certain components were removed, others stabilised and so on. In other words, the museum's acquisition of this artefact affected its final form.
47 Millard, D, note 14
48 Black Arrow Seminar, 18–19 October 2001, Science Museum, London
49 Finn, B (ed.), *Exposing Electronics* (Amsterdam: Harwood Academic, 2000), p1
50 Boon, T, 'Material: culture: history: science', unpublished paper delivered at the *British Society for the History of Science Conference*, Liverpool, 27 June 2004
51 Boon, T, note 50

Philip Scranton

Behind the icon: NASA's Mercury capsules as artefact, process and practice

During a fellowship year at the National Air and Space Museum (2003–04), I frequently spent time examining one of the central icons of America's space programme – John Glenn's Friendship 7 Project Mercury capsule, mounted on a platform in the first floor's main hall. Dwarfed by rockets to one side and planes to the other and above, it seems almost a meagre device in comparison even with the nearby Gemini and Apollo spacecraft; several of them easily could be fitted into the cargo bay of the massive Shuttle displayed at NASM's Udvar-Hazy Center near Dulles Airport. Yet the artefact that carried John Glenn as the first American into an Earth orbit remains a magnet for visitors. As I was researching the Mercury capsule's design and fabrication, it was a guilty pleasure to watch families and clusters of teens or young adults hover around it. Built by the McDonnell Aircraft Corporation (MAC), the spacecraft stands just under 12 feet (3.7 m) tall and about 6½ feet (2 m) across at its widest, and looks like an inverted cone with a plug in the top. At launch, with its escape tower and retrorockets attached, it weighed a bit more than 2 (US) tons, then dropped more than 40 per cent of that poundage before splashing down after a flight (Colour plate 5).[1]

Resisting the temptation to offer uninvited commentaries, usually I just listened. Two simple themes struck me, among many in the conversations. Male teens and adults at times peered through the astronaut's window and observed: 'Wow, there's hardly any room in there at all' (or something similar). The technologically savvy, a smaller cohort, talked about the capsule interior's crowded, even 'primitive', arrays of dials, switches and levers, appreciating its historical location and observing that we've moved a long way from such 1960s-era apparatus.[2] For me, the 'Wow' response signalled a visitor's encounter with an icon – no questions, no requests for information or context, no interaction. By contrast, those marking the capsule as technologically primitive were, in a rough-handed way, thinking about history and progress, reflecting on then and now, taking the first step to moving behind the icon.

Yet without extensive collateral information, without an enriched *context*, the capsule artefact cloaks its origins in a time of cultural fright and political anxiety, in an era of urgent NASA designing, engineering, testing, redesign and fabrication, in a world of nuclear stalemate, mutually-assured destruction, and technological rivalry. This spacecraft surely is 'frozen history', a notion David Noble evoked and Martin Collins has emphasised in this volume's introduction. Yet what does the capsule as artefact freeze and exclude? One absence is the *process* through which its creation was accomplished and, by extension, the people who activated that process.

The Mercury effort involved an expensive and erratic learning curve concerning space technologies and their associated sciences, from metal-bending to metallurgy and from soldering communications connectors to electronic theory. Consistently, the line of development ran from technological imagination through engineering design and artefact fabrication, with an occasional sidestep to commission targeted scientific research. The Mercury capsules were not a consequence of scientific findings, but rather, inverting the usual frame, provoked a broad set of questions for scientific investigation while struggling with empirical challenges that science could little clarify, *c.* 1958–63.

Evoking these macro-level dynamics and challenges can contextualise the artefact, but we also should consider how the artefact, and in Martin Collins's words, 'the details of [its] creation and use', can 'illuminate' the surrounding culture. Thinking specifically of space history and its apparatus, he has bracketed a series of themes that I will reframe as questions to which the remainder of this discussion will attempt tentative responses.

1. If science and technology have come to be regarded as 'the pre-eminent means for understanding and controlling nature', how do space artefacts confirm or challenge that pre-eminence and that goal?
2. How can a space artefact serve as a 'nexus through which one could comprehend both technical and cultural change'? In what sense does the artefact 'in and of itself offer the opportunity for insights into technical or social change'?
3. If project-management cultures are a key part 'of the structure of big technology projects', how do space artefacts embody that culture and structure?
4. How can a space artefact communicate the notion that Cold War projects 'alter[ed] social boundaries and tend[ed] to de-centre the work and contributions of individual teams or research sites'?
5. How can these technologies, and the details of their creation and use, help us recognise that 'space artefacts [rarely] were fully settled entities in a design or material sense'?

Now, rather than working mechanically through these issues, I will shift into storytelling mode, offering a group of 'Mercury tales' and images that resonate with an effort to get behind the icon, to locate the people and the process, the politics and the engineering, and to grapple with the 'stuff' that worked, the 'stuff' that did not and the unknown/unknowable bits that jumped up to bite holes in budgets, schedules and artefacts.

From the end, back to early days

At the October 1963 Project Mercury Summary Conference, principals from NASA and McDonnell Aircraft described to reporters the process and the experiences central to fabricating America's first piloted space capsules. Newspaper and magazine writers had recently stressed a report of 700 'system or component discrepancies' in the MA-9 flight capsule (Gordon Cooper for 22 orbits), three-quarters of which were 'attributed to faulty workmanship',[3] but much of interest to historians and curators of technology was also offered that morning.

NASA Deputy Administrator Hugh Dryden delivered these opening comments: 'We learn how to build things to last longer by *trying to build them, by operating them in space, finding out what goes wrong, correcting [and] learning more* about the environment [...] we learn by going into space and working there; not from some theory in the laboratory.' The ghost of Thomas Edison surely beamed at Dryden here, for this was innovation in true, empirical, Edisonian fashion, referencing what engineers have long termed 'cut and try' methods. The NASA manager continued:

> We have learned that the requirements for things to work in space are very much more rigid than those that work on automobiles or even on airplanes [...]. In the space program, for the first time we have opened up to the American public the full gold fish bowl, how a complicated research and development project proceeds in a frontier area of technology [...]. Those of us who have been engaged in such projects for many, many years, particularly in the military projects, are very familiar with all these things, but the public has not been familiar because they have not been exposed to the detail of progress of these complex developments.[4]

Yet NASA Deputy Director (and longtime Space Task Group member) Walter Williams complicated this portrayal of learning-intensive transparency, indicating that while perhaps there *was* learning, there was no learning curve:

> You might expect with time that there [would] be a learning curve, but I think *what offsets this* is, one: a mission [becomes] more complicated as we have moved on, which set the standards higher; two, I think we did decrease the mesh of the screen [through] which we were filtering these problems so that we are constantly finding better ways to look deeper, look further.[5]

Spacecraft development was not just shooting at a moving target; the entire project was constantly in motion, platforms and targets alike, facing a demand curve that escalated unevenly. Just because your team knew how to accomplish a task today didn't mean that the task had stabilised. Tomorrow or next month, it could morph unrecognisably, demanding fresh approaches, tighter tolerances, higher performance – devaluing received knowledge and shoving aside any notion of incremental learning and artefact stabilisation. In his paper for the closing conference, Williams observed, in something like a runaway sentence:

> We knew [...] that to do this program at any reasonable length of time, wherever possible, existing technology and off-the-shelf equipment would have to be used, wherever practical, and [...] although it was expected to find much equipment on the shelf, I think many of our problems were really finding which shelf this equipment was on, because, in almost every area, because of the design constraints, some new development had to be undertaken to meet the new requirements.[6]

McDonnell's Walter Burke reinforced Williams's point:

> In this particular venture, we were going into a method or mode of operation that had never been attempted before. There are no pieces on Project Mercury that are off the shelf from any other program that has ever existed. [My own sense is that this claim was too sweeping, but were it qualified a bit, the point could stand.] The problem of designing and making work this complex group of systems is one which will require and did get a degree of attention to detail far surpassing [any] that has ever been evident in any industrial effort up to date.[7]

A newsman sagely suggested that Admiral Rickover might challenge this assertion, as building nuclear submarines was arguably fully as complex and risk-intensive as fabricating spacecraft,[8] but Burke continued in his heroic mode.

Turning to production, Burke asserted that building the Mercury capsules succeeded 'only because we were able to objectively view, openly criticize our own work and take the necessary steps boldly and with courage', claiming that there was 'never any evidence of any deliberate or sloppy workmanship'.[9] Burke was reacting to the reports of deviations from design and the widely-known delays in completing and qualifying capsules. For his part, Dryden dodged a question about whether he was 'satisfied with the level of quality controls' during fabrication. He acknowledged only that the 22-month delay 'between the planned orbital flight and the actual one' was 'the result of new information arising in the development tests'.[10]

Over and again, components when tested did not work or did not work as expected, systems once assembled from components failed to operate, and sets of systems installed in 'finished' capsules interfered with one another. All this demanded reworking, redesigning and retesting. McDonnell's Burke explained that discrepancies between blueprints and actual fabrication were inevitable:

> In doing re-work of any configuration, there are many times, when you are right on the job, you can see a different way of doing it than would have been apparent were you back at a drafting board with nothing but blue prints to look at. The requirements to go ahead and [get it done] would be the cause of the issuance of drawing deviations.
>
> Indeed, if you examine the individual pieces that go into a spacecraft and examine the limited number of such pieces that are ever built, then go back and recognize the problem of developing the tooling itself to produce these parts and the learning on the part of the employees [...], you will find that almost no pieces in Project Mercury had more than a couple hundred, at the outside, duplicates made. Now [...] in an airplane factory, it requires anywhere from sixty to a hundred or more airplanes to go down through the line before you will have coordinated the tools from one area to another.[11]

Nothing like that number of iterations was available in fabricating spacecraft.

In closing though, NASA's Williams stuck to his point about the insufficiency of 'learning' as a concept to describe the pathways through uncertainty and the unknown that aerospace development entailed. When Warren Burkett asked whether what was learned in the Mercury project 'gives you confidence that you can reduce the amount of check-out time on this first Gemini', Williams replied, 'By spreading the knowledge [from Mercury] we will not have the same problems in Gemini or Apollo. [... Yet] there [...] *we will have some problems that we have not been smart enough to anticipate or ask questions about.* The complexity is greater in these missions.'[12]

So what was going on here? Though press coverage missed the larger point, both NASA and McDonnell leaders were talking discreetly about how dreadfully difficult and demanding fabricating a spacecraft proved to be and how thoroughly their initial expectations and principles were undermined by experience. The top spokesmen for each organisation strove to underscore how much had been learned from Mercury by their organisations, their workers and staff. Critically, however, Williams in part demurred – any claims about learning curves, he argued, were more than offset by the rising engineering and performance challenges within Mercury and beyond, by the constant redesigns and frequent reshaping of production practices, and by the recognition that questions beyond the scope of existing knowledge would surely surface during Gemini and Apollo.

Yet this 1963 Project Mercury conference does provide a basis for recognising key interpretative issues that are built into the space capsules as a set of manufactured artefacts:

- The cultural and political demands of a difficult partnership between corporate and government organisations
- The challenges of dealing with recurrent error and failure
- The overriding importance of practical engineering (rather than theory)
- The tangled and bumpy path from design to usable artefact in an environment of uncertainty that features both too much information and too little knowledge
- The multilateral tensions and conflicts (between NASA, McDonnell, the Army, the Air Force and the astronauts, at a minimum[13]) emergent around shifting requirements, contract revisions and engineering changes.

To grapple with these issues and highlight others, we will cycle back to the Mercury project's beginning and make a selective tour of the spacecraft's developmental trajectory.[14] That arc led to the end-of-project conference just reviewed and laid the basis for continued experimentation in the Gemini and Apollo programmes. We may start with an overview of the six elements I regard as central to the spacecraft development and fabrication effort, before examining each in a bit more depth: programme, place, process, problems, responses and results.[15] Programme refers to Mercury's objectives and principles, whereas place indicates the spaces of design, fabrication and testing – the St Louis plant of McDonnell, the prime contractor, subcontracting firms' many, scattered facilities, and NASA's administrative, laboratory, test and launch sites. Process and problems reference the contested dynamics of artefact creation, the arrays of design changes and questions of control, quality, reliability and schedule. Responses include efforts to rethink managerial and project practices, to systematise available knowledge and generate new information, and to build effective institutions and networks for information and negotiation among the parties. Results surfaced at the 1963 closing conference – in sum, building Mercury proved to be a lumpy but successful programme, accomplishing much problem-solving but providing limited legacies for the more complex and ambitious Gemini and Apollo initiatives.

Programme

I begin with the original September 1958 statements concerning the capsule's objectives and principles. Key design propositions, for which the legendary Max Faget was centrally responsible, included the expectation that 'the vehicle' would be ballistic with 'high aerodynamic drag', that it would be 'statically stable over the mach number range', and that it would 'withstand any combination of

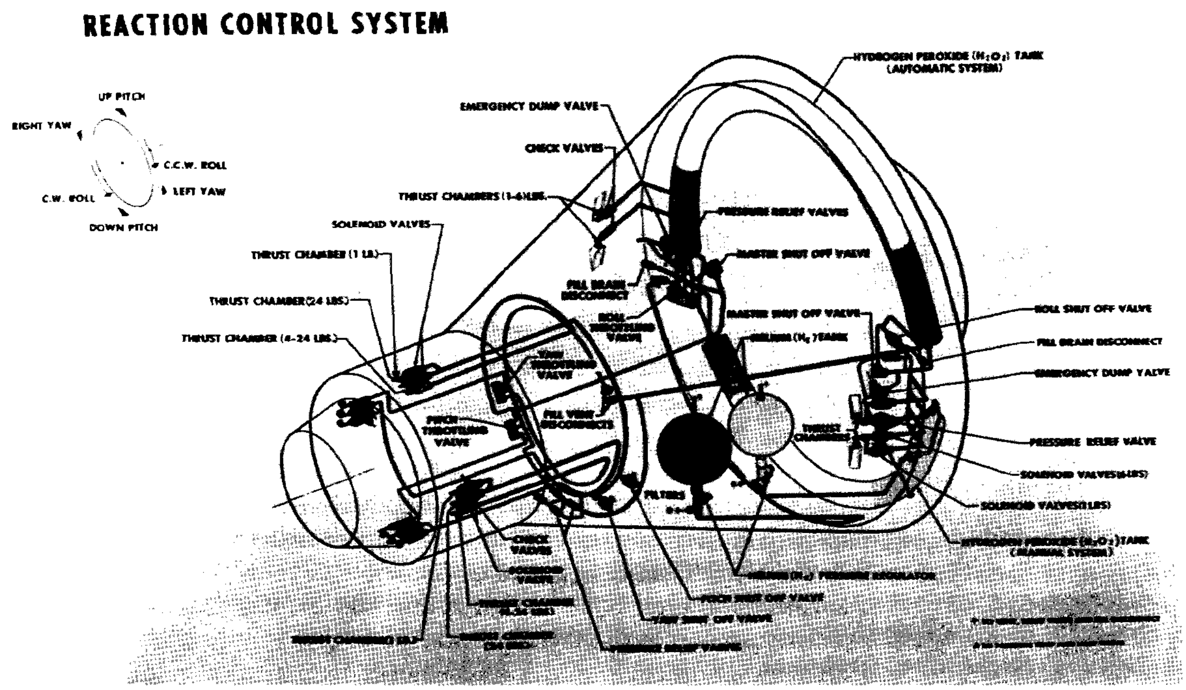

Figure 1 Diagram of the Mercury capsule's Reaction Control System. Source: Box 74, Project Mercury Photographs, Entry No. 70, History Office Source Files, LBJ Space Center, NASA Records RG 255, NARA-Southwest Region (Fort Worth). (NASA)

acceleration, heat loads, and aerodynamic forces that might occur during boost and reentry'.[16] The first item entailed the capsule's stubby cone form, broad at the base and slender towards the top, rather than the sleek needle-nosed aircraft and rocket styling that so enchants museum visitors. (After all, the thing is *ugly* and scarred by re-entry – a culturally-inflected judgment that provides an opportunity for interpretation.) It needed to be stable at all speeds, so that it would not spin, wobble or tumble, putting, for example, the narrow end forward on re-entry, which would guarantee disaster. Both structural shapes and weight-balancing aimed at this concern, with a range of attitude-control devices added to correct deviations from the norm. These were combined into the 'Reaction Control System' and managed yaw, pitch and roll – three dimensions of trouble aloft (Figure 1). The third criterion dealt with the structural challenges that stresses, vibration and heat posed. The dish-shaped heat shield underneath the capsule was the most visible evidence of design elements addressing these problems, but virtually every system, structural and operational, had to engage them, as, for example, vibration could break some of the capsule's thousands of electrical connections or dislocate instruments' calibrations. Three simple, necessary principles – a cascade of implications.

NASA supplemented these basics early in 1959, defining the project's objectives as to achieve orbital flights and recovery and to test man's capabilities in a space environment. Three additional principles appeared: that the project should take the simplest and most reliable approach, involve a minimum of new developments and operate through a progressive build-up of tests, first components, then devices, then systems of devices, then integrated systems.[17] NASA managers regularly referenced this set of principles (using a briefing slide that presented them) for the next four years; indeed, in the closing press conference speakers discussed that slide. Yet though the two objectives were achieved, none of the three principles rested unscarred by the capsule-fabrication experience.

Simplicity went out of the window first, as the paramount requirement for astronaut safety mandated creating redundant systems and backup components within the fixed shell. This generated considerable complexity, with the result that operational capsules were stuffed with technology, scattered about their tiny innards, as the schematic for the Reaction Control System confirms. Moreover, escalation of programme expectations added equipment and weight to each capsule and increased the complexity of, for example, the internal wiring arrangements and the interconnectivity of systems. As Charles Perrow so forcefully reminded us in *Normal Accidents*, increasing complexity generates enhanced capabilities and multiplies opportunities for failure. For example, no single individual can 'know' the entire structure, much less track its permutations, even as the likelihood of component breakdowns compounding to system failures also rises. Expert systems are created to contain the universe of information, to be sure, but they serve as a reference base, not a body of organised knowledge.[18]

As McDonnell's Burke later affirmed, hardly anything that went into the capsules, down to bolts and screws, was standard or stock. Indeed, the second 1959 principle was actually inverted, for Project Mercury provoked not a minimum, but a 'maximum' of new developments. Testing was of course exhaustive, bordering on obsessive. NASA's William Bland and Lewis Fisher noted in August 1963 that 'We have been accused, in the Mercury Program, of testing equipment to death. This may be true to a large degree.'[19] Despite this attention to detail, the 'progressive build-up' proved to be far more uneven and erratic than was hoped. The original plan to build and test components, amass these into each of 14 systems which would be tested independently, then assemble them into an entire capsule that would be tested as a unit, broke down persistently. Some components were just balky or unreliable and a constant frustration (e.g. batteries), whereas some worked fine in stand-alone tests, then failed when slotted into systems (valves were renowned for this). Some systems generated a durably-low confidence level (famously, reaction control and its small thrusters), whereas others failed almost randomly (electronics and instrumentation). The whole-capsule tests, somewhat akin to the 50-hour and 150-hour qualification tests long necessary for new military jet engines, at times turned into horrible experiences, yielding unexpected and inexplicable breakdowns. Thus, although the programme's objectives and the first set of capsule-design principles remained solid and sound, the second cluster of principles, oriented to managing the project's course, repeatedly hit snares set by complexity, production deficiencies and insufficiencies in technical experience and scientific understanding.

Place

Our next step is to visit the spaces where engineers, managers and skilled workers undertook the design and fabrication of capsules and thereby established and tested the internal and external linkages necessary for creation of complicated artefacts. Internal linkages are direct – the material connections and functional relations of a capsule's elements and systems. External relations are, to use Anthony Giddens's term, 'distanciated', that is, stretched across time and space, and here across multiple enterprises and institutions.[20] Components came from scores, eventually hundreds, of subcontractors across America,[21] and when they were deficient, long-distance raving filled the phone and telex wires.[22] Supervision and technical advice came through NASA, not just from Washington and Langley, but from its labs around the nation, from consultants and from independent testing and research institutions (some universities and separate enterprises such as Battelle or Mellon). Thus, fabrication was both centred at St Louis and decentred, in the dual senses that multiple, spatially-scattered agents were essential to building capsules and that elaborate interactions among primes, subcontractors, NASA and external organisations and specialists proved necessary to problem-solving.

Now we'll enter the McDonnell plant, midway through building the capsule series. Here it first is critical to recognise that a major phase in aerospace innovation history began in a workshop occupying a tiny proportion of McDonnell Aircraft Corporation's sprawling facilities alongside the St Louis Airport. Second, both major and minor elements of the capsule went out to subcontractors, which were both major and minor firms. For example, Minneapolis-Honeywell agreed to create the Automatic Stabilization and Control System (ASCS) on a 'very tight schedule', which necessitated a 'high order of liaison [...] through a St. Louis engineering representative [...] through periodic week-long contacts by other M-H system engineering personnel and by periodic visits of appropriate persons.'[23] AiResearch created the environmental control system, Collins Radio the telecommunications, whereas the flashing recovery light, illuminated on splashdown, went to relative newcomer ACR Electronics, and Kollsman, a precision instrument company founded in 1928, snared the altimeter and the cabin pressure indicator contract.

Figure 2 McDonnell's main work area for fabrication of the major components of the Mercury capsules. Source: Box 75, Project Mercury Photographs, Entry No. 70, History Office Source Files, RG 255, NARA-Southwest. (NASA)

Figure 2, one among a set of pictures taken on 14 April 1960, shows McDonnell's main work area for major Mercury components fabrication. At the upper left, behind the curtain wall, we can barely see the fuselages of several jet aircraft, being constructed 'next door' to the capsule workspace. In the spacecraft section, at the right we find three circular bottom plates or pressure bulkheads, with a fourth behind them, lying flat, before insertion in the empty circular work-frame. At the far right are welding machines for the main cone, whereas at the far left a partially-finished cone has had its cylindrical top attached. Very little machinery occupies this space; rather it is organised around desks and worktables, with cabinets for drawings, manuals and small parts running along the vertical centre line. The shop manager's office was at the left, outside this view, with desks for engineers and technicians in the open area nearby. Very much like Kelly Johnson's Skunk Works, Lockheed's famed centre for aircraft design creativity,[24] here the engineers work right down on the shop floor, so that regular interactions between them and the skilled workers were facilitated. What we have here, then, is a traditional metalworking job-shop layout, but notably all but a few of the workers at this moment are consulting files, checking drawings, and the like – not fabricating. That day, the photographer took three views of this shop, in which 24 men appeared, just eight of whom were at work on the artefacts. This place, then, offers a window into early spaceware production as design and paperwork intensive, as connected deeply to the culture and practice of aeronautics manufacturing, and, in this era, as a boundary zone where white- and blue-collar workers intersected and interacted in urgent but frustrating efforts.

Process

Moving away from the assembly floor for a moment allows us to view and consider the overall process of capsule fabrication. The initial plan provided for 12 identical spacecraft, following the simplicity principle. The NASA contract with McDonnell was soon modified to authorise 20 individually-designed capsules in five groups – uninstrumented boilerplates (dummies), instrumented boilerplates, animal-carrying and piloted, first for ballistic then for orbital flights. These differed in detail because some flights needed to be automated (boilerplates and animal, 24 of these in total) whereas the six manned flights needed a wholly different set of controls, redundancies, supply systems, etc. Moreover, engineers and space scientists soon recognised that there were distinctive design challenges for ballistic flights and for orbital ones. These considerations fed back into the fabrication setups, of course. Here, plainly, the Mercury capsule was an unstable artefact in that much the same exterior configuration was employed toward multiple uses.

Though McDonnell was the official fabricator, NASA was ever-present at the St Louis plant; literally through Wilbur Gray, the Agency's resident field representative,[25] occasionally through visiting panels of NASA principals, and through a constant flow of telexes and phone calls. Relations with subcontractors turned critically on quality control, scheduling and documentation, this last being a standard misery. At one point a firm which had completed a $50,000 subcontract calculated the man-hours necessary to generate all the documentation MAC and NASA wanted, and estimated it would cost $114,000 more. At times it took more effort and time to create manuals of practice for devices than just to build and test them.[26]

In terms of the paperwork flow, the lifeblood of Mercury's engineering dynamic was production of Specification Control Drawings (SCDs) for components and systems. These detailed design portraits were supposed to be 'frozen' so that procurement could proceed reliably. But the feedback from testing wrecked this linearity and stability. Failures entailed fixes; fixes had to be configured into the SCDs. Changes ranging from the moving of wires to the substitution of materials all had to be documented, but as remarks at the 1963 conference indicated, reporting and entering shop-floor alterations

Figure 3 Electrical motherboard for wiring assembly. Source: Box 75, Project Mercury Photographs, Entry No. 70, History Office Source Files, RG 255, NARA-Southwest. (NASA)

was not reliably carried out. Moreover, this flux interacted with the individualised capsules in a centrifugal fashion, as both the numbers of drawings and the volume of changes to drawings escalated, with the changes being relevant to one, some or all spacecraft, whether planned, in progress or finished.

Once the cones were welded and their structures completed, workers levered them onto wheeled carts and rolled them to one of a series of 'clean rooms' built inside the St Louis aircraft plant. With fluorescent overhead panels, flat-surfaced partitions, no windows and workers in white jumpsuits and hats rather than street clothes, the clean room was a place substantially different from the open shop, a place for more delicate and intricate processes. There, technicians completed electrical wiring work at a number of stations, with components then installed in the capsule frames and bottom panels before the latter were linked to pressure bulkheads and the all-important heat-shield dish. At the electrical stations, mock-ups replicated the elaborate spaghetti system of capsule wiring flattened onto a panel (Figure 3). Hold this image in your mind, then consider what troubles would be caused by implementing scores of electrical design and component changes.

Other photos from 14 April show the insertion of electrical, communications, environmental and instrumentation apparatus into partially-assembled capsules. Many of the outside plates had been installed, but most had not. Thinking about this for a moment suggests how staggeringly complex the fabrication process was, for each external plate could only be bolted on when everything underneath its particular space had been installed. When design or parts changes occurred, gaining access to concealed components was miserably time-consuming, for elements of the 14 systems were distributed throughout the capsule and multiple outside plates had to be removed in order that replacement parts could be substituted.[27] Clearly, in constructing one of the space age's iconic, hi-tech-for-its-time artefacts, McDonnell employed urgent and problematic system design and relatively low-tech, job-shop fabrication practices, to which it appended an early version of a clean room.

Problems

As noted earlier, material deficiencies caused persistent problems in building Mercury capsules; these aggravated organisational inadequacies traceable to the project's complexity and the interacting firms' and agencies' differently-framed competencies and interests. One index of material problems with capsule fabrication is the flow of requests for rework by subcontractors, another is the flood of Engineering Change Requests for individual parts substitution or redesign (which reached into the thousands by 1962). A third is the accumulation of the more substantial Contract Change Proposals (CCPs), the mechanism through which project costs rose from an initial $15 million to roughly ten times that sum over five years. By January 1960, after just 13 months of effort, either McDonnell or NASA had filed 125 CCPs; in November 1961, at the close of Mercury's third year, that total reached 360.[28] In consequence, Mercury's draftsmen worked overtime creating, checking, releasing, revising and re-releasing thousands of engineering drawings (Figure 4). This chart, issued in late March 1960, shows the dramatic effect that engineering changes had on design drawings. Six months into the project, planners had expected that about 500 drawings would be needed to detail the Basic Capsule Configuration (Point A). Actually, 700 drawings had been needed, but with changes included, the Basic Configuration demanded 1600 drawings (the September 1959 point on Line D, labelled 'Total Releases including Changes'). By March 1960, the base drawings for the 20 capsules in their varied configurations reached 1100, but engineering changes swelled the total drawings released to 5000.[29] Little wonder that McDonnell reported that it often ran its Mercury facilities on three shifts, 24 hours a day.

Testing, of course, was a key initiator of artefact instability; it operated in four domains: components, systems, development and whole-capsule operations. Testing to failure presumed to establish the life expectancy of components, but as so many of these had been

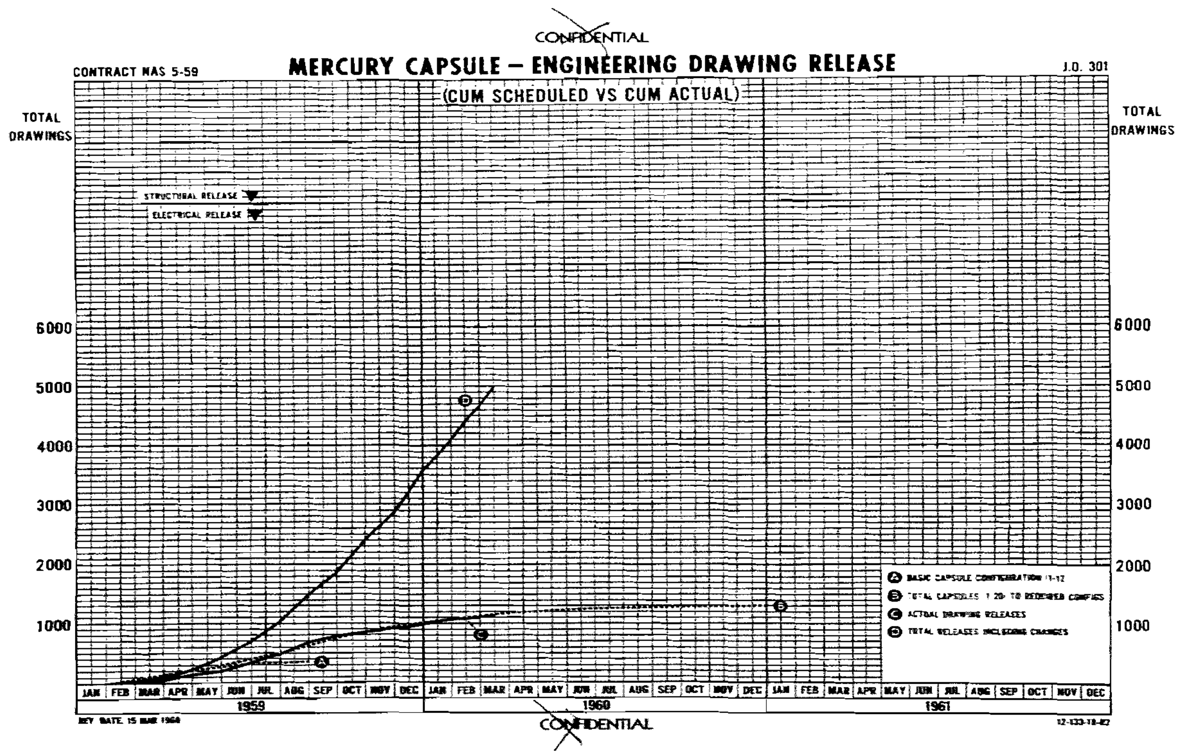

Figure 4 Engineering drawing release for the Mercury capsule, March 1960. Source: Box 22, Entry 100; Contract Administration Files: Procurement Division, RG 255, NARA-Southwest. (NASA)

ordered and produced in batches and often redesigned, the small-numbers problem made it statistically unreal to expect such testing could assure reliability. Component acceptance tests aimed to certify that items provided by subcontractors worked as planned, but often they did not. Systems tests were more aggravating, as at times the causes of deficiencies proved elusive and alternative hypotheses difficult to test in mock-up systems or impossible to trace in failed, installed systems. As testing gurus Bland and Fisher explained, producers could trigger surprise problems either when skimping or when improving:

> We have seen occasions where components, after having been completely qualified through the rigorous Mercury-qualification program, would exhibit a history of failures. These failures would occur when production units were subjected to acceptance tests or other routine testing. The subsequent investigation revealed that the vendor had hand-built the prototype units [used for qualification] to the highest standards of quality control. When production began, however, the units were made by different people, by different methods, and to relaxed quality control standards. Sometimes parts were rearranged as an expedient in production to cut costs.
>
> A second aspect of this problem is when the vendor decides to make small 'product improvement' design changes. No matter how seemingly innocuous and straight-forward, small changes [...] can completely

> invalidate the qualification of the unit. The side-effects of such changes – that is, the[ir] effects [...] on the operations of the system as a whole – cannot always be anticipated [...]. Such things have led us to a philosophy which says, in effect, that where components and systems are operating satisfactorily, leave them alone and don't try to improve them. Don't change things just for improvement's sake.[30]

Operating away from the assembly shops, development testing had a distinctive role: it was the foundation for 'engineering studies', research designed to increase MAC/NASA's knowledge base regarding new materials and techniques put forward for possible use in capsules and their fabrication. Examples from 1959 concerned exploring beryllium's properties at elevated temperatures; it was being considered for the heat shield, but was dumped in favour of an ablation technology. Ablation here refers to the shield's capacity to shed tiny fragments of burnt heat-absorbing material on re-entry without cracking or losing overall integrity. Materials such as graphite, PTFE and some ceramics could have this property, but they, and ablation more generally, were poorly understood scientifically, so testing of the heavy (600 lb, 270 kg) metallic shield went forward in parallel with attempts to fashion a lighter, fibreglass-based alternative shield.[31] Here, problem-solving looked more like R&D laboratory work, unlike the majority of component and system fixes undertaken.

The summit of factory testing was the Capsule System Test (CST), which evaluated the integration and proper functioning of all 14 spacecraft systems. For the first two capsules, these efforts demanded two months' work apiece, with many fixes triggering delays in mating capsules with boosters and in organising launches and recovery teams. Once boilerplate capsules had been sent aloft (the final test before launching primates and people), NASA and McDonnell engineers discovered that, despite all efforts at careful assembly and cleaning, a variety of 'space junk' emerged from crannies in the artefact under zero gravity, floated about for a while, then deposited itself all round the capsule interior. Consisting chiefly of metal and plastic shavings and tiny parts, this was very dangerous material, for it could potentially interfere with electrical links, slip into places to jam levers, or, as did happen, clog a fan inlet, producing a failure. Thus the Project devised an additional testing procedure, capsule tumbling, in which a 'finished' spacecraft was bolted into a frame, then spun and rolled so as to loosen this detritus. The yield from tumbling Capsule No. 13 in December 1961 appears in Figure 5, and includes washers, nuts, wire, plastic sheaths, insulation and, at the centre, what seems to be about a ¾-inch hex-head bolt.[32] So many things could go wrong, and some unknown number of them, like the floating space junk, could be discovered, as Dryden explained at the end-of-project conference, only by going into space.

Figure 5 Yield of loose materials from tumbling Capsule No. 13 in December 1961. Source: Box 76, MSC Capsule No. 13 Photos, Entry No. 70, History Office Source Files, Folder 1, RG 255, NARA-Southwest. (NASA)

A briefing chart created in March 1960 attempted to anatomise the flood of engineering changes, the information flows and paperwork which threatened to derange project personnel, if not derail the project as a whole. Only 20 per cent derived from 'improvements and requirements changes' – for example, upgrading valves and the Reaction Control System and installing the astronauts' window. The remaining 80 per cent of the capsule redesigns came from development work – testing, manufacturing and special engineering studies. Because of 'concurrency', simultaneity in design, fabrication, testing, research, *et al.*, most of the project was in a development phase at all times. Both the chimpanzee and human flights, after all, were tests. In the manufacturing bloc (25 per cent of all changes) necessary rework could be traced to vendors not meeting specifications, to shortages in materials (forcing substitutions), to production and tooling problems (some parts could not be made as planned and had to be rethought) and to physical interferences among components once assembled.

Engineering research (10 per cent) generated redesigns chiefly in structures, instrumentation, materials and electronics. However, testing forced nearly half of all changes (45 per cent), a tribute to the rigour of Bland and Fisher's colleagues and source of many conflicts with MAC management, engineering and subcontractors.[33] Not

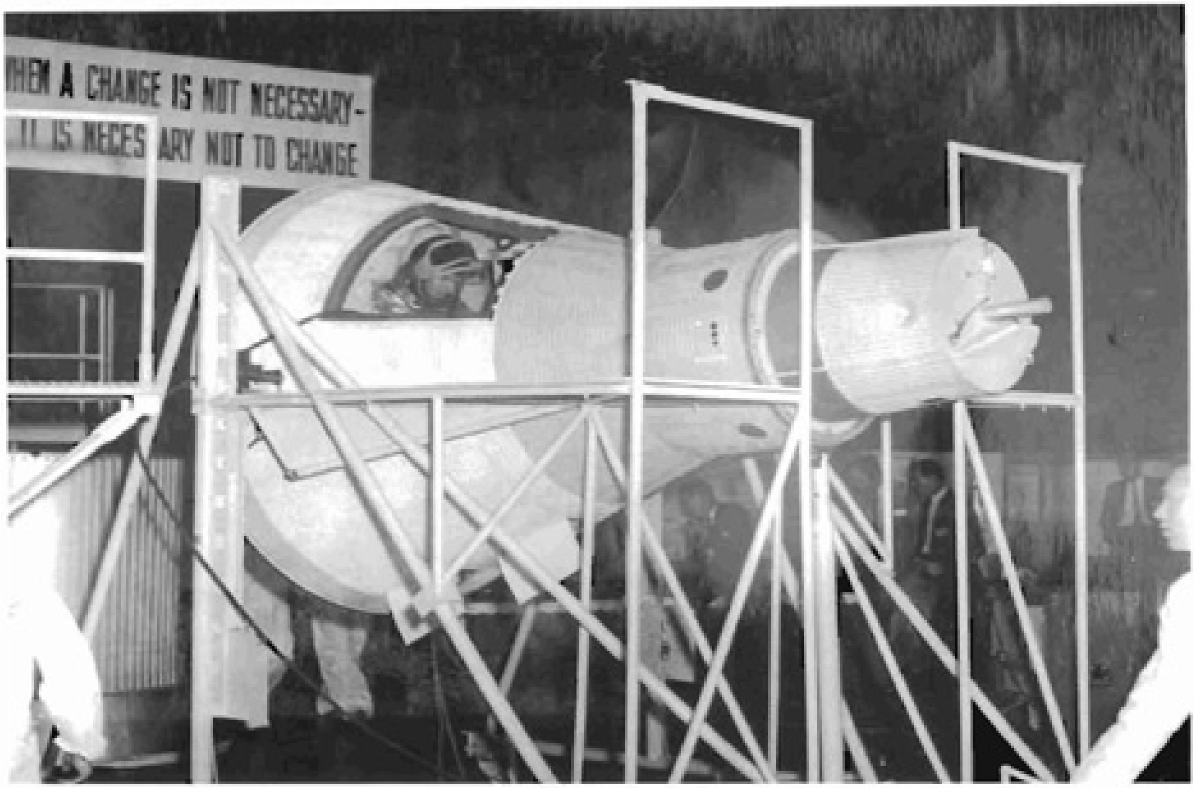

Figure 6 Mock-up Mercury capsule with sign. Source: Box 74, Project Mercury Photographs, Entry No. 70, History Office Source Files, RG 255, NARA-Southwest. (NASA)

surprisingly, placards appeared in the McDonnell plant urging that changes be kept to a minimum, undertaken only when 'necessary', as Figure 6 indicates. Yet the definition of what was necessary was hardly obvious, often contested and rarely settled among the contending partners struggling to fabricate a spacecraft that was workable, safe and reliable.

Two major testing failures indicated how fragile the capsule as artefact actually was. On 29 July 1960, test flight MA-1 boosted Mercury Capsule No. 4 toward an instrumentation run, the first occasion on which a spacecraft was mated with an Atlas rocket. Testing and rework had consumed over two months following the capsule's delivery to Cape Canaveral in late May. Bad weather caused a series of holds on launch day, but a little after 09.00 the Atlas blasted off into the heavy cloud cover. A minute later all contact with the rocket's instrumentation was lost; the missile 'either exploded or suffered a catastrophic structural failure' about 6 miles above the Earth. Ironically, the capsule's telemetry continued to broadcast until the whole apparatus slammed into the Atlantic, 7 miles offshore. As the water there was but 40 feet deep, recovery efforts gathered many portions of the shattered capsule, which were 'painstakingly reassembled' for an engineering analysis, a process that stalled the programme for six months (Figures 7 and 8). In a double irony,

Figure 7 Capsule No. 4 wreckage on the floor. Source: Box 72, Project Mercury Photographs, Entry No. 70, History Office Source Files, RG 255, NARA-Southwest. (NASA)

this comprehensive failure occurred on the very day that NASA announced its plans to follow Mercury with a more ambitious programme called Apollo.

Throughout 1960, a series of panels attempted to establish the reasons behind the crash, but as these remained obscure, efforts soon focused on improving the interface between the spacecraft and the booster. Then in September another Atlas on a non-Mercury mission 'failed severely. This forced a wholesale review of the Atlas as a launch vehicle. Everybody responsible for MA-1 was trying to determine the cause of that failure, but each only discovered that there were too many other bodies, both organic and organizational, partly responsible.' Questioned about this indeterminacy at a late-October press conference, NASA administrator Robert Gilruth responded: 'We have answered all the questions we have asked ourselves – but have we asked the right questions? We can't be sure.'[34] As before, though engineering and science were crucial to the project, insufficiencies in reliable knowledge and a surplus of uncertainties meant that just knowing you were asking the right questions presented huge challenges. A month later, a Mercury–Redstone flight package took the legendary 'four-inch flight', when the rocket engine shut down just after liftoff at the Cape. The booster–spacecraft combo settled back onto the launch pad, and though it neither fell over nor

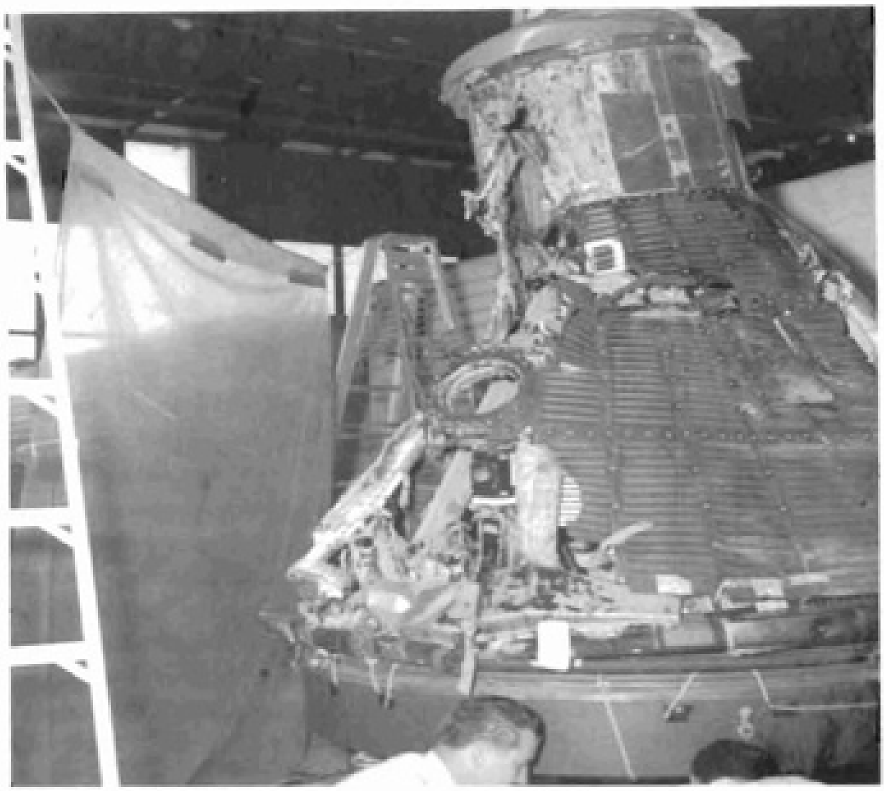

Figure 8 Reassembled Capsule No. 4 wreckage. Source: Box 72, Project Mercury Photographs, Entry No. 70, History Office Source Files, RG 255, NARA-Southwest. (NASA)

exploded, 'November 21, 1960 marked the absolute nadir of morale among all the men at work on Project Mercury.'[35]

Still, not six months later, Alan Shepard rode Freedom 7 (on a Redstone) skyward, marking the US's first piloted space flight. Another ten flights in 1961 were wholly or largely successful, including the second human-carrying launch, with Gus Grissom. Yet just as John Glenn was finishing training for the first orbital flight (February 1962), on 9 January Capsule No. 2 burst into flames during a McDonnell test procedure. This capsule had flown on an unmanned Redstone mission, was recovered at sea and returned to St Louis, where after cleaning and equipment updating it became 'a Reaction Control System [RCS] Development Test Bed'. It had been subjected to a 12-hour orbital test simulation on 6 January, during which the RCS's 'one pound roll clockwise assembly failed to fire after 8 hours and 52 minutes'. That device was replaced, but three days later the same assembly caught fire after a 13½-hour test sequence, due to a 'small propellant leak'. Technicians extinguished the fire within a few minutes, but damage to the capsule's underside bulkhead was considerable; in space such a fire, fuelled by the hydrogen-peroxide propellant, could have been disastrous.[36]

If you look back to the schematic of the Reaction Control System (Figure 1), you will notice the two curved, sausage-like elements at

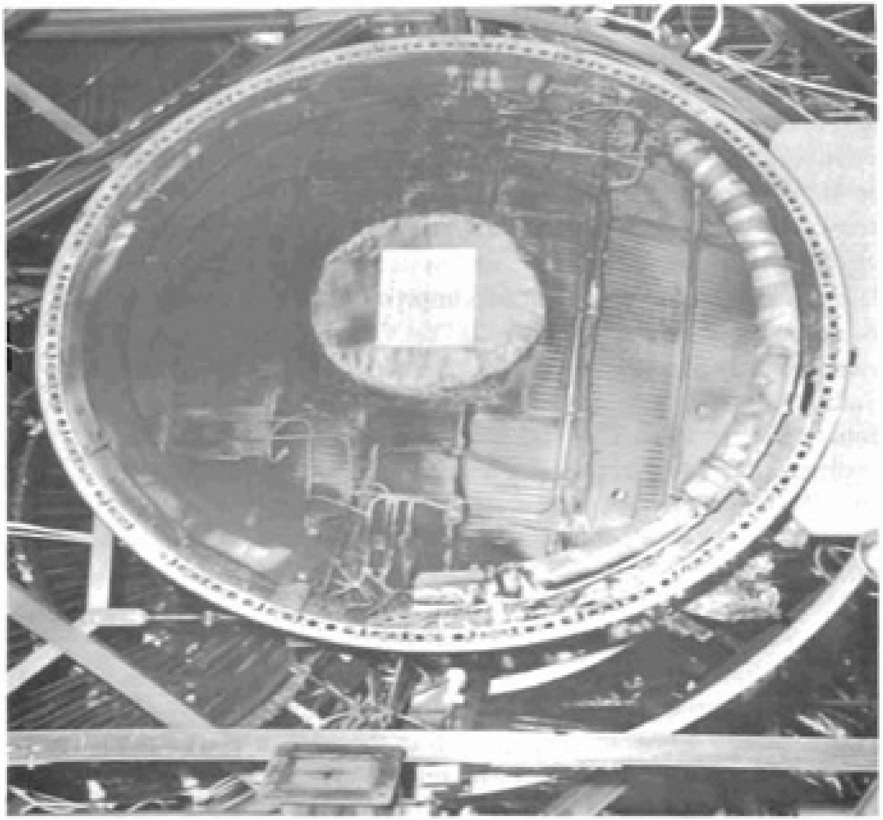

Figure 9 Fire-damaged large pressure bulkhead, January 1962. Source: Box 27, McDonnell Technical Documents (Mercury Project Office), Entry No. 198C, McDonnell Technical Reports, Report No. 8626, 'Investigation of the Capsule No. 2 incident'. (NASA)

the right, forming a circle along the capsule bottom. In Figure 9 one of these has almost disappeared, flattened by fuel loss and blackened by the fire. Ever thorough, McDonnell included scores of diagnostic photographs in its 89-page report on the 'incident', issued on 16 January. But two broad messages were implicit: replacing components could involve errors that could generate component failures and accidents, and, in spacecraft, fires could destroy missions and mission personnel. A few weeks later, John Glenn reported RCS failures during his orbital mission in Friendship 7, the capsule that sits so serenely on the NASM's ground floor. This forced him to take manual charge of attitude control (an RCS right-yaw thruster didn't work), using other system elements to dampen cycling oscillation. Those efforts completely depleted the spacecraft's RCS fuels, but there was no fire, just a good deal of stress.[37] In Mercury, as everything was an experiment, testing and redesign carried no performance guarantees.

Responses

Given the variety of problems that capsule construction spawned, responses at NASA and McDonnell were diverse as well. Yet managerial or engineering attempts to respond rationally to a non-rational environment (persistent uncertainties, repeated deficiencies and failures, insufficiencies of reliable knowledge, along with political pressure for performance/success) can border on the comic. On the engineering side, we must take seriously the tension between Bland and Fisher's leave-well-enough-alone 'philosophy' and Wilbur Gray's relentless pursuit of the perfect testing procedure, a tension internal to NASA, but evident throughout the programme. Remember, the test-it-to-death pair eventually reached a 'philosophy which says, in effect, that where components and systems are operating satisfactorily, leave them alone and don't try to improve them. Don't change things just for improvement's sake.' Yet Gray resolutely and a bit remorselessly oversaw and chronicled every conceivable discrepancy and malfunction, as if intensified fixes would yield a stabilised, well-functioning artefact. This did not happen. Instead, on one hand, project conflicts continued – a May 1960 report carefully noted that 'NASA–MAC relations were strained in many instances while attempting to resolve differences of opinion as well as technical differences'.[38] On the other hand, having no time for perfection, NASA moved on to building Gemini and Apollo capsules, working on the two concurrently, and, in a sense, hoped for the best.

Nonetheless, the project had to be managed somehow, and this was undertaken through a host of organisational units, a series of special initiatives and a blizzard of paper, all in the service of communication and integration of NASA and McDonnell approaches. For the spacecraft, the crucial managerial unit was the Capsule Coordination Group (CCG), a joint committee through which flowed everything from Contract Change Proposals to concerns over securing licence plates for 'the trailers to be used at the various launching sites'.[39] Its members each took responsibility for oversight of one section of the capsule project – for example, structures, controls or telemetry. Four subgroups rapidly emerged and recurrent all-hands meetings at McDonnell's plant served to tackle the flow of changes and controversies. By September 1960, the CCG had morphed into the Project Control Board, with mechanical, electrical and operational subunits, attempting to limit the changes in the capsule configuration and thereby speed launch readiness.

In parallel both NASA and McDonnell produced a mass of internal publications. McDonnell began issuing 'Mercury Newsletters', and NASA circulated capsule activity reports, project status reports, CST daily outcome statements, with collaboration on Service Engineering Department Reports (SEDRs), which became the operating manuals for capsule systems. SEDRs also contained specifications and protocols, but had to be regularly revised, given the rush of changes. In managerial terms, as problems multiplied McDonnell established a 'reliability section' at St Louis, while NASA undertook to create its own quality-control procedures, borrowing practice from the Department of Defense and from the private sector. Still, troubles continued, yielding summits and emergency conferences, ventures into implementing statistical methods from operations research, and introduction of the Development Engineering Inspection. From this distance, collectively these efforts appear to have been fevered attempts to throw all available management techniques at the project, though none of them had been designed for an environment where the necessity for constant 'product' redesign defeated any attempt to prioritise efficiency, standardisation, scheduling or cost management.

Nothing worked well, or well enough, and, apparently exasperated, on 8 January 1962 NASA announced the mandatory application of PERT (Program Evaluation and Review Technique) to McDonnell's operations.[40] Designed to identify the most 'critical paths' in an ongoing project, provide those handling them with immediate resources, and calculate repeatedly each segment's position ahead of or behind schedule, PERT had originated in connection with the Polaris missile programme for Admiral Rickover's nuclear submarines, being the product of a 1956–57 collaboration between the Navy, Lockheed and consultants Booz, Allen & Hamilton. Perhaps more effective as ideology than practice, the approach spread like wildfire by the early 1960s, although there is 'considerable evidence that the method was oversold [by the military], with the aim of keeping Congressional and other critics at arms length'.[41]

In 1962, two months after NASA forced PERT on McDonnell, an industry observer announced that some 52 management techniques derived from Department of Defense attention to 'long range planning and management efficiency' now crowded the field, many of them PERT variants.[42] At NASA/McDonnell, implementation went hand in hand with adaptation, as planners began to build in schedule time for surprises – perhaps not quite what the methods' originators had envisioned. A November 1962 PERT Analysis reported that: 'The most critical path for [the] MA-9 flight [Gordon Cooper, the last Mercury launch in May 1963] is the preparation of the spacecraft.' Managers had created a testing plan 'with approximately 18 working days allowed for making changes which are not scheduled (or possibly not known) at this time'.[43] There may have been a learning curve after all in Project Mercury's responses to problems, but its trajectory involved learning to schedule time for the unknown instead of asserting management control over time and technology.

Conclusion

Having undertaken to contextualise Project Mercury's spacecraft along lines of *programme*, *place*, *process*, *problems* and *responses*, and recognising that the *result* of the joint NASA/McDonnell effort was an anxious, messy success story, we now return to the artefactual interpretation questions with which this discussion opened. How can this artefact's 'details of creation and use' speak to issues: first, in the wider American culture of the era, second, in understanding the significance of technology and science to that culture, and third, relevant to 'technical and cultural change'? On other fronts, what can the Mercury spacecraft evoke concerning big technology projects and their management, the dynamic amalgamation of individuals and teams within projects and the instability of complex technological artefacts?

Starting with American culture broadly, appreciating the capsules' fabrication resonates with the national fascination with technology, with puzzles and problem-solving, with overcoming natural obstacles in order to plant the machine in the garden, or in this case way, way above the garden. Building and using these artefacts also speaks to our national impatience – get it done, now! – a certain contradictory stubbornness, and our reliance on and discomfort with expertise. With no authority, shop workers made fixes and redesigns on the spot, repairing some problems and initiating others, while sending Wilbur Gray into paroxysms of outrage. NASA and McDonnell fought over opinions, technology and money – each certain of its own rectitude, each blaming the other for slowing down the work. The capsules must be helped to voice these interpretations, to be sure, but delving into the documents behind the icon can make this a straightforward matter.

On the significance of technology and science and on technical and cultural change, the spacecraft have much to teach museum curators and visitors. The entire project, with the capsules literally on top, was a distanciated, disaggregated, experimental engineering works, with technologies, materials, processes and designs both scattered spatially and in flux empirically, even as Capsule No. 20 was being readied for the final Mercury launch. Science did not inform Mercury's efforts in any linear application way; instead, because science was so incomplete on matters extraterrestrial (zero gravity, near-absolute-zero temperatures, for example), elaborate engineering simulations and a great deal of estimation had to suffice. Certainly, there was technical change in Mercury, even across just its five active years, but a great deal of this change fell into the 'doesn't work, try something else' Edisonian category. Putting a series of capsule interiors side by side would, at a minimum, show the technical change from the boilerplate to the animal to the piloted ballistic and piloted orbital designs.

Moreover, as Williams noted at the closing conference, in effect once a technical competence was achieved, another sort of change arrived as NASA or McDonnell raised the stakes – 'Nice work, now let's put two guys in a spacecraft; good job, let's try for the Moon.'[44] Thus, in Project Mercury, technical change was both *urgent* and *temporary*, and this process of relentlessly displacing achievements surely reinforced a cultural change in engineering that perhaps began with Second World War emergency projects: 'slow and steady loses every time to fast and intense, to upping the ante and raising the stakes'. In the first generation,[45] NASA projects, like earlier efforts to build 50,000 aircraft or struggling to master jet propulsion, were exciting, frustrating, high-pressure experiences, followed by much more routine times or by unemployment and career shifting. 'The best years of our lives' is a phrase of great meaning here, for subsequent projects could rarely match the glow from Mercury, Gemini and Apollo.

Perhaps putting the capsule builders into the same vital, anxious, even terrifying, spaces the astronauts inhabited could help integrate the artefact's interpretative messages. Even as pilots, engineers and managers projected a calm competence, a professional demeanour, one contradiction could hardly be avoided, for those inside the projects knew that terrific risks were being run in the face of a great many complexities and a host of unknowns. Likewise, the instability of the artefact itself – its endless changes, its components' irritating unreliability, its sudden fragility and vulnerability (see Figures 7–9) – also contradicts its iconic solidity on the exhibition-hall floor. These are both productive, instructive contradictions, which imaginative curators can translate for publics through research and through revoicing the icon.

Notes and references

1 http://encyclopedia.lockergnome.com/s/b/Project_Mercury, Table 1

2 Oddly enough, these reactions are mirrored in the on-line Wikipedia entry for the Mercury capsules, which opens: 'Mercury spacecraft (also called a *capsule* or *space capsule*) were very small one-man vehicles; it was said that the Mercury spacecraft were not ridden, they were worn. Only 1.7 cubic meters in volume, the Mercury capsule was barely big enough to include its pilot. Inside were 120 controls: 55 electrical switches, 30 fuses and 35 mechanical levers.' See the Wikipedia Project Mercury Webpage at http://encyclopedia.lockergnome.com/s/b/Project_Mercury.

3 Swenson, L, Grimwood, J and Alexander, C, *This New Ocean: A History of Project Mercury*, reprint edn (Washington DC: NASA History Office, 1998), p507

4 Dryden, H, transcript remarks, 'Project Mercury Summary Conference', pp1–2, RG255 NASA-JSC Records, Entry 196: Subject Files, Box 1, File: Mercury Final Conference, September–October 1963 (emphasis added)

5 Williams, W, transcript remarks, note 4, p5

6 Williams, W, 'Project review', RG 255, NASA-JSC, Entry 196, Subject Files, 'Mercury Final Conference, September–October 1963', p1

7 Burke, W, transcript remarks, note 4, p6

8 For a contemporary perspective on this issue, see Sheets, H E, 'The engineering of submarines', *Mechanical Engineering*, 84 (January 1962), pp37–42. Sheets was Chief Research and Development Engineer at Electric Boat in Groton, CT, which built a number of Rickover's nuclear submarines.

9 Burke, W, transcript remarks, note 4, pp7, 8. This odd phrasing, 'deliberate or sloppy', may be a transcription error, as Burke may have said 'deliberately sloppy'.

10 Dryden, H, transcript remarks, note 4, p11

11 Burke, W, transcript remarks, note 4, p15

12 Williams, W, transcript remarks, note 4, p16

13 The Army and Air Force provided launch vehicles and communications/tracking technologies and expertise, which was not often a smooth process. The astronauts were

powerful, roving critics of capsule design, most famously in demanding a window be added. Mercury-programme documents in the National Archives also suggest that US intelligence services had some interest and involvement.

14 Other elements of the larger project impossible to review here include the rockets upon which the capsules were mounted (Redstone, Atlas), transportation/launch facilities and practices, communications and tracking stations and their technologies, capsule recovery and astronaut training.

15 Again, other elements were also critical, though perhaps not so directly related to the spacecraft as artefact, including politics, finances, contracting practices, publicity and media relations.

16 Swenson, L, Grimwood, J and Alexander, C, note 3, p111

17 Swenson, L, Grimwood, J and Alexander, C, note 3, p134

18 Perrow, C, *Normal Accidents*, rev edn (Princeton, NJ: Princeton University Press, 1999)

19 Bland, W and Fisher, L, 'Reliability through attention to detail', Lecture No. 39, Seminar on Engineering Design and Operation of Manned Spacecraft, 9 August 1963, pp9–10, RG 255, NASA-JSC, Entry 196, Box 1, 'Conferences and Symposiums (General)', 1963

20 Giddens, A, *The Consequences of Modernity* (Stanford, CA: Stanford University Press, 1991)

21 Arguably, political exchanges through Congress reinforced this spatial scattering, but researching this plausible assumption is beyond the scope of the present work.

22 Classically, subcontractors would essentially hand build prototypes to secure contract approvals, then would produce components on standard machinery to save time and money. Once delivered, these items regularly failed to meet specifications or proved disappointing in use, triggering sharp exchanges and a great deal of rework (for which NASA was reluctant to compensate McDonnell as the prime contractor responsible for managing capsule subcontracts).

23 'Engineering status report, 12 January 1959 to 1 April 1959', p11, RG255, NASA, JSC, Entry 198C, McDonnell Technical Reports, Box 6A, Engineering Status Reports

24 Rick, B R, and Janos, L, *Skunk Works* (Boston, MA: Little, Brown, 1994)

25 Most of Gray's daily reports can be found at RG255 NASA-JSC, Entry 198E, Contract Administration Files, Box 12, NASA Representative Files (organised by date, e.g. April–May 1960).

26 RG 255, History Archive – Mercury Series, Chronological Files, Box 49, File 1, Project Mercury, Space Task Group, 'Report of Capsule Coordination Committee', 1 August 1959, p5

27 One of the positive legacies of the Mercury capsules for the Gemini programme was that these systems were modularised such that removing access panels would allow technicians to work on most or all of their components in one location within the capsule. See Hacker, B and Grimwood, J, *On the Shoulders of Titans: A History of Project Gemini*, NASA Special Publication 4203 (Washington DC: NASA, 1977), pp33–4.

28 RG255, Entry 100, Contract Administration Files, Box 20, Contract Change Proposals Status Reports. Not all McDonnell CCPs were accepted at NASA headquarters, though.

29 *Ibid.*, Box 20, CCP Status Reports, 1960

30 Bland, W and Fisher, L, note 19, pp10–11

31 Empiricism and urgency, not a deepened scientific understanding, led to the selection of the ablation shield after *one* successful flight test (Big Joe, 9 September 1959), which showed two-thirds of the fibreglass shield intact after a very steep, hot re-entry. Swenson, L, Grimwood, J and Alexander, C, note 3, pp127–8, 200–7. Other development tests in the project's first full year involved testing the foamed plastic materials for the pilots' body-moulded couches and doing fabrication studies on very tough titanium sheets.

32 RG 255, Entry 70, Source Files, Box 76, MSC Capsule 13 Photos, Folder 1, 'Trash removal from Capsule 13 – 12/22/61'

33 RG255, Entry 100, Contract Administration Files, Box 20, CCP Status Reports. At one point in 1961, so many engineering changes had been processed which NASA

detailed as McDonnell's fault (and thus not fundable) that McDonnell seems to have threatened to cease work unless its bills submitted for this work were paid. This was one flashpoint in the ongoing tensions between McDonnell and NASA, with the former claiming the latter was too critical and fussy and NASA regarding McDonnell as sloppy and contractors as slipshod. (For the 1961 conflict, see RG255, Entry 100, Contract Administration Files, Box 4B, General Correspondence, SA56 Supplementary Agreements.)

34 This discussion drawn from Swenson, L, Grimwood, J and Alexander, C, note 3, pp275–9, quotes from p279.

35 Swenson, L, Grimwood, J and Alexander, C, note 3, pp293–4

36 For details see the full report, RG255, NASA-JSC, Entry 198C, MAC Technical Reports, Box 27, Lilienkamp, R H, 'Investigation of the Capsule No. 2 incident, 9 January 1962', Report No. 8626. NASA's Wilbur Gray, resident representative at the McDonnell plant was far more acid, however. His report on Capsule No. 2's 'Initial Reaction Control System Checks', held on 4 April 1960, 21 months before the fire, reads, in part, as follows: 'During this first day [...] it became apparent that: 1.1 Work was poorly organized. 1.2 No "dry run" or other preparations had been made by the [test] crew prior to receipt of the capsule [...]. 1.4 There were too many people in the capsule test area to permit compatibility with safety restrictions or systematic step-by-step procedure of the test [...]. 2.1 *Almost every joint in the system leaked*, indicating improper installation procedure. 2.2 Plumbing lines were found to be improperly installed and were re-shaped more or less on the spot, without, in our opinion, adequate inspection supervision.' Gray, W, 'Memorandum for Mr. J.A. Chamberlain', 8 April 1960, RG255, Entry 198E, Contract Administration Files, Box 12, NASA Representative, April–May 1960 (emphasis added).

37 Swenson tells this story well (Swenson, L, Grimwood, J and Alexander, C, note 3, pp428–32), but the underlying transcript of Glenn's debriefing is riveting (see RG255, Entry 198E, Contract Administration Files, Box 31, File 'MA-6 Pilot's Debriefing'). The RCS presented persistent problems; a thorough review can be found in Greil, K, 'History of the Reaction Control System', 1963, RG255, NASA-JSC, Entry 70, Source Files, Box 7, Mercury Technical History Project.

38 Bland, W and Fisher, L, note 19, p11; Kleinknecht, K S, to Gray, 5 May 1960, RG255, Entry 198E, Box 12, File 'April–May 1960' (Kleinknecht was Mercury Program Manager)

39 For the licence plates see 'Report of Capsule Coordination Group meeting', 4 August 1959, p3, RG255, Entry 70, Source Files, Boxes 49–50, Capsule Coordinating Committee Records, 19 May 1959 – 3 April 1963.

40 Purser, P, NASA, to Burke, W, McDonnell, 8 January 1962, and Burke's reply on 12 January, RG255, Entry 100, Contract Administration Files, Box 12, PERT Reports, File 'PERT'. For more on PERT, see Steiner, G and Ryan, W, *Industrial Project Management* (New York: Macmillan, 1968) and Morris, P, *The Management of Projects* (London: Thomas Telford, 1997).

41 Morris, P, note 40, pp27–31, quote from p31

42 Geddes, P, 'The year of management systems', *Aerospace Management* (March 1962), pp89–91

43 'Manned one-day mission (Mercury spacecraft)', PERT Analysis, 16 November 1962, RG 255, Entry 100, Box 12, File 'Remainder of PERT Reports'

44 As Bart Hacker describes it, Gemini started as a collusive extension of Mercury with both NASA and McDonnell personnel scheming to do bigger things before top leadership had either funding or plans. Hacker, B and Grimwood, J, note 27, Chap. 2.

45 A term used to frame the years from Mercury's beginning to Apollo's triumph, which I first encountered in Howard McCurdy's work on NASA engineering cultures.

Kerrie Dougherty

Retrieving Woomera's heritage: recovering lost examples of the material culture of Australian space activities

Introduction

Woomera Rocket Range. Once it was a name to conjure with, carrying all the mystique of Cold War secrecy coupled with the excitement of space exploration. Yet today, the site where Australia joined the 'space club', where both Britain and Europe made their first attempts at developing an independent launch capability, is largely abandoned and virtually forgotten by younger generations of Australians, who associate Woomera only with a controversial US military tracking station[1] and, most recently, an equally controversial detention centre for illegal immigrants.[2]

Established in 1947 as the long-range weapons test facility of the Anglo-Australian Joint Project, Woomera was born out of Britain's Cold War desire to develop its own missile systems and nuclear deterrent. Unable to test such weapons adequately within the narrow confines of the United Kingdom and its surrounding waters, Britain sought a secure test range within the Commonwealth and ultimately selected a location in the remote outback of South Australia which offered huge tracts of virtually uninhabited desert over which to fly missiles, drop bombs and, later (though this was not immediately in the minds of the initial developers), launch rockets into space. Woomera, at its greatest extent, was the largest overland weapons test range in the Western world, and – at one point – the busiest. Over the lifetime of the Joint Project (1947–80)[3] more than 4000 British, European, American and Australian missiles and rockets and 3000 bombs and other weapons[4] were launched and tested there, for both military and civilian purposes (Figure 1).

Space-related activities carried out at Woomera during the Joint Project included sounding-rocket programmes (British, Australian and some European projects in the 1970s), the European Launcher Development Organisation's (ELDO) Europa launch-vehicle programme,[5] Britain's Black Arrow[6] independent satellite launcher project and the Wresat project, which enabled Australia to become the fourth nation to launch its own satellite.

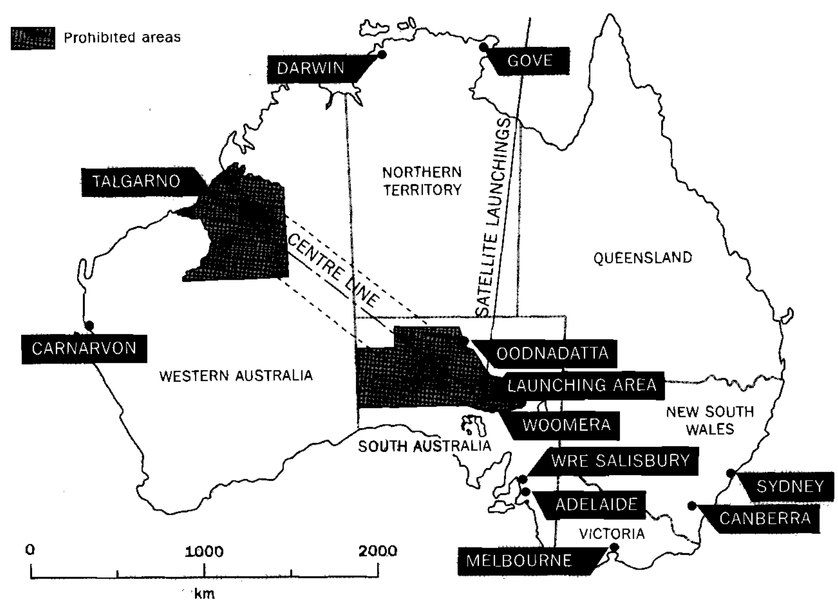

Figure 1 Map of Australia, showing the location of the Woomera Prohibited Area, Woomera township and the launch area (actually several different launch sites spread around the Rangehead area). The downrange track used by Wresat and for the ELDO launches is also shown. (Redrawn from diagram supplied by DSTO/Australian Government Department of Defence)

The material culture of space activities in Australia

In its broadest definition, material culture encompasses everything that can be seen, handled and used by human beings in the course of their lives. Every human activity generates artefacts of material culture and the exploration and exploitation of space are no exceptions: the 'material culture of space' includes all the hardware created to achieve access to space (launch vehicles) and do something useful once there (satellites, spacecraft, spacesuits, etc. and their subsystems and ground-based segments) and all the facilities created to design, build, test, launch and retrieve that hardware.

It might be assumed, therefore, that with the high level of activity at the Woomera Rocket Range during its heyday, and with the Range's reputation for being 'the best in the world',[7] a significant amount of material culture relating to these activities would remain in Australia. However, despite more than 30 years of missile and rocket tests and launches at Woomera during the Joint Project, very little of the material heritage of these programmes survives in the country today. Much of the physical plant on the Woomera Range – the launch sites, test facilities, workshops and staff amenities – has been lost: demolished, sold for scrap, abandoned to deteriorate, or used for demolition and target practice by the armed forces. Although other facilities relating to the activities at Woomera have survived in better condition (albeit with a change of role or focus),[8] since the end of the 1970s the Range itself has progressively lost more and more of its 'value' as the key site in the material culture of space activities in Australia.[9]

Similarly, because the majority of the hardware used at Woomera was manufactured in the UK (and Europe in the case of ELDO) and shipped to Australia for final testing and launch, the quantity of artefacts that has survived here is very low compared to the level of activity at the Range. When any particular programme was cancelled or wound down, hardware shipment to Australia would cease, the remaining stock at Woomera would usually be fired off in final tests and any surplus hardware would be retained by the manufacturer back in Britain. When the Joint Project was itself winding down, contractor subsidiaries in Australia also repatriated or scrapped most remaining stocks of material in this country. As a consequence of these practices, apart from the remains of spent rocket casings and failed firings littering the desert, very few examples of space-related hardware remained in Australia to find their way into museums, there to provide a tangible reminder to the community of this country's involvement in space projects.[10]

In the dying years of the Joint Project (the late 1970s), the Weapons Research Establishment (WRE), the agency of the Australian Department of Supply that managed Woomera on behalf of the Joint Project, began to amass a 'heritage collection' of rocket and missile hardware and other artefacts relating to programmes at Woomera, though there does not appear to have been any deliberate and consistent collection policy applied to the creation of this collection. It was, rather, a somewhat eclectic mixture of original artefacts (some never flown and some recovered or salvaged from the Woomera Range) and models or replicas originally created for public-relations purposes by the Weapons Research Establishment, the Department of Supply and the Department of Defence.

During this same period, the Woomera Board, responsible for the management of the township of Woomera (as distinct from the Rocket Range), decided to establish a community museum, to keep alive the memory of the rocket and missile activities undertaken on the Range. Locally funded and operated by volunteers, the Woomera Heritage Centre was established in a prominent part of the ever-diminishing township, close to the shopping centre and town facilities.[11] It was hoped that it would attract the tourists who, it was envisaged, would be curious enough to visit the town once it became an open facility, when security restrictions were relaxed as the Joint Project wound down to its close.[12]

A significant proportion of the WRE 'heritage collection' was made available to the Woomera Heritage Centre for display, becoming the nucleus of what is now the most significant collection of artefacts related to the history of long-range weapons development and space activities in Australia.[13] In addition to the WRE material, the Woomera Heritage Centre has acquired, by loan or donation, material from other sectors of the Defence Department and other government agencies that have had association with Woomera, and from private individuals who lived and worked in the township and on the Range. The museum's collection thus encompasses material relating both to the technical and social history of the Range and township.[14]

In addition to the establishment of the Heritage Centre itself, the community volunteers, with the aid of the Lions Club service association, also created an outdoor 'Rocket and Missile Park', directly in front of the museum, to display examples of missile and rocket hardware too large to be contained inside the building. The artefacts on display in this park are a mixture of genuinely original hardware and 'recreated' items composed of amalgams of 'spare parts', material recovered from the Range and repaired/restored for display, and replica sections, included where necessary to provide a visually complete exterior finish for the object. The examples of space material on display in the Rocket Park fall into this latter category. Launch vehicles represented in the park include a variety of sounding rockets, a Black Knight rocket and a Black Arrow satellite launcher. None are entirely composed of authentic, original components, and, while visually complete, none contain their full internal fit-out with tankage and motors (Colour plate 6).

Like many local history museums in Australia run by volunteer staff, the Woomera Heritage Centre, until very recently, lacked the input of museum professionals or historians into the development of its collections and displays.[15] Its collection policy was, essentially, to acquire whatever Woomera-related material was offered to it; its display policy was to get as much of its holdings as possible 'on the floor' to present the many varied aspects of Woomera's history to visitors. Its approach to the interpretation of the collections was celebratory and nostalgic, reflecting the attitudes and feelings of the Woomera residents and former Range personnel who made up the Heritage Centre's staff, while issues of artefact integrity (i.e. maintaining the originality of an object) were superseded by the desire to present an externally complete, visually correct re-creation of major artefacts.

These comments are not meant to denigrate the work that the Heritage Centre's volunteer staff have undertaken; despite the limitations of their own experience and the constraints of budget and staff availability, they have brought passion and enthusiasm to their self-appointed task of preserving and presenting an important, and now frequently-overlooked, aspect of Australia's scientific and technological history. The strength of that desire to preserve the material culture of a past undertaking with which they had been associated, and for which they felt a strong personal affinity, would eventually motivate a major project to return to Woomera some of the most significant examples available of the material culture of its past activities.

Until the 1990s, conspicuous by its absence in the Woomera Rocket Park was any representation of examples of the Europa launcher, the largest rocket launched at Woomera, and the Wresat Redstone, which was responsible for launching Australia's first satellite. This, however, would soon change with the inception of the Rocket Retrieval Group at Woomera and its space heritage recovery projects.

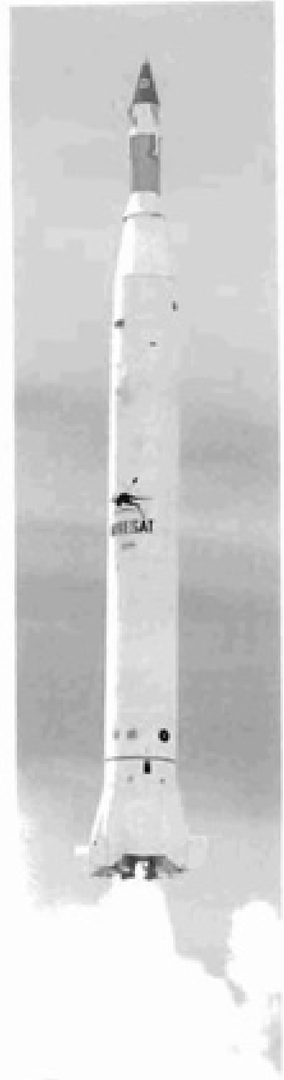
Figure 2 Launch of Wresat, Australia's first satellite. The launch vehicle comprised a Redstone rocket first stage with two small solid-propellant upper stages. The Wresat logo depicts a kangaroo over a woomera (throwing stick) and spear. (DSTO/Australian Government Department of Defence)

The Wresat Redstone recovery

Australia's first satellite, Wresat (Weapons Research Establishment Satellite) was launched from the Woomera Rocket Range on 29 November 1967 (Figure 2). Developed by the WRE and the University of Adelaide as a successor to the Australian upper-atmospheric sounding-rocket programmes previously conducted at Woomera, Wresat was considered a remarkable achievement in its day, having been designed, built and launched in less than a year.[16] Its success enabled Australia to claim entry into the so-called 'space club' as only the fourth country to launch its own satellite.[17] The first stage of the launch vehicle was a Redstone rocket, the last of a batch that had originally been brought to Australia as part of the US Army's Sparta Project.[18] Following the launch, this Redstone stage fell into the northern part of the Simpson Desert, one of central Australia's major sandy deserts that even today is largely unexplored and difficult to traverse. There being no reason to retrieve the 'tried and true' Redstone for study after the launch, the discarded rocket was left where it fell. Wresat itself re-entered the atmosphere and disintegrated after successfully operating for about two months.

However, in 1989, Australian entrepreneur and adventurer Dick Smith, inspired by an article on the history of the Woomera Range, recognised the significance of the Wresat launcher in Australia's technological history and became determined to locate its remains.[19] As there had been no imperative to recover and/or examine the Wresat first stage after launch, its impact site had never been accurately determined. However, at Smith's initiative, the Defence Science & Technology Organisation (DSTO, the successor to the Weapons Research Establishment) allowed the Range Safety Officer from its Ranges Measurements Branch, Bruce Henderson, to undertake the determination of the probable location of the rocket's remains. Using original data from the Woomera Range's instrumentation records of the flight (such as telemetry, optical tracking records and radar data),[20] Henderson established a predicted impact location that was, within an error range of 8 km, 623 km north of Woomera and 255 km west of the outback Queensland town of Birdsville.

In August 1989, using these data, Smith established a base at Oodnadatta, on the southwest corner of the Simpson Desert: at approximately 250 km from the predicted impact site, it was an ideal location from which to begin the search for the Wresat Redstone. Smith was an experienced helicopter pilot[21] and used his own craft in the search, although fuel supply limitations contributed to an unsuccessful initial attempt. After a re-examination of the available data, DSTO's Bruce Henderson produced a revised estimate of the impact location, making allowances for wind drift and atmospheric drag on re-entry. This identified a search area of about 85 km^2.

To avoid a repeat of his fuel supply problems, Smith arranged for a fuel dump to be established at Peoppel Corner (the intersection of the Northern Territory, Queensland and South Australian borders), and then commenced a second search from Oodnadatta in early October 1989. This time the search proved immediately successful and the remains of the Wresat Redstone were located and identified. They were found approximately 10 km from the revised probable impact site.

Broken into three segments, but still largely intact, the Redstone was partly concealed by a large bush that had grown up through the remains. Although painted a brilliant white at launch, to facilitate optical tracking against the blue desert sky, the rocket's outer coating had weathered away in the Simpson Desert's harsh environment, revealing the Redstone's original American khaki livery, the words 'US Army' visible on its side. This green colouring blended with the vegetation cover (low scrub and spinifex) common in this part of the Simpson, making the rocket hard to distinguish (Colour plate 7).

Although, as discussed above, the most significant collection of surviving artefacts relating to space activities in Australia is that held by the Woomera Heritage Centre, that collection contained no original artefacts relating to Australia's first satellite.[22] While Dick Smith himself had been content simply to locate the Redstone's remains, in the weeks following his discovery discussions began at Woomera among a group of (mostly local) heritage-minded volunteers on the feasibility of recovering the Redstone rocket for inclusion in the Woomera Rocket and Missile Park. It was felt that retrieving the Redstone and returning it to Woomera would enable a much larger section of the Australian community to have access to the physical remains of an important milestone in Australia's scientific and technical history, than if the rediscovered rocket stage remained in its remote desert location. As a result of these discussions, the Redstone Rocket Retrieval Group was formed and set about planning for the recovery of the rocket.[23]

Plans were laid to mount a recovery expedition in April 1990, six months after the rocket was located. Travel in the extreme environment of the Australian deserts is never to be taken lightly and this was the first available 'safe' period for crossing the Simpson Desert, where summer temperatures (November–March) can rise to 60 °C. Consequently, excursions into the Simpson are normally undertaken in the winter period, between the months of April and October, but even during the cooler months, the harsh environment and difficult terrain make meticulous advance planning a necessity. Access and departure routes to the rocket impact site had to be

Figure 3 Traversing a sand dune in the Simpson Desert during the Wresat recovery expedition. Difficult terrain and harsh desert conditions made the rocket retrieval operation potentially hazardous, requiring careful advance planning. (Bruce Henderson)

carefully planned, as the sand dunes in the region could only be crossed from east to west and were difficult to negotiate, being on average 18 m high and between 150 and 600 m apart (Figure 3).

Owing to the remoteness of the impact site, everything needed by the Retrieval Group volunteers – food, water, shelter and equipment – had to be carried by the expedition, requiring careful logistical planning. Supplies were needed for a 2800 km, 14-day round trip: although fresh food would last for the first half of the journey, Army ration packs were needed to provide the meals thereafter, while 2400 litres of drinking water had to be carried, and 5000 litres of diesel fuel and 8600 litres of petrol were needed for the vehicles. In anticipation of mechanical breakdowns, 600 kg of spare parts were also carried, particularly for the trucks. When the rigours of traversing the dunes caused the loss of a clutch plate on one of the expedition trucks, the team was able to remove and refit the gearbox and transmission and repair the clutch assembly in six hours, aided by cranes fitted to one of the recovery vehicles. Despite all the preparations that were undertaken, the difficult conditions meant that at least two days of the recovery journey would see only 4 km of travel.

In the event of a medical emergency, evacuation procedures were established with the Royal Flying Doctor Service and the Australian Army. The South Australian Police were also advised of the recovery exercise.[24] Because much of the Simpson Desert is designated as National Park or Reserve, permits to enter the region had to be obtained from the National Parks and Wildlife Service, which required the expedition to comply with regulations regarding the disposal of refuse while en route, travelling on unstable sand dunes and possible damage to sensitive vegetation. As much of the route to and from the impact site was rarely visited, the recovery team was also asked to carry out plant-identification tasks for various research groups, including the photography of examples of fauna and flora.

Accurate navigation was critical, but was accomplished mainly by hand-held compasses and odometer readings, due to the poor Southern Hemisphere coverage by navigation satellites at the time. Satellite navigation systems could, at best, only provide a position check, and although the expedition carried both Navstar and GPS receivers, the former required up to an hour to determine position fixes, while the latter frequently need to acquire fixes in the early hours of the morning.

As the Woomera Heritage Centre lacked any funds to support the recovery exercise, sponsorship funding was sought and approximately 40 major companies ultimately donated funds to the amount of Aus$28,000, in addition to in-kind sponsorships covering fuel, lubricants, food, drinks, etc. The largest single donation was $12,000 from the TRW Corporation, the original builders of the Redstone rocket.[25] A cook, camping equipment and a professional photographer to document the expedition were provided by the Australian Army, while Australia's national telecommunications carrier, Telecom Australia,[26] provided an Iterra mobile satellite ground station, allowing access to telephone, fax and television services that was otherwise unavailable in such a remote region. The Retrieval Group members themselves gave their time to the recovery expedition and its planning on a voluntary basis.

The recovery team would eventually consist of 22 people with 11 light four-wheel-drive vehicles, four International six-wheel-drive trucks and one six-wheel-drive heavy recovery vehicle, towing a Redstone transport trailer. This trailer, part of the original equipment used to transport the Project Sparta Redstone rockets from the US to Australia, had been fortuitously located in storage at Woomera.

The recovery expedition departed on 12 April 1990, taking seven days to reach the impact site. The Redstone was loaded onto the trucks the following day. Although the recovery exercise and the impact area were photographically documented, no provision had been made to perform any sort of archaeological survey and recording of the site, prior to the rocket's removal. However, a stainless-steel plaque engraved with the history of the flight and recovery details was left at the site to mark the impact location.

The return journey to Woomera commenced on the ninth day of the expedition. With the experience gained on the outward leg of the trip, the return journey progressed more smoothly, allowing the Retrieval

Group expedition to arrive back in Woomera on the evening of 26 April. The recovery of the Wresat Redstone attracted considerable media interest, both locally and nationally, although the tenor of the coverage tended to focus more on the adventure of the recovery than the heritage significance of the artefact itself.

Following its retrieval, a decision had to be taken as to how the Redstone should best be displayed, in order to maximise its potential for educational and tourism purposes. Recognising that its interest value to visitors depended as much upon its mystique of having been recovered from a fairly inaccessible part of the desert, as from its association with the Wresat project, it was decided to display the rocket in a re-creation of its impact site. Because there was little space available for such a re-creation at the original Missile Park, a new 'adjunct' Rocket Park was established literally across the road, on a cleared site beside the Woomera School. Here, the Wresat Redstone became the first exhibit of a new display area that has grown considerably over the past decade. The recovered pieces of the Redstone were laid out on a bed of desert sand in the same configuration as they were found in the desert, complete with a bush growing through the centre of the debris field, just as had occurred at the original impact site. To prevent small pieces being 'souvenired' by visitors, the entire display was surrounded by a vandal-proof enclosure (Figure 4).

Figure 4 The recovered Redstone rocket on display inside its enclosure in the Woomera township. The presentation sought to re-create the rocket's original Simpson Desert location, complete with a bush growing through the remains. (Kerrie Dougherty)

The Europa F-4 recovery

With a successful recovery project behind them, the Retrieval Group was fired with enthusiasm to attempt further recoveries of astronautical heritage artefacts from the desert. While many rocket impact sites had already been discovered over the years (mostly to the north of the Simpson Desert, where access is easier), these had generally been disturbed, with material being 'souvenired' by their discoverers, local property workers or tourists. Since no-one asserted ownership over these rocket relics,[27] the owners of the properties on which they had impacted sometimes moved the rocket stages or engines to the homestead or some other 'public' location (such as a railway siding)[28] for display, with significant damage and deterioration occurring as a result. The Retrieval Group therefore preferred to direct its efforts towards recovering rockets that had not previously been located and whose sites were therefore undisturbed.

One of the most significant rocketry projects undertaken at Woomera was the European ELDO satellite-launcher development programme, with ten launches occurring between 1964 and 1970. Yet, despite its historical importance, the ELDO Europa vehicle was not represented in the Woomera Missile Park and only some small-scale models existed in the Heritage Centre's collection. The Retrieval Group therefore turned its attention to the possibility of recovering an ELDO stage and the Europa F-4 and F-5 vehicles were considered as likely candidates, as they were both known to be in the Simpson Desert but were still unaccounted for at that time.[29]

As the first two full-configuration Europa vehicles,[30] both F-4 and F-5 were considered significant. The F-4 flight had been controversially aborted by the Range Safety Officer only 136 seconds after launch due to an error on the flight predictor, which indicated that the rocket was deviating from its flight path. It was later shown that the apparent deviation was a radar prediction fault and that the rocket had, in fact, not strayed: the flight need not have been terminated. The subsequent F-5 flight was a repeat of the aborted F-4 mission and was fully successful. In both these flights, the upper stages of the Europa were inert dummies, filled with a liquid to represent the fuel weight. However, each stage carried all the necessary electronics and the dummy 'satellite' payload was equipped with telemetry electronics to record and send data back to ground tracking equipment (Figure 5).

As with the Wresat Redstone, there had been no requirement to recover the Europa vehicles after flight, so their impact sites had not previously been accurately determined. Therefore, Retrieval Group member Roger Henwood, together with Bruce Henderson, commenced research in the ELDO flight-trial archives, in an attempt to establish the likely impact locations for both vehicles. Over 14 months they researched telemetry data, aerial photographs, Landsat

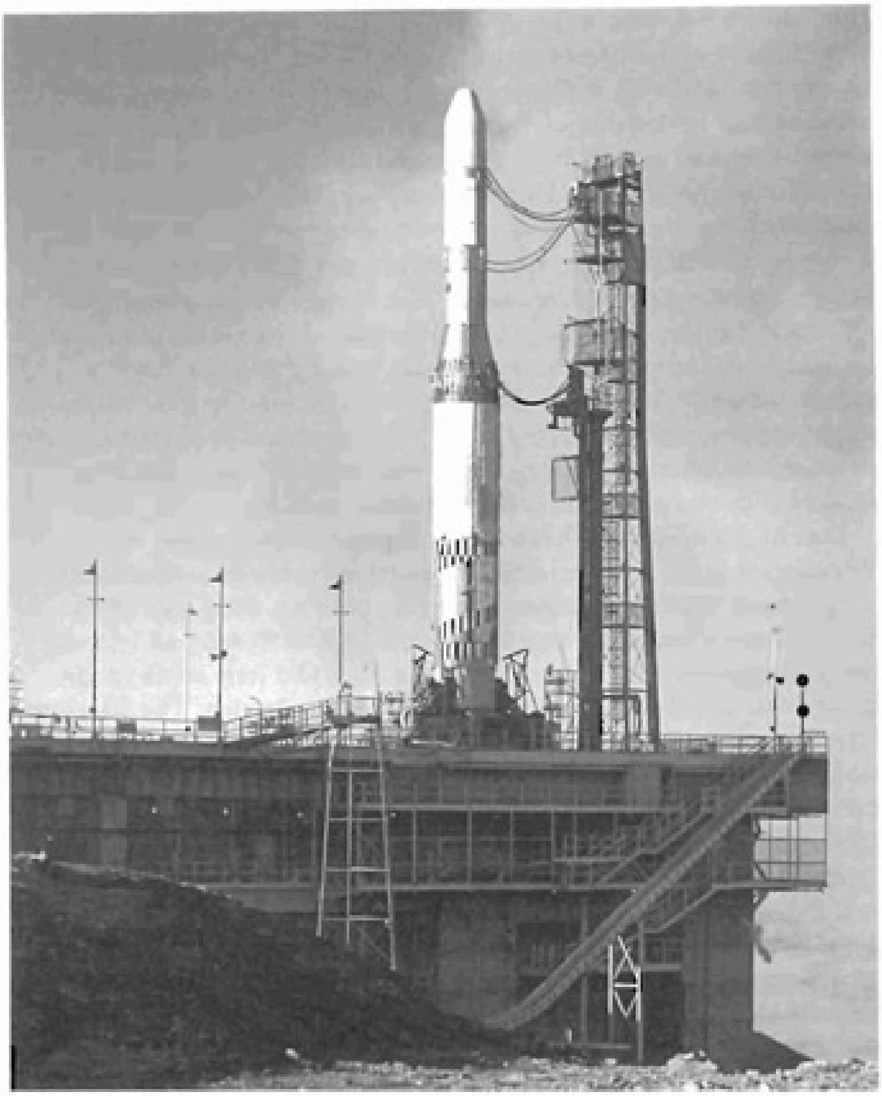

Figure 5 Launch of Europa F-5, the second full-configuration test of the ELDO Europa launch vehicle. Although virtually identical, Europa F-4 and F-5 met with very different fates, due to an equipment malfunction, which resulted in the termination of the F-4 flight. (DSTO/Australian Government Department of Defence)

images and flight analysis reports to establish likely search areas. The impact area for F-4 was deduced to be in the southern Simpson Desert, 473 km downrange from ELDO's Woomera launch facility.[31] The F-5 vehicle, which completed the full flight profile, impacted 780 km downrange. As it was the closer of the two rockets, the Retrieval Group planned to attempt the recovery of the F-4 vehicle first. It was initially hoped that, because of the way in which the aborted flight was terminated, with small charges used to vent the main propulsion tanks, the rocket might have pancaked down to the ground and survived largely intact.

With a probable impact area for F-4 established, two initial ground searches were undertaken in September/October 1991 by a small party of Retrieval Group volunteers using four-wheel-drive vehicles.

Although unsuccessful, these excursions indicated that any recovery operation would be more difficult than that for the Redstone, as the southern part of the Simpson Desert proved to be more difficult to traverse than its northern regions, with dunes up to 25 m tall and as close together as 200 m.

Undeterred, the Retrieval Group persuaded the Royal Australian Air Force to incorporate a broad-area search of the F-4 impact area into its GPS evaluation-trials programme in 1992. They found no sign of the rocket, nor did a subsequent aerial search in April that year, undertaken by members of the Ausroc amateur rocketry group (at that time preparing for the first launch of its small Ausroc 2 sounding rocket from Woomera).[32]

With the lack of success of both aerial and ground searches, concern arose that the F-4 vehicle may have been shattered by the ignition of its remaining fuel supply, when the explosive charges of the destruct system were activated. However, a new opportunity to locate any remains of the F-4 was offered by a South Australian remote sensing company, SciTec Pty Ltd, which wanted to demonstrate the effectiveness of its newly-developed satellite-imagery analysis software. As a research project, SciTech undertook the task of digitising and analysing a selection of aerial mapping photographs of the predicted impact area. SciTech claimed that their software could locate every artefact within an image and determine its location within 30 m, and the Retrieval Group hoped that it could pinpoint any large pieces of the F-4 that might have survived an explosive destruction.[33] Disappointingly, the quality of the aerial photography prints available was not high enough for successful scanning and flaws in the photographs gave false image readings that were mistaken for possible rocket fragments.

In August 1993 another attempt was made to search the probable impact area from the air, with the assistance of a US Air Force pilot from the tracking station at *Nurrungar*, near Woomera. He gave his time on a voluntary basis, while the five-day aircraft hire and fuel costs were partly sponsored. Three experienced observers from the Retrieval Group volunteered to be part of the search, meeting their own expenses for the exercise. Based at Oodnadatta (previously used as the Wresat search base) the team planned an intensive search of an area 80 km long by 7 km wide, covering a swath 3.5 km either side of the original flight path. This intended search area was 120 km from Oodnadatta. Two searches were conducted each day, with the plane returning to the town at midday for refuelling. Each search was carried out with the plane flying at an altitude of 500 feet, traversing the 80 km track along the flight path at half-kilometre spacings. GPS navigation, by now providing more comprehensive Southern Hemisphere coverage than during the earlier Redstone recovery, was used to assist the search.

Finally, on 13 August 1993, the searchers noticed what appeared to be a glint of metal struck by the low afternoon sunlight. After circling the area, they determined that they had, indeed, seen the sun reflecting off metal: in that remote desert area, it was likely to be remnants of the Europa rocket. Although the pilot attempted to take the plane down to 90 feet for a closer inspection, the 20 m-tall sand dunes in the vicinity made this too risky and the team returned, elated, to Oodnadatta. They flew back to the location of the sighting the following morning, in order to obtain confirmation of their discovery. However, to ascertain that the sighted metal was actually rocket debris, a ground expedition made a preliminary survey of the crash site in October 1993. Following this excursion, it was initially decided not to proceed with a recovery expedition, because the material found was in an extremely fragmented state, with debris scattered over a very wide area.

Despite this decision, within the Retrieval Group there was a growing momentum in favour of recovering the rocket remains and another survey expedition was finally mounted in May 1994 to explore the crash site further. In two light four-wheel-drive vehicles, this small team returned to the debris found the previous August: this was now determined to be the Europa F-4 dummy satellite, still attached to part of the third-stage transition mounting ring. The satellite had impacted about 1.2 metres into the ground, but despite the impact and 30 years in the desert sand, the team excavated several artefacts in remarkably good condition, including a quantity of telemetry equipment, two solid-state flight recorders and an endless tape recorder. Although the survey team searched on foot around the satellite impact area for the next few days, no further material was located.

Coincidentally, Dick Smith, who had originally located the Wresat Redstone rocket, was at Woomera while this expedition was under way.[34] After being contacted by the survey team, he flew up to their camp to aid the search using his own helicopter. Smith's assistance enabled an aerial search to be undertaken south along the flight path for 20 km, which succeeded in locating many smaller items of rocket debris. Each of these finds was logged and its position determined using GPS, for future investigation.

The success of this initial survey encouraged the Retrieval Group team to plan for a further ground search and the retrieval of material already located, to take place in late 1994. The 3/9 Light Horse, South Australian Mounted Rifles (APC) unit of the Australian Army, based in Smithfield, South Australia, volunteered its assistance to this retrieval task as an adventure training exercise, which it named 'Operation Blastoff'. However, to take advantage of the Army's offer of support, the recovery expedition would have to be carried out late in the 'safe' period for desert travel, which was a less than ideal situation: it was fortunate that temperatures did not climb beyond the mid-30s degrees Celsius during the retrieval operation. The joint Army/

Figure 6 Members of the Rocket Retrieval Group and Army team on their return to Woomera following the Europa F-4 recovery. Roger Henwood is on the far left of the group. (Roger Henwood)

Retrieval Group team would eventually consist of 26 people: 14 Army personnel and 12 from the Retrieval Group. The Army provided two trucks, two armoured personnel carriers (one fitted with a light crane) and several light four-wheel-drive vehicles. The Retrieval Group team travelled in six light four-wheel-drive vehicles (Figure 6).

After extensive logistical planning, similar to that undertaken for the previous Redstone retrieval exercise,[35] and ensuring that the necessary safety requirements and contingency plans were in place, the recovery expedition left Woomera on 3 October 1994, for a 14-day return journey. With travel to and from the planned camp site expected to take about four days each way, the remaining time could be devoted not only to loading material already located, but also to continuing the search for additional artefacts.

After arriving at the F-4 camp site, the team spent the first four days locating and retrieving many of the items charted earlier in the year. As had been suspected, the state of many of the recovered items indicated that the rocket had exploded in midair, shattered either by its termination charges or as a result of those charges detonating its fuel. Nevertheless, artefacts of significance were retrieved and returned to Woomera, including: the dummy satellite, one of the Blue Streak stage's two Rolls-Royce RZ2 engines, one of the first-stage turbo pumps, a number of electronic modules including a flight guidance computer, and a quantity of Lox valves, manifolds and piping (Figure 7).

Figure 7 Recovered debris from the Europa F-4 vehicle, indicating the level of damage resulting from the activation of the abort system. Unlike the Wresat Redstone, the F-4 remains were in a highly fragmented state. (Roger Henwood)

Media interest in the Europa F-4 project was considerable, as it had been for the earlier Redstone retrieval, and the decision was made to display the recovered material beside the Wresat vehicle, similarly laid out on desert sand in another vandal-proof enclosure. Unlike the Redstone, the Europa F-4 display was a less accurate re-creation of the original site, insofar as the limited size of the enclosure meant that the retrieved artefacts could not be spread out to the full extent that they were scattered in the desert. Also, as no archaeological survey of the debris field had been carried out, the exact relation of all the small fragments to each other in the field could not be duplicated precisely back at Woomera. Nonetheless, the presentation at the Rocket Park certainly evoked the considerably more fragmented condition and scattered impact site of the F-4 when compared with the Redstone. The recovered contents of the dummy satellite were placed on display in the Woomera Heritage Centre, rather than in the rocket enclosure, so that visitors could better observe them at close quarters. Although it was not possible to retrieve any data from the recorders after more than 30 years, they were still considered valuable examples of the technology of the period.

The Europa display was undertaken as a project for the Woomera Rocket Range's 50th anniversary celebrations in April 1997, which brought many former Woomera employees and their families to the township. The strong, positive public response to the exhibit prompted another reconnaissance expedition to the F-4 site in May 1997, to locate and identify additional material for future retrieval. After being put on hold until the completion of the Europa F-5 recovery, the final expedition to the F-4 site took place in 2001. During this trip, the second of the Europa F-4's RZ2 engines, which had not been retrieved previously, was returned to Woomera along with other material located on previous trips.[36]

The Europa F-5 recovery

The successful F-4 recovery project encouraged the Retrieval Group to proceed with an attempt to retrieve the Europa F-5 vehicle as well. As it was identical in configuration to the F-4 vehicle, it was hoped that since the F-5 rocket had successfully completed its flight, its remains would be in a better state than those of the F-4; the only destruction that should have occurred would be that caused by the stage-separation charges and the actual impact with the ground.

While the Retrieval Group had been operating out of Woomera, another group of rocket enthusiasts based in the Northern Territory town of Alice Springs, which included Retrieval Group member Stan Spencer, had also carried out expeditions into the Great Sandy Desert of Western Australia to locate the (previously found and disturbed) remains of the Europa F-1 to F-3 Blue Streak flights. Enthused by these adventures, in 1997 they offered to assist the Retrieval Group in its search for the F-5 vehicle. With the predicted impact point for the F-5 located southeast of Alice Springs, only a day and a half travel time from that town, the Retrieval Group took the opportunity to enlist the Alice Springs enthusiasts' aid to conduct initial searches for the F-5 remains on its behalf.

After being provided with details of the predicted impact area, the Alice Springs Group made three sorties into the northern Simpson Desert in 1998, successfully locating several artefacts from the F-5 vehicle. Among the items they found were the dummy satellite, two of the four inert engines from the French Coralie stage and one turbine from the Blue Streak stage, in addition to many pieces of electronic equipment. Despite having split open on impact, the dummy satellite still contained all its electronics and telemetry equipment (Figure 8).

None of the material located on these expeditions was recovered until May 1999, when the Retrieval Group, still composed largely of the same team that had initiated the rocket retrieval programme in 1990, joined forces with the team from Alice Springs to search for and recover as much of the remains of the Europa F-5 vehicle as possible. This all-volunteer expedition was composed of 12 light four-wheel-drive vehicles, plus several trail bikes equipped for desert conditions. Travelling from Woomera, the Retrieval Group team had to plan for a round trip of nearly 4000 km and 14 days duration. Although the terrain of the far-northern Simpson Desert is not as difficult as the

dune area in which the F-4 impacted (the sand dunes averaged only 8–10 m in height and were much easier to traverse), none of the precautions and emergency backup procedures employed on previous recovery expeditions was ignored.

It took the team from Woomera four days to reach the base camp established by the Alice Springs Group at the search area. This camp, which would be occupied for five days, was located at a point near the impact ellipse where all the heavier debris was expected to have landed. Although the area was covered with low vegetation (Simpson Desert spinifex and sand-hill cane grass), this was not expected to impede the search for larger rocket fragments.

After an initial inspection of the vicinity, it was decided to conduct close-in searches along the ground track of the flight path by foot, while areas out to about 7 km would be searched by vehicle and trail bike. With average daily temperatures in the low 30s degrees Celsius, foot searches were undertaken in the cooler hours of the early morning and late evening. Searching at these times also offered the advantage of lower sun angles that would spark reflections off metal fragments, making them easier to detect.

The initial search and recovery effort focused around the previously-located dummy satellite, which was retrieved along with

Figure 8 The Europa F-5 dummy satellite, as found. Although the casing had split open on impact, the contents were intact and in good condition. (Roger Henwood) its contents (the endless tape recorder and flight recorders) and other instruments fitted into the satellite base, such as telemetry equipment, transponders and accelerometers. Several canisters apparently pressurised by dry nitrogen were also recovered. In the same area, searchers also located one of the inert Coralie engines, a number of electronic panels from the Coralie (second) and Astris (third) stages and the boost separation motor providing first/second stage separation. The latter was in remarkably good condition. The rate of finds in this vicinity then slowed, with only skin sections, fuel pipe and some pressure cylinders being found over two days of searching.

As a result, the focus of the search was switched back into the area where some of the heavier debris had been located on the earlier expedition. An intensive foot search of this area with 12 people located several significant new artefacts, including both half sections of the first-stage engine platform, which were found 5.2 km apart. One section still had the Rolls-Royce turbo pump attached. The most exciting find was a complete Rolls-Royce RZ2 rocket engine, which had impacted into an area covered with dense desert mulga trees, about 2.5 m tall, which had screened the motor from previous searches.[37] The motor had landed at an angle of approximately 45°, its front section partly embedded in the sand, although the engine skirt had not touched the ground. It was in particularly good condition in comparison with the RZ2 engine previously recovered from the Europa F-4, which had considerable damage to the skirt.

The southernmost artefact to be found was the first stage/second stage transition bay, which was located 18.5 km from the dummy satellite, the northernmost item located. Between the two, the heavier components were dispersed only a few hundred metres either side of the line of flight, while the lighter fragments were much more widely spread. However, to the disappointment of the search team, the remaining two Coralie engines, Rolls-Royce turbo pump and RZ2 engine were not to be located: they remain undiscovered in the desert.

The expedition's finds were displayed for one day at the Central Australian Aviation Museum, before being shipped back to Woomera, where they attracted considerable media attention and resulted in a serendipitous incident: seeing the material on display, the manager of a cattle station (ranch) in the Northern Territory, situated along the flight line, offered the Retrieval Group an engine from a Europa Astris stage, which he had found in 1988. Believed to be from either the Europa F-6/2 or F-7 vehicles, this artefact may be the only surviving example of a flown Astris engine.

Following the return of the F-5 material to Woomera, the RZ2 motor was placed on display alongside the Europa F-4 debris, while the remaining material was either placed into storage or made available on loan to the National Museum of Australia for incorporation into its travelling space exhibition, 'To Mars and Beyond'.

Conclusion

Because so little of the physical evidence of Australia's space activities remains, the recovery of material which still exists, but is located in inaccessible regions, is an important contribution to the material-culture record of those activities. Between 1990 and 2001, the search and recovery programme carried out by the Woomera Rocket Retrieval Group was instrumental in rescuing examples of significant space heritage artefacts from one of the harshest environments in Australia, the Simpson Desert. While these operations may not have been carried out with the full level of archaeological survey and documentation that museum professionals and technological historians might have preferred, they have nevertheless been responsible for retrieving material with significant heritage value for educational display and research use.

The activities of the Retrieval Group provide an excellent example of the way in which highly-motivated and well-coordinated volunteer groups can assist the professional astronautical history community in the preservation of the physical evidence of space activities and contribute to public knowledge and awareness of the history of space flight. Their efforts have enriched the accessible material-culture record of space-related activities in Australia, not only by contributing to the collection of the Woomera Heritage Centre, but also by providing a pool of material that can now be made available on loan to other museums around the country to increase community awareness of Australia's historical involvement in space activities.

Acknowledgment

This chapter derives from a previous paper by the author, 'Recovering rockets from the desert: exercises in retrieving Australia's space heritage from the Simpson Desert' (IAA-99-IAA.2.1.06), which was presented at the 50th International Astronautical Congress in Amsterdam in 1999. That original paper used information kindly provided by Roger Henwood, the Logistics Officer for the Rocket Retrieval Group. A long-time Woomera employee, he is now the Range Activities Manager. His advice and assistance in the development of the original paper and this chapter are gratefully acknowledged.

Notes and references

1 The Joint Defence Facility *Nurrungar*, operated by the US Air Force and the Australian Department of Defence. This station monitored the US Defence Support Program early-warning satellites and operated from 1971 to 1999.

2 The Woomera Detention Centre, located a few kilometres from the township, was opened in 2000 and closed in 2003. Housing illegal immigrants, many of them people displaced by the 'war on terror', detained while their applications for refugee or general-migrant status were determined, the centre was extremely controversial and frequently the site of protests and inmate unrest.

3 The official history of the Joint Project is presented in Morton, P, *Fire Across the Desert* (Canberra: Australian Government Publishing Service, 1989). A short history of Woomera up to 1992 can also be found in Dougherty, K and James, M, *Space Australia* (Sydney: Powerhouse Publishing, 1993).

4 Bardwell, H, 'Cold comfort', *The Australian Listener*, 17 (19–25 November 1988), p15

5 ELDO's Europa programme was intended to develop an independent satellite launch capability for Europe, to free it from reliance on the United States for launch services. The Europa vehicle consisted of a British first stage (Blue Streak), a French second stage (Coralie) and a West German third stage (Astris), with the satellite provided by Italy and other ELDO nations contributing telemetry and electronic equipment. The vehicle never successfully launched a satellite from Woomera and, after the programme was transferred to Kourou, was eventually scrapped. Despite their failure, ELDO and Europa paved the way for the later success of ESA and the Ariane launcher series.

6 Black Arrow was Britain's final attempt to develop an independent satellite launch capability after it withdrew from ELDO in the late 1960s. The first Black Arrow flight took place at Woomera in 1969; the fourth and last Black Arrow launch in 1971 successfully orbited Prospero, only the second satellite ever launched from Woomera.

7 James, M L, 'Into space from down under – the early days', *Journal of the British Interplanetary Society*, 41/12 (1988), pp539–54

8 For example the WRE Headquarters facility at Salisbury, South Australia, near Adelaide, which is now the home of the Defence Science and Technology Organisation, or the Aeronautical Research Laboratory, at Fishermen's Bend in Victoria, which is now the home of DSTO's Aeronautical and Maritime Research Laboratory.

9 It was not until 1999 that the Woomera Rocket Range was designated as a National Engineering Landmark by the Institution of Engineers, Australia, in recognition of the outstanding engineering and scientific achievements associated with the creation of the Range and the activities carried out there.

10 Apart from some early examples of surplus RTV test missiles, which can be found in a number of technological museums around the country, and a few examples of missiles tested at Woomera located in military museums, there are almost no artefacts relating to the Woomera programmes in the collections of museums outside South Australia – and even there, the number of examples is small. For almost three decades, the best display outside the Woomera Heritage Centre itself was that of the privately-owned Rohrlach Museum near Adelaide, which owned a collection of re-created sounding rockets (composed of relics recovered from the Woomera Range) and other examples of hardware salvaged from the Range after flight. Following the death of its owner and the closure of the Rohrlach Museum in 2001, the collection was dispersed at auction, with some of the more significant items of rocket hardware being acquired by the Powerhouse Museum in Sydney.

11 The Heritage Centre was originally located in the former St Barbara's Anglican Church, where it operated until the late 1990s. With the transfer of the Oasis Leisure Centre (built by the US Air Force as an amenity for its personnel working at *Nurrungar*) to Woomera Board control, as *Nurrungar* was shut down, the main display venue of the Heritage Centre was moved to its current location within the Oasis Centre. Although now physically separated from the Missile Park by a short distance, the two display venues of the Heritage Centre continue to complement each other in providing public education about the programmes carried out at Woomera. The old Heritage Centre building continues to act as a storage facility for parts of the collection not able to be displayed in the new, smaller Oasis Centre venue.

12 In spite of its remote location, Woomera was a 'closed town' from its inception, owing to the perceived Cold War security need to prevent espionage and sabotage: security passes were needed to access the township, with additional security clearance being required to access the Range. Casual visits to the town, by tourists or the curious, were prohibited under the Joint Project. Security restrictions were relaxed at the end of the Project – the

author made her first visit to Woomera as a tourist in 1979 – and it was anticipated that tourists to the outback region would be interested in visiting the town once it was accessible.

13 The rest of the collection remained in storage at WRE/DSTO Headquarters in Salisbury, with material from it occasionally being loaned out for promotional exhibitions. The care given to this collection varied over time, depending on the interest of the officer tasked with its management. In the late 1990s, the bulk of the collection not at Woomera (mostly promotional models, replicas and some examples of recovered Skylark sounding-rocket hardware) was handed over 'on permanent loan' to the South Australian Aviation Museum.

14 As well as covering the technological and social history of the Range and township, the museum has also attempted to address the 'pre-Woomera' history of the Range area, acquiring material relating both to the Aboriginal communities who originally occupied the region and to the pastoralists, raising sheep, who pioneered European settlement in the area from the 1870s.

15 Some funding was made available in the 1990s to enable the collection to be catalogued and so that a collection management system could be established. In 2002 the new facilities management company for the Range, BAE Systems, with support from the local Regional Development Board and the South Australian Tourism Commission, funded the redevelopment of the Heritage Centre to improve its tourist potential. A heritage professional, freelance historian Geoff Speirs, was commissioned to provide professional input into the content development and design of a new exhibition for the Heritage Centre. This new display opened in March 2005.

16 Details of the Wresat project can be found in both the publications cited in note 3.

17 Prior to Wresat, only the USSR, USA and France had launched their own satellites independently. Australia's position is anomalous in that, while it developed the satellite and launched it from a facility in its own country, it used a 'donated' US launch vehicle.

18 Essentially a modified V-2, the Redstone rocket was originally developed by Wernher von Braun's team in the United States as an intermediate-range ballistic missile for the US Army. It later became the launch vehicle used for the suborbital flights of the Mercury programme. Project Sparta was an American-led investigation into the physical effects of high-speed re-entry on missile warheads, using the Redstone to power various experimental warheads into the atmosphere at re-entry velocities.

19 Hill, C, 'Lost and found – one Redstone rocket', *Australian Geographic*, 18 (April–June 1990), pp20–1

20 These data had been documented and archived in the 1960s and were available for reference at DSTO Headquarters in Salisbury.

21 A prominent Australian businessman, social identity and adventurer, Dick Smith can count among his many achievements the first solo helicopter flight around the world, carried out in 1982–83.

22 The collection does, however, include two full-size cutaway models of the Wresat satellite.

23 Alan Lockett MBE, the Area Administrator for Woomera, was appointed as Chair of the Retrieval Group. The Area Administrator was responsible for overseeing the activities of both the Range and the town.

24 It is a standard procedure when travelling in the Australian outback to alert the police in local towns prior to undertaking desert travel. In this way, it quickly becomes noticed if travellers do not arrive at their destination within a reasonable time, so that a search can be initiated.

25 A manager from TRW's space-activities division joined the Retrieval Group for the recovery mission.

26 Now renamed Telstra.

27 Neither the WRE/DSTO, the Australian or British governments, nor any other entity with an interest in the original Woomera projects has so far asserted any rights of ownership or control over the remnants of rockets and missiles on the Range, or in the

downrange flight paths. During the Joint Project, any hardware required to be recovered for research or other purposes was retrieved at the time by special teams from Woomera.

28 In the 1970s, a battered Black Arrow first stage was recovered from the Simpson Desert and placed on the railway platform at the Williams Creek station of the old Ghan Railway route as a tourist attraction. Although the Ghan service was re-routed in 1980 and the Williams Creek station fell into disuse, the Black Arrow remained on the platform until some time in the 1990s, when it was apparently hauled away for scrap. Another Blue Streak first stage from a Europa launcher was at one time established as a 'garden ornament' in front of the homestead at Tobermory Station (ranch) in the Northern Territory. It had been removed as scrap by 1979.

29 When making his solo trek across the Simpson Desert in 1985, adventurer Denis Bartell came across an unidentified Blue Streak stage which may have been the F-5 vehicle.

30 The Europa F-1 to F-3 flights were Blue Streak first stages only, which were launched in a northwesterly direction and impacted in the Great Sandy Desert of Western Australia.

31 ELDO used the Launch Area 6 complex, on the edge of the Lake Hart salt lake. Originally established for the British Blue Streak missile programme, this facility was allocated for ELDO's use when Britain offered Blue Streak as the first stage of the Europa launch vehicle. There were two launch pads at the site, but only Launcher 6A was ever completed and made operational. Following the transfer of ELDO operations to Kourou, the Launch Area 6 complex was mostly demolished, except for the massive bases of the launch pads, which still remain today, albeit much scarred from being used for target practice by the defence forces.

32 The Ausroc amateur programme was the precursor of the Australian Space Research Institute, a volunteer space engineering and education association which undertakes educational rocket-launch campaigns for school and university students, and provides experience for engineering students on its Ausroc sounding-rocket development programme and student satellite projects.

33 Trent, D, 'Looking for a needle in the Simpson Desert', *Genesis*, 9/6 (December 1992), pp1–3

34 He was filming Australian Army exercises for a TV documentary.

35 For example, while vacuum-packed provisions formed the main food supply for the expedition, the team expected to supplement this with freshly-caught wild game, including rabbit, duck and wild pigeon, which was plentiful in this part of the desert at that time. Tinned food was also carried as a backup supply. Small vehicle refrigerators were used to keep food fresh in the high ambient temperatures.

36 This engine was made available to the National Museum of Australia for inclusion in 'The Australian Connection' theme of its major temporary space exhibition 'To Mars and Beyond', displayed between 2001 and 2003.

37 Search teams had travelled past the engine, and within 150 metres of it, without sighting it, during two vehicle searches of the area.

Asif A Siddiqi

Privatising memory: the Soviet space programme through museums and memoirs

Introduction

In the years after Sputnik, Soviet museums dedicated to space exploration played an important role as 'custodians' of space history. Artefacts in museums presented and helped to create a unifying 'consensus narrative' that fostered a shared sense of identity among both participants and observers of the space programme, an identity that underpinned the myth of a Soviet space effort whose engine was heroism, ingenuity and, most of all, priority.[1] Their claims were buttressed by a huge body of literature issued by 'official' journalists who extolled the virtues of the Soviet space programme. The state-sanctioned histories served as supporting texts for the museums, where carefully-selected artefacts, usually spacecraft that had achieved certain 'firsts' in the early history of space exploration, were displayed and celebrated as monuments to Soviet technocracy. (For a discussion of Soviet space museums and Soviet exhibitions at World's Fairs, see Cathleen Lewis's essay in this volume.)

Three elements defined the memorialisation of Soviet space history during the late Soviet era, i.e. from the 1960s to the late 1980s. First, writers and curators eliminated contingency from the story: all successes were assumed to be inevitable and the idea of failure was made invisible. Second, under pressure from censors, writers and curators constructed a space of 'limited visibility' for both actors and artefacts, i.e. only a few selected persons – usually cosmonauts – and objects were displayed to the public. Military domination of the Soviet space programme engendered a culture of enveloping secrecy over most of its participants, institutions and artefacts. For example, when it was first flown, the Voskhod spaceship was described in the Soviet media as a substantive evolution beyond the older Vostok. In actuality, it was simply a rigged-up version of its predecessor; in order to buttress official but untrue claims, Voskhod was never publicly displayed anywhere, rendering an entire programme invisible.[2] Finally, for the public, there was a single master narrative – a Soviet space history that included a set of fixed stories in which the central characters were key (and usually deceased) individuals such as Konstantin Tsiolkovski, Sergei Korolev and Yuri Gagarin, and institutions such as the Bolshevik (and later Communist) Party.

The collapse of the Soviet Union represented a rupture for custodians of public memory. If, previously, Russian historians had been forced to work under extreme constraints defined by state-sanctioned narratives, with the coming of *glasnost* ('openness') in the late 1980s, they could not only fill in the gaps of skeleton stories but flesh out entirely new ones. For Russian space history, the transformations were profound. In the previous 40 years, the field had been delimited by secrecy and an obsession with progress and success. Now, former engineers, cosmonauts and politicians spoke out in newspapers, journals and public lectures. The single narrative of Soviet space history – teleological and Whiggish – fractured into multiple and parallel narratives full of doubt (for the claimed successes of the programme), drama (for the episodes we never knew about) and debate (over contesting narratives of history).[3]

In the post-1991 era, the state's retreat – both commercially and culturally – has profoundly affected the ways in which invested participants contest the history of Soviet space exploration. The state's withdrawal produced conditions where memory was 'privatised' as atomised and decentralised views of history populated the landscape of remembrance. Economic deregulation allowed a new generation of small corporate museums to open their doors, each showcasing artefacts that propagate their respective institution-centred narratives. Artefacts of the former Soviet space programme have also dispersed across the world through commercial auctions and semi-legal means into the collections of interested foreigners, blurring claims for ownership of the detritus of Soviet space history.

The medium of memoirs added a new critical element to the emerging debates over competing narratives of Soviet space history. Freed from Soviet-era constraints, a veritable flood of written material from participants in the space programme – including memoirs, diaries and collections of tributes to deceased comrades – filled the space left vacant by absent official histories. Memoirs represented a different type of 'privatised memory' where history was determined no longer in official, collective and public discursive spaces, but rather through individual action; these memoirs were private ruminations, depending on reflection rather than rhetoric, the personal instead of the public. The high public profile of these post-Soviet memoirs of the space programme has introduced new complexities into the privatised 'market of memory', particularly in claims for ownership of history. In the new context of 'privatised memory', artefacts and memoirs together point to no simple answer to the question: Now that the Soviet Union no longer exists, who owns the Soviet space programme?

The old museums

During the Soviet era, all museums were state-owned. Through the display of selected artefacts, they propagated a master narrative that focused primarily on three deceased personalities: Konstantin Tsiolkovski (1857–1935), who first mathematically substantiated the possibility of space exploration in the early twentieth century, Sergei Korolev (1906–66), the legendary 'chief designer' of Sputnik, and Yuri Gagarin (1934–68), the young hero cosmonaut who made the first trip to space in 1961.

The most important museum of national stature was also the earliest to open; in 1967, government officials inaugurated the K. E. Tsiolkovski State Museum for the History of Cosmonautics in the rural town of Kaluga, about 150 km southwest of Moscow. Although the museum's mandate included publicising the whole history of Soviet space exploration, its collection was focused largely towards deifying the late Tsiolkovski. His original residence at Kaluga had been made into a 'home museum' in 1936 soon after his death, and, following the formation of the new museum, it became an adjunct to the main facility.

Artefacts on display at the museum were split between material artefacts of the space programme (such as rockets, spacecraft, spacesuits and instrumentation) and Tsiolkovski's personal effects or models of his various imaginary spaceships.[4] Because of the high secrecy associated with the space programme, as well as the reluctance of design organisations working within the military–industrial complex to hand over items, the museum typically displayed models rather than actual flight or test hardware. Even replicas had to be carefully screened and then cleared by the relevant security services in case they disclosed what might be construed as state secrets.[5] Although the museum was a three-hour train ride from Moscow, official statistics suggest that at least 10 million people visited it during Soviet times, i.e. before 1992. It was by far the most popular Soviet-era museum dedicated to space exploration.[6]

A second major state-sponsored museum from the Soviet era, the Memorial Museum of Cosmonautics, was opened in 1981 at the site of the 'Conquerors of Space' memorial in Moscow. Smaller than the Tsiolkovski museum (only about 900 m^2), the Memorial Museum displayed replicas of about 30 spacecraft or spacesuits that celebrated progress, success and priority.[7] More famous than the Memorial Museum was its branch facility located not far away, the S. P. Korolev Memorial Home Museum. Korolev's surviving mother and daughter opened the branch in 1975 as a way of paying tribute to Korolev's contributions in founding the Soviet space programme.[8] The opening of the memorial home coincided with the appearance of several hagiographic biographies of Korolev, which helped to escalate the hero worship that has surrounded Korolev's legacy to this day.[9]

The house, a shrine to Korolev's life, served as a striking reminder of the personality-centred history of the Soviet space programme, a perspective that rendered opaque the notion that thousands of others might have had something to do with the extraordinary Soviet successes in space flight. Housing over 2000 items from Korolev's life, the facility split its activities between popularising aspects of Korolev's life and sponsoring further historical research into his scientific and engineering legacy through letters and documents donated by his family.[10]

Probably the most significant site for displaying space artefacts during the Soviet era was the Kosmos Pavilion, a building that was part of the massive display complex dedicated to highlighting Soviet economic and industrial achievements, the VDNKh (Exhibition of Achievements of the National Economy) in Moscow.[11] In 1960, Korolev wrote letters to top Communist Party and government officials suggesting that the government 'organise a display for space' at the VDNKh, a proposal that was soon approved.[12] Recently declassified archival documents underscore the degree to which top government officials such as Dmitri Ustinov were involved in approving and sanitising what was appropriate for public display; they even discussed the aesthetic display value of one artefact over another.[13] Less a museum than a storehouse open to the public, the Kosmos Pavilion housed numerous replicas of spacecraft, beautifully constructed and hung from ceiling pylons, communicating majesty, grandeur and progress. Placards typically provided detailed and arcane technical information about the artefact or, conversely, vague claims about the social benefits of space travel. Although the displays were not overtly personality-centred, official and disembodied portraits of the three most important faces of the Soviet space programme – Tsiolkovski, Korolev and Gagarin – loomed over the display areas, providing a human element to the celebration of technocratic progress, social harmony and national enlightenment, the major themes of the single state-sponsored narrative of Soviet space travel.

Crossing the divide

By the late 1980s, at the height of *glasnost*, Soviet space history – like every other area of Russian history – entered a period of radical revisionism, a process that continued, albeit at a slower pace, through the 1990s. In official literature and museums, Soviet space history and its curators came face to face with a new world of contingency, expanded visibility and multiple narratives.

The state-sponsored space museums did not fare well in the post-1991 landscape. As the economy ground close to collapse, the museums lost their financial base, their prominence and their audience. In 1991, only 180,000 people visited the Tsiolkovski Museum, half the number that visited the previous year. By 1997, the museum was already 500 million roubles in debt and workers were being paid on a limited basis. Curators could add new artefacts only because of the generosity of cosmonauts or their families who donated personal items.[14] Meanwhile, at the Memorial Museum of Cosmonautics, the 'main' space museum in Moscow, the number of annual visitors dropped to a dismal 7000 per year in the early 2000s. At the Space Pavilion at the VDNKh, literal relocations masked metaphorical ones: most of the celebratory artefacts of the space programme were shoved aside from view to make way for western European automobiles and sailing boats for sale to the *nouveaux riches* in Moscow.

The financial realities went hand in hand with the state museums' inability to respond critically to the new emerging narratives of Soviet space history. As new 'rediscovered' elements of Soviet space history appeared on an almost daily basis in various newspapers such as *Izvestia*, *Pravda*, and *Krasnaia zvezda*, the narratives propagated by the museums became irrelevant and old-fashioned. If political elites and popular constituencies competed to redefine memorialisation sites and struggle over the meanings of identifiers such as 'Soviet' and 'Russian', space museums avoided such debates entirely in the vain hope that the older master narrative still held resonance.[15] Already in 1992, the curator of the Tsiolkovski Museum recognised the 'fragmentary nature' of his artefacts and their inability to reckon with the new space history, partly attributable to 'the special status of cosmonautics in [... the] country and its connection to the military–industrial complex'.[16] Beyond a few cosmetic changes, the older museums retained their old collections of artefacts and added little that was new.

As state-owned memory fragmented into privatised memories, the old museums also faced competition. By the mid-1990s, Western observers (and the Russian general public) discovered that the Soviet Union had had a parallel but entirely secret world of space museums that displayed the most coveted space artefacts of the period. These were analogous to corporate museums in the Western context, i.e. they were operated by the formerly secret organisations that developed various Soviet space-flight-related objects such as spacecraft, launch vehicles, rocket engines, spacesuits and so on.

The most important of these corporate museums was the museum of the Energia Rocket-Space Corporation (RKK Energia, or in English RSC Energia), the firm that, in its original incarnation, designed and built the most important Soviet space vehicles, including Sputnik, Vostok, Voskhod, Soyuz, Salyut, Mir, etc. Under Korolev's initiative, in 1963 Energia had opened a 'display hall' on its premises devoted to showing various artefacts that they could not allow to be displayed in the public museums. The Energia museum housed such jewels of the Soviet space programme as the Vostok(-1) spaceship that took Yuri Gagarin into orbit in 1961 and the Vostok-6 vehicle that did the same for the first woman in space, Valentina Tereshkova.[17] Its collection spanned the entire era of rocket design, from the 1930s to the present, and included models or ground-test articles of ballistic missiles, launch vehicles, manned spacecraft, space stations, lunar and interplanetary probes, applications satellites and experimental rockets.[18] After the death of Korolev, who had supported the idea of a display hall as a way to 'enlighten' his employees, access to the facility was severely limited. Most of Energia's employees – even those with special passes for access to all parts of the organisation – were forbidden to visit the area.[19] In the post-1991 period, Energia was partially privatised. In search of any and every economic opportunity to survive during the economic collapse, Energia's corporate bosses recognised that its display hall could be a useful public-relations tool. The company converted the old viewing area into a museum and offered tours by appointment. Over 8000 people, half of them foreigners, now pay to visit the facility every year.[20] Other newly-privatised spacecraft design corporations followed Energia's lead by opening their own corporate museums, a process that not only fractured the unified narrative of Soviet space history, but also denied artefacts of universal significance to the major state-owned museums, which were struggling to retain their importance in the face of obsolescence.[21]

The privatisation of memory had another important dimension: the unprecedented drain of artefacts from Russia that were put up for sale overseas by cash-strapped veterans of the Soviet space programme. Already in 1992, the director of the Tsiolkovski Museum complained that 'unique museum artefacts have been dispersed across the country and abroad. Any kind of [...] work to collect [these artefacts] has become almost impossible.'[22] Two Sotheby's auctions in New York, in 1993 and 1996, represented only the first volleys in the wholesale movement of space artefacts from Russia to the rest of the world. In the first auction alone, observers estimated that 227 artefacts worth $7 million had been sold. One Russian company sold for $68,500 a vehicle that is still on the surface of the Moon.[23] The chaotic nature of the rush for sale inevitably incurred losses. For example, one full-scale model of the Soviet space shuttle Buran was found languishing in a desert in Bahrain by German journalists after being displayed in Sydney, Australia, for several years. In another case, in 2001, first cosmonaut Yuri Gagarin's notebooks were sold at Christie's for $170,000, only for Russian governmental sources to complain that the diaries, as state documents, were sold illegally to the buyer.[24] Soviet space items found a home in the most unlikely places. A random search on eBay in May 2005 with the search terms 'Soviet space' shows at least 81 items from the former Soviet space programme on sale, including a compression girdle from a cosmonaut spacesuit and a 'genuine' heat-shielding tile from the Buran space shuttle.

The medium is the memoir

At a fundamental level, the physical buying and selling of artefacts from the former Soviet space programme – possible because of the transition to a capitalist economy – not only privatised memory but created a market for it. When people paid money for artefacts, they obtained a physical object; but on a deeper level, the transaction was about ownership of the history of the Soviet space programme. Claims of ownership of this history were contested through the multiple, fractious and contradictory narratives of the history of the Soviet space programme that began appearing in the medium of memoirs in the 1990s. Published largely by private publishers and written by private individuals in a privatised universe, these memoirs became an essential commodity – as artefacts in themselves – in the market of memory. In the new privatised universe, they also had an important function in the market, of ascribing value to traded artefacts – and implicitly to competing narratives – of the history of the Soviet space programme.

The medium of testimony, including both retrospective memoirs and published diaries, has a long and distinguished tradition in the Russian literary and intellectual canons dating back to the pre-Romantic era. Through the Tsarist and Soviet eras, the memoir or *vospominania* (literally 'recollections') performed important functions beyond individual expression and historical recording (and everything in between). As Beth Holmgren has noted, 'For centuries Russians have embraced the memoir as a form of autobiography with [...] a conscience or an agenda.'[25] During Soviet times, the published memoir represented a new way to confirm official narratives of the Revolution (or, as was the case most often, martyrdom for the cause of the Revolution).

In the post-1991 era, memoir-writing in Russia boomed, and the medium's value as history rather than reflections on history has escalated, partly because official sources of history simply disappeared from the book stores. Memoirs occupied a significant part of the resulting vacuum, many of them seeking to refute and then fill in the blank holes of official Soviet history. Cultural critic Alexander Prokhorov claims that memoirs in the post-Soviet era 'do not pursue any didactic or propagandistic goals; [...] rather they offer an anecdotal account of a famous life that may be consumed as entertainment'.[26] But if such a generalisation can be made about the memoirs of popular entertainment figures in present-day Russia, it is most certainly not true of the canon of memoirs on the former Soviet space programme. These space memoirs, voicing individual and personal perspectives, represent another kind of 'privatised' memory, one that is not only commercial in nature but also generated and promoted by private individuals. The memoirs also serve two important and interconnected functions: first, they operate as 'linking narratives' that imprint personalities and value onto technological artefacts of the former Soviet space programme dispersed throughout private collections across the world; and, second, memoirs represent a new kind of artefact in the era of privatised memory, i.e. liminal objects of memorialisation that complicate claims for ownership of memory as they travel across thresholds and definitions.

Retrospective memoirs

In the 1990s, Boris Evseevich Chertok (Figure 1) published what was undoubtedly the most famous and widely-referenced memoir of the Soviet space programme, issued under the general title *Rakety i liudi* (*Rockets and People*).[27] Chertok, who turned 80 in 1992, played important roles in the founding of the post-war Soviet ballistic-missile programme which later gave birth to the Soviet space programme. He served as a senior designer specialising in guidance and control systems under Korolev and contributed to almost every major Soviet human space project ever attempted. By the time of his semi-retirement in 1992, his name, like those of many other former participants, appeared widely in Russian newspapers and journals as he took on the role of a private commentator on the early history of the programme.[28] Many contemporaries of Chertok also published their own memoirs, but Chertok's writings were more visible than his competitors' for several reasons.[29] First, they were linked to the most important personality in the Soviet space programme, Sergei Korolev. Second, in contrast to the older state-sponsored narratives, which were vague and nebulous, Chertok's writings were extraordinarily detailed. Finally, they were the first 'revelatory' memoirs to appear, inevitably making everything that came after anticlimactic. In Chertok's memoirs, for the first time readers saw details of a spectrum of previously veiled programmes and events; he dedicated the entire fourth volume to chronicling the Holy Grail of formerly-secret Soviet space history, the N-1 superbooster project that failed to put a Soviet cosmonaut on the Moon (Colour plate 8). In the absence of any official and comprehensive post-1991 histories of the Soviet space programme, Chertok's four volumes became, by default, a canon in and of themselves.[30]

Figure 1 Boris Chertok, pictured here in 2003, served as one of the principal deputies of the Soviet space programme from the 1940s to the 1990s. His four-volume memoirs have become important historical markers of the 'new' history of the Russian space programme. (Jesco von Puttkamer)

By definition, memoirs are selective narratives, since they represent very personalised impressions of events; each person involved in an endeavour will have his or her own individual experiences and perspectives. Besides Chertok, other deputies of Korolev – such as Bushuev, Kriukov, Mishin or Okhapkin – had they written memoirs might have created overlapping but very different narrative spaces with different actors and artefacts. But in the absence of any 'official' state history of the Soviet space programme, or indeed a syncretic work written by a professional Russian historian, Chertok's memoirs – and the particular spaces they created with embedded actors and artefacts – have produced one of the most dominant narratives of the history of the Soviet space programme. As a result, for the physically dispersed artefacts of Korolev's legacy, Chertok's dominant narrative serves as a 'linking narrative', i.e. it plays a curatorial role that connects disparate artefacts into coherent stories of Soviet triumphs and failures in exploring space during the years of the Cold War.

By giving a space in which selective events are presented as coherent narratives, by locating the various artefacts of the former Soviet space programme dispersed across the world within those narratives, and by serving in a curatorial role, memoirs such as Chertok's function as a valorising agent for artefacts of the former Soviet space programme. In other words, in the privatised market of memory where ownership of history is bought and sold, memoirs help establish the value of the items exchanged. This value is not necessarily measured in added monetary value (although it can be), but rather in added narrative value, i.e. by adding narratives to artefacts, they make the artefacts 'readable'.

One of the most extensive collections of formerly-secret Soviet space hardware is currently accessible for viewing at the Orevo laboratory complex of the Bauman Moscow State Technical University (formerly the Higher Technical School) at Dmitrov, outside Moscow. Covering about 100 hectares of grounds, the facility houses an enormously varied collection of objects including proposed, developed and abandoned ballistic missiles and spacecraft. Among them are several artefacts from the abandoned Soviet manned lunar programme, including the L1 (Zond) circumlunar vehicle and the LK lunar lander. As objects displayed completely without context – with only brief placards summarising technical characteristics such as thrust, mass, designation, etc. – they represent the extreme version of atomised narratives of Soviet space history. They originally existed as objects without narratives. Chertok's memoirs, among others, gave a space for these artefacts to exist as meaningful elements in a story; in other words, viewers use the memoirs to ascribe meaning and value to artefacts. Besides providing context, memoirs add value in other ways: for example, they imprint personalities on each artefact as identifiers ('Mishin's L1 spacecraft', 'Chelomei's TKS', etc.); they foreground artefacts that represent narratives of absence ('the lunar lander that was never flown') and failure ('all of this hardware was all for nothing'); and they assign descriptive categories to objects by not mentioning them at all ('never mentioned in any Russian source!').

Because Chertok's memoirs dominated post-1991 historiography, his valuations – such as those of success and failure – often trump contending valuations. Like Chertok's writings, other memoirs have also been connected to specific personalities, and they also performed similar roles. Other memoirs, of course, produce parallel and usually contradictory narratives to the Korolev-centred one of Chertok. For example, engineer Ivan Evteev's memoirs *Operezhaia vremia* (*Ahead of the Times*) imprinted personality and importance on all the missiles and spacecraft produced by the organisation headed by the late Vladimir Chelomei. Similarly, Vladimir Trofimov's *Osushchestvlenie mechty* (*Accomplishment of a Dream*) did the same for rocket engines created under the late Valentin Glushko.[31] No private publisher has yet sponsored a memoir that puts Korolev's successor Vasili Mishin centre stage. In other words, there is no major narrative space given to the artefacts created under Mishin's command; typically those artefacts are attached to his predecessor (Korolev) or successor (Glushko).

The emergence of multiple and contradictory narratives for contesting memory has uncorked levels of contentiousness unimaginable in the Soviet era, acrimonies which are at core about claims for ownership of memory in the Soviet space programme. No other conflict weighed more heavily on contemporaries in the 1990s than the one between the two giants of the Soviet space programme, Korolev and Glushko. Both had been thrown into Stalin's Gulag in the late 1930s amid technical disagreements in their workplace that escalated into mutual denunciations.[32] In the late 1950s, as they rapidly rose in rank into powerful positions in the Soviet defence industry, they fell out over conflicting technological preferences that proved to be irreconcilable. Their bitter disagreements over the design of the N-1 superbooster contributed to the programme's sad and dramatic ending as rocket after rocket exploded over Kazakhstan. When Korolev died in 1966, the two men were barely on speaking terms. In an ironic twist, less than a decade after Korolev's death, the Soviet government appointed Glushko to head Korolev's old organisation, Energia. In the 15 years that he led this large industrial empire, Glushko single-mindedly tried to whitewash space history by relegating Korolev to a secondary place behind himself. In 1974, in one of his first acts as head of Energia, Glushko instructed the curators of Energia's highly-restricted 'display hall' to remove all traces of Korolev's handiwork (such as the famous R-7 rocket that put Sputnik into space) and replace them with his own rocket engines.[33] Similarly, in the years before his death in 1989, Glushko sought to rewrite the official historical narrative in subtle ways that would not be noticed by foreigners – for example, by having chapters on his research precede those on Korolev.[34] In one of his last lectures, Glushko accused Korolev's old comrade-in-arms Mikhail Tikhonravov, also the designer of Sputnik, of having written the deadly denunciation that landed Glushko in the Gulag in the 1930s.[35]

These types of struggles over the remembered history were hidden and muffled under the dominance of a single state-sponsored master narrative during the Soviet era, but they were unleashed into public discourse, and then contentiously carried into the 1990s by 'curators' responsible to the individual legacies of Korolev, Glushko and others. These curators operate through memoir-type publications known as 'memoirs of contemporaries' (*vospominania sovremennikov*), which themselves represent a centuries-long genre in Russian history and literature that has been a vehicle for tribute, reflection and reminiscence.[36] A typical example of the 'contemporaries' genre includes dozens of short essays by the associates of a single and late heroic figure, compiled and edited by a single person, usually the legacy curator of a person or an institution. In the 1990s, curators on behalf of the major deceased participants of the former Soviet space programme devoted their livelihoods to publishing collections of essays about their 'patron' individual. In Korolev's case, the curators of his memorial home and his daughter have published a wealth of material, including essay collections by contemporaries eulogising the man and reducing the role of Glushko and Chelomei.[37] For the late Glushko, a host of admirers, including a son, continue to publish uncritical hagiographies that reject Korolev's dominance of the Soviet space programme.[38] Similarly, Chelomei has curators who defend and promote his legacy against what they consider to be unfair slander from others.[39]

What do these deep-rooted conflicts over history mean in a climate characterised by privatised memory? In the new market of memory, these contradictory narratives are first and foremost struggles to valorise particular narratives over others. In a national context where the state no longer imbues space history with a master narrative, the private curators of space history have become the primary actors in a contentious market that may never reach equilibrium. Hostile to the notion of multiple and contradictory narratives of the history of the Soviet space programme, the new curators of memory are, in their own way, nostalgic to return to a single master narrative of the space history, i.e. a narrative that elevated their own patron over others, a narrative that in fact remains as far from the real history of the Soviet space programme as the 'official' version was during the Cold War.[40] Memoirs represent a new and growing force in the politics of memory of the Soviet space programme, one that is caught between nostalgia for an imaginary past and hope for an impossible future.

Diaries

Historians have long used diaries as historical sources. Their unique value in Russian history and literature has been the subject of much debate.[41] Historians of technology have used diaries to explore the act of invention and innovation; diaries and notebooks have been especially important to supplement purely artefact-driven explorations of invention, particularly for studying the eighteenth and nineteenth centuries.[42] In the historiography of the Soviet space programme – at the intersection of Russian history and the history of technology – the diary represents a tool that was impossible to use during the Soviet era. In the post-1991 landscape, however, published diaries of prominent personalities have become important evidential bases for interpreting history.[43]

Like the many artefacts of the Soviet space programme that have been bought and sold at various international auctions, *unpublished* diaries from participants in the former Soviet space programme have also changed hands.[44] Probably the most important diaries were those of Korolev's successor, Vasili Mishin; the strange and remarkable trajectory of his diaries provides a window into the complex negotiations over ownership in the privatised market of memory of the former Soviet space programme. Mishin originally wrote daily notes of his work activities in at least 31 notebooks covering the period 1960 to 1974. Because of his senior position in the Soviet space programme, first as Korolev's principal deputy and then as successor to Korolev, these diaries were considered extremely important for future historians. When Mishin put his diaries on sale at Sotheby's in 1993, one expert observer noted that 'any attempt at telling the history of the space race without the materials in these notebooks will be second-rate'.[45]

Mishin enjoyed a peculiar place in the history of the Soviet space programme, since he was one of the few figures universally reviled and blamed for the failure of the Soviets to send a cosmonaut to the Moon in the 1960s. Contemporaries blamed him for all manner of shortcomings (including a weakness for alcohol), while younger Russian historians now mention him sparingly, if at all. His diaries represent a type of counter narrative or 'counter artefact' of the Soviet space programme, since it is unlike all of the multiple-victory narratives of Korolev, Glushko, Chelomei *et al.* that at their core represent celebrations over success rather than recordings of failure.

At Sotheby's, the Perot Foundation (funded by Ross Perot) purchased the whole set of Mishin's diaries for a reputed price of $190,000.[46] Perot took the diaries, along with a vast array of other purchased artefacts from the Soviet space programme, back to his corporate headquarters in Texas. After a prominent American novelist hired by Perot failed to distil Mishin's story into a popular entertainment novel, Perot decided to donate a few pages of the diaries to the Smithsonian Institution's National Air and Space Museum to display as part of their 'Space Race' exhibition, which opened in 1997 (Figure 2). The displayed entries from the diaries illuminated aspects of the failed Soviet Moon programme that Mishin oversaw in the late 1960s.[47] The museum was the first in the world to devote attention, however cursorily, to the Soviet side of the Moon race. The entire set of diaries, meanwhile, remained inaccessible to historians until 2004, when the Perot Foundation donated a full set of copies to the National Aeronautics and Space Administration (NASA) in the hope that their History Division would find something useful to do with the manuscripts. In early 2005, NASA formally issued a 'request for a proposal' for a contract to translate, edit and then publish portions

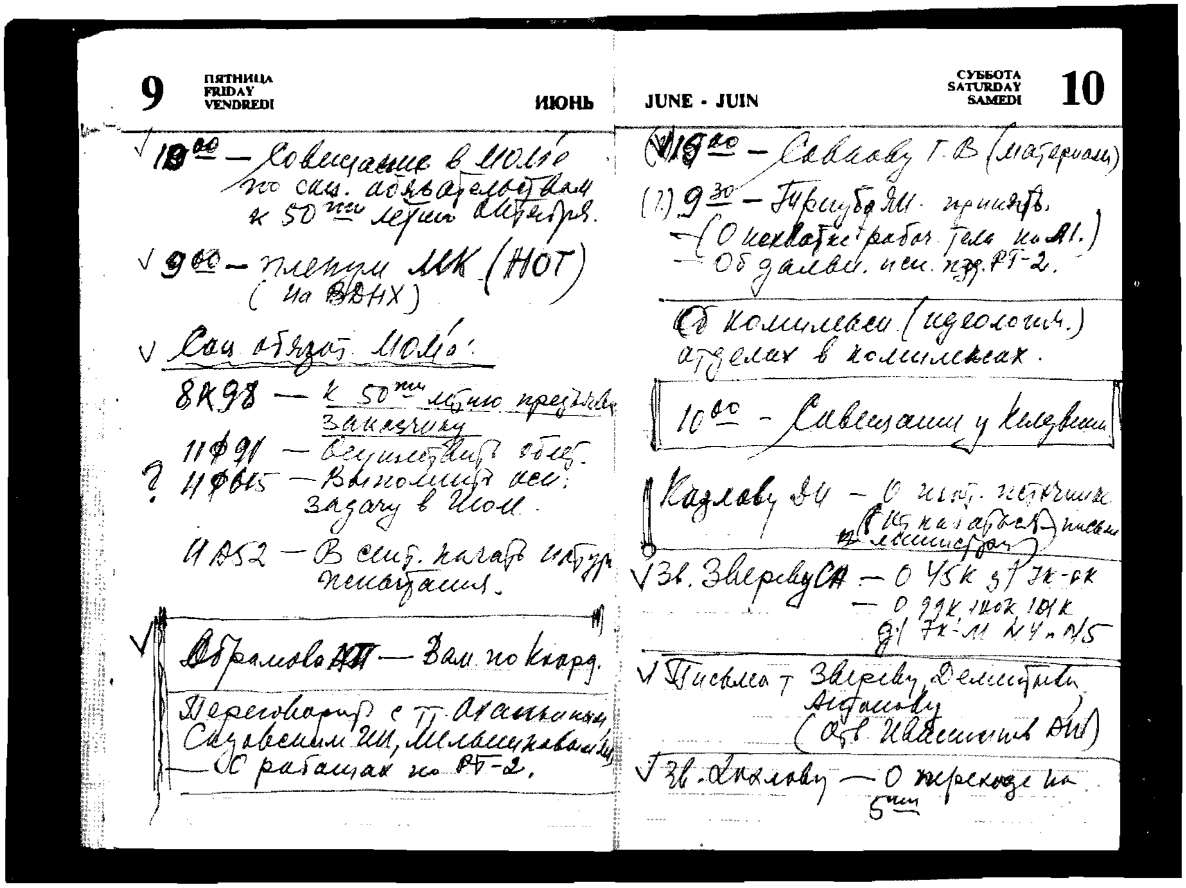

Figure 2 Pages from the diaries of Vasili Mishin, a former senior manager of the Soviet space programme, which are now on display at the National Air and Space Museum in Washington DC, as part of an exhibition devoted to the Cold War space race. Mishin's diaries were purchased at Sotheby's in 1993 by the wealthy American Ross Perot. (Smithsonian National Air and Space Museum)

of the Mishin diaries as part of its NASA History Series issued by the US Government Printing Office. The agency allocated $85,000 for the project.[48]

Mishin's diaries are an example of a new liminal artefact in the world of privatised memory of the former Soviet space programme. Since their creation as personal diaries they have repeatedly crossed over lines of ownership, definition and categorisation. The memoir was written by a former employee of the Soviet state; it was sold as the personal property of a Russian individual; it is physically owned by a private American individual; it has been on display as an artefact of the Soviet space programme in an American exhibition whose purpose is to celebrate American victory in the space race of the 1960s; here, it was 'read' as both a written source of history and as an artefact of history; soon, it will be published by an agency of the US government. In the privatised market of memory, Mishin's diaries fall between categorisations: they are part written memoir, part displayed artefact; they are part Soviet, part Russian, part American; they are part public and part private. In a period when memory has been privatised and can be bought and sold, all of these claims for ownership will remain deeply embedded in Mishin's words, inseparable from the history that they communicate.

Conclusions

Throughout the first 30 years of the space age, i.e. during the Soviet era, Soviet space history comprised a single master narrative of technocratic progress, social harmony and national enlightenment. This 'consensus narrative' fractured into multiple competing narratives at the break-up of the Soviet Union in 1991. In this milieu, as the beginnings of capitalism took hold in the Russian economy, formerly-secret artefacts of the former Soviet space programme were openly displayed at private corporate museums in Russia or dispersed all over the West in privately-held collections. This 'privatisation of memory' created a market for history where memory was bought, sold and traded in a process that was primarily about claims of ownership of history.

The conflicting claims of ownership of the space programme were reinforced by the multiple, fractious and contradictory narratives propagated by the dozens of memoirs from former participants of the Soviet space programme that appeared in the 1990s. Published by private publishers and written by private individuals in the deregulated space left vacant by the withdrawal of state discourses, these memoirs joined the market of memory as a critical commodity. In the new privatised universe, memoirs played an important function in the market, by imprinting personalities and ascribing value to traded artefacts from the history of the Soviet space programme. By doing so, they also valorised competing narratives in the new market of memory. Memoirs represent a new kind of 'private' artefact in the era of privatised memory, i.e. they are liminal objects of memorialisation that complicate claims of ownership. By crossing borders and categories in the privatised market of memory, memoirs and diaries – and the artefacts they valorise – have rendered the question 'If the Soviet Union no longer exists, who owns the Soviet space programme?' all but irrelevant.

Acknowledgments

The author would like to thank Dr Dina Siddiqi at the University of Pennsylvania and Dr Martin Collins at the National Air and Space Museum.

Notes and references

1 With the caveat that shared historical myths are not characteristic of only repressive state regimes, see Sherlock, T D, 'Myth and history in transitions from nondemocratic rule: the role of historical *glasnost* in the collapse of the Soviet Union', PhD dissertation, Columbia University, 1994.

2 Voskhod(-1) and Voskhod-2, launched in 1964–65, were two of the most spectacular Soviet space missions of the 1960s. The first carried three cosmonauts into orbit for the first time in a single spaceship. During the second, cosmonaut Aleksei Leonov peformed the world's first 'spacewalk' by leaving his space capsule. The first photographs of the Voskhod spaceship were published in 1980. Keldysh, M V (ed.), *Tvorcheskoe nasledie Akademika Sergeia Pavlovicha Koroleva: izbrannye trudy i dokumenty* (Moscow: Nauka, 1980), pp470–6.

3 For historiographical overviews of Russian/Soviet space history, see Siddiqi, A A, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (Washington DC: NASA, 2000), pp861–70; Siddiqi, A A, 'Series introduction', in Chertok, B, Siddiqi, A A (ed.), *Rockets and People* (Washington DC: NASA, 2005), ppix–xix.

4 For descriptions, see Belova, N G, '3 oktiabria – 10 let so dnia otrkytia gosudarstvennogo muzeia istori kosmonavtiki imeni K. E. Tsiolkovskogo (1967 g.)', *Iz istori aviatsi i kosmonavtiki,* 33 (1978), pp148–52. For Tsiolkovski's home museum, see Kostin, A V, '19 sentiabria – 40 let so dnia otkrytia doma-muzeia K. E. Tsiolkovskogo (1936 g.)', *Iz istori aviatsi i kosmonavtiki,* 29 (1977), pp118–19.

5 During the Soviet era, the only major flown item on display at the Tsiolkovski Museum was the Vostok-5 descent module. Replicas included another Vostok, a Soyuz descent module and robotic spacecraft such as Luna-9, Luna-10, Luna-16, Mars-3 and a Molnia-1 satellite.

6 Kuzin, E N, 'Dvadtsat' piat'let gosudarstvennomu muzeiu istori kosmonavtiki imeni K. E. Tsiolkovskogo', in *Trudy XXVII chteni, posviashchennykh razrabotke nauchnogo nasledia i razvitiu idey K. E. Tsiolkovskogo (Kaluga, 15–18 Sentiabria 1992 g.): Sektsia 'Issledovanie nauchnogo tvorchestva K. E. Tsiolkovskogo i istoria aviatsia i kosmonavtika'* (Moscow: IET AN SSSR, 1994), pp103–11

7 'Flown' objects at the museum included the Korabl Sputnik-2 ejection seat, the Soyuz-37 descent module and the spacesuit that cosmonaut Oleg Makarov used on Soyuz T-3.

8 The museum was opened on the estate where Korolev had lived in complete anonymity from 1959 until his death in 1966.

9 The three earliest biographies of Korolev appeared in 1969, but these were superseded by seven more, published between 1971 and 1976. See Romanov, A P, *Konstruktor kosmicheskikh korablei,* 2nd edn (Moscow: Politizdat, 1971), plus 3rd edn (1972), 4th edn (1976); Astashenkov, P T, *Orbity glavnogo konstruktora,* 2nd edn (Moscow: DOSAAF, 1973); Golovanov, Ya K, *Korolev* (Moscow: Nauka, 1973); Starostin, A S, *Admiral vselennoi* (Moscow: Molodaia gvardia, 1973); Astashenkov, P T, *Glavnyi konstruktor: o S. P. Koroleve* (Moscow: Voenizdat, 1975).

10 Kostrikina, Z I, 'O rabote memorial'nogo doma-muzeia Akademika Sergeia Pavlovicha Koroleva', *Iz istori aviatsi i kosmonavtiki,* 34 (1978), pp61–7

11 The VDNKh traced its origins back to the All-Union Agricultural Exhibition (VSKhV), which opened in 1939. In 1954, the original complex was expanded to 80 pavilions spread over nearly 600 acres to highlight *all* Soviet economic achievements.

12 Raushenbakh, B V and Vetrov, G S (eds), *S. P. Korolev i ego delo: svet i teni v istori kosmonavtiki: izbrannye trudy i dokumenty* (Moscow: Nauka, 1998), pp676, 678

13 'O pokaze na vystavke dostizheni narodnogo khoziaistva sssr i na zarubezhnykh vystavakh po osvoeniu kosmicheskogo prostranstva v sssr novykh eksponatov' ('On displaying new exhibits on the mastery of cosmic space by the USSR at the VDNKh and foreign exhibitions'), 9 June 1964, Russian State Archive of the Economy (RGAE), f. 29, op. 1, d. 3443, ll. 1-2. With this letter, Ustinov and several leading Soviet space-industry managers petitioned the Central Committee for permission to display models of the Vostok, the Vostok descent module, the Vostok ejection seat, the mission profile of Vostok and the Elektron-1 and -2 satellites. As a result of these decisions, the first Vostok vehicles were shown in the Soviet Union and abroad in 1965–67.

14 Kuzin, E N, note 6, p106; Savkin, K and Davydova, V, 'Muzeiu kosmosa v Kaluge – 30 let', *Novosti kosmonavtiki,* 12 (1998), p48

15 For the ways in which constituencies debated post-Soviet identity through memorials and museums, see Forest, B and Johnson, J, 'Unraveling the threads of history: Soviet-era monuments and post-Soviet national identity in Moscow', *Annals of American Geographers*, 92/3 (2002), pp524–47.

16 Kuzin, E N, note 6, p110

17 Flown artefacts on display included Vostok(-1), Vostok-6, Voskhod(-1), Voskhod-2, Soyuz-3 and Zond-5.

18 For pictorial surveys, see Pirard, T, 'The space museum at RKK Energia', *Spaceflight*, 42 (2000), pp247–52 and the *Novosti kosmonavtiki* Website, http://www.novosti-kosmonavtiki.ru/content/photogallery/gallery_017/index.shtml. For the museum's Website, see http://www.energia.ru/energia/history/museum/museum.html (both accessed 5 May 2005).

19 Vetrov, G, 'S. P. Korolev i razvitie muzeev po kosmonavtike', in note 6, pp195–200

20 Chernyi, I, 'Muzei RKK "Energia"', *Novosti kosmonavtiki*, 5 (1999), p59; Nikulin, A, 'Muzei RKK "Energia"', *Novosti kosmonavtiki*, 4 (2005), pp70–72

21 Other museums included that of the S A Lavochkin Scientific-Production Association (NPO Lavochkin), which built all of the Soviet Union's latter-day deep-space probes. Founded in 1965, the Lavochkin museum opened to the public in the 1990s. See Kopik, A, 'Muzei NPO im. S. A. Lavochkina', *Novosti kosmonavtiki*, 5 (2005), pp70–72; http://www.laspace.ru/rus/museum.php (accessed 5 May 2005). The Gagarin Cosmonaut Training Centre, officially subordinate to the Russian Air Force, also opened its own museum at Zvezdnyi gorodok ('Star City') outside Moscow. See http://www.museum.ru/M491 (accessed 5 May 2005).

22 Kuzin, E N, note 6, p108

23 Martin, D, 'Space artifacts of Soviets soar at $7 million', *New York Times* (12 December 1993), p47. For catalogues of the two Sotheby's auctions, see *Russian Space History, Sale 6516: Property of the Industries, Cosmonauts and Engineers of the Russian Space Program* (New York: Sotheby's, 1993); *Russian Space History, Sale 6753* (New York: Sotheby's, 1996).

24 Higgins, A, 'Why a spaceship landed in Bahrain and never departed', *Wall Street Journal* (11 April 2005), p1; Dolgov, A, 'Gagarin diary sold for $170,000 "stolen from Russia"', *Foreign News* (11 May 2001), p16. A small portion of the artefacts on sale at these various auctions were purchased by the billionaire Ross Perot's Perot Foundation and then loaned to the National Air and Space Museum in Washington DC. See Burchard, H, 'Splashdown of Soviet artifacts', *Washington Post* (23 May 1997), pN55.

25 Holmgren, B (ed.), 'Introduction', in *The Russian Memoir: History and Literature* (Evanston, IL: Northwestern University Press, 2003)

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27 Chertok, B E, *Rakety i liudi* (Moscow: Mashinostroenie, 1994); *Rakety i liudi: Fili Podlipki Tiuratam* (Moscow: Mashinostroenie, 1996); *Rakety i liudi: goriachie dni kholodnoi voiny* (Moscow: Mashinostroenie, 1997); *Rakety i liudi: lunnaia gonka* (Moscow: Mashinostroenie, 1999)

28 Chertok wrote openly for the first time in the journal *Aviatsia i kosmonavtika* (*Aviation and Cosmonautics*) in 1988. In 1992, *Izvestia* correspondent Boris Konovalov prepared a series of publications based on interviews with Chertok, which had the general title 'U Sovetskikh raketnykh triumfov bylo nemetskoe nachalo' ('Soviet rocket triumphs had German origins'). See *Izvestia* (4 March 1992), p5; (5 March 1992), p5; (6 March 1992), p5; (7 March 1992), p5; (9 March 1992), p3.

29 For only a small sampling of recent space-programme memoirs, see Filin, V M, *Vospominania o lunnom korable* (Moscow: Kultura, 1992); Khrushchev, S, *Nikita Khrushchev: krizisy i rakety: vzgliad iznutri: tom 1 i 2* (Moscow: Novosti, 1994); Kerimov, K, *Dorogi v kosmos (zapiski predsedatelia Gosudarstvennoi komissi)* (Baku: Azerbaijan, 1995); Filin, V M, *Put' k 'Energi'* (Moscow: GRAAL, 1996); Zakharov, A G, *Kak eto*

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31 Trofimov, V F, *Osushchestvlenie mechty* (Moscow: Mashinostroenie 'Polet', 2001); Evteev, I, *Operezhaia vremia: ocherki* (Moscow: Bioinformservis, 1999)

32 Siddiqi, A A, 'The rockets' red glare: technology, conflict, and terror in the Soviet Union', *Technology and Culture*, 44/3 (2003), pp470–501

33 Vetrov, G, 'S. P. Korolev i razvitie muzeev po kosmonavtike', in note 6, p199. Some of the original artefacts were returned after the secretary of the local Moscow Communist Party (*obkom*), V I Konotop, expressed displeasure over the changes.

34 For a critical look at Glushko's revisionism, see Nazarov, G, 'You cannot paper space with roubles: how to save billions' (in Russian), *Molodaia gvardia*, 4 (1990), pp192–207.

35 Rakhmanin, V F and Sterpin, L E (eds), *Odnazhdy i navsegda...: dokumenty i liudi o sozdatele raketnykh dvigatelei i kosmicheskikh sistem akademike Valentine Petroviche Glushko* (Moscow: Mashinostroenie, 1998), pp103, 174–6

36 For a historical look at the 'contemporaries' genre, see Walker, B, 'On reading Soviet memoirs: a history of the "contemporaries" genre as an institution of Russian intelligentsia culture from the 1790s to the 1970s', *Russian Review*, 59 (2000), pp327–52.

37 See, for example, Ishlinski, A Yu (ed.), *Akademik S. P. Korolev: ucheni, inzhener, chelovek* (Moscow: Nauka, 1986); Filina, L A (ed.), *'Byl veku nuzhen Korolev': Po stranitsam arkhiva Memorial'nogo doma-muzeia akademika S. P. Koroleva* (Moscow: MDMA Koroleva, 2002). Korolev's daughter Natalia Koroleva has also published a two-volume biographical work on her father. See *Otets: kniga pervaia* (Moscow: Nauka, 2001) and *Otets: kniga vtoraia* (Moscow: Nauka, 2002).

38 For the massive 'memoirs of contemporaries' collection dedicated to Glushko, see Rakhmanin, V F and Sterpin L E, note 35. Glushko's son Aleksandr Glushko has published numerous pieces in the journal *Novosti kosmonavtiki* (*Journal of Cosmonautics*) deifying Glushko and all the personalities connected to his legacy.

39 See, for example, Evteev, I, note 31; Evteev, I, *Zolotoi fonda akademika Chelomeia: dokumental'nyi ocherki* (Moscow: Bioinformservis, 2004); Khrapovitski, D (ed.), *General'nyi Konstruktor Akademik V. N. Chelomei* (Moscow: Vozdushni Transport, 1990).

40 For a look at nostalgia for Communism, see Efimova, A, 'Communist nostalgia: on Soviet aesthetics and post-Soviet memory', PhD dissertation, University of Rochester, 1998.

41 See, for example, Paperno, I, 'What can be done with diaries?', *Russian Review*, 63 (2004), pp561–73; Hellbeck, J, 'The diary between literature and history: a historian's critical response', *Russian Review*, 63 (2004), pp621–9.

42 See many of the essays in McGaw, J A (ed.), *Early American Technology: Doing and Making Things from the Colonial Era to 1850* (Chapel Hill, NC: University of North Carolina Press, 1994). The use of diaries has been particularly important for explorations of gender and technology. See, for example, Maines, R P, *The Technology of Orgasm: 'Hysteria', the Vibrator, and Women's Sexual Satisfaction* (Baltimore, MD: Johns Hopkins University Press, 1999). For methodological considerations, see Asner, G, 'Researching the history of technology at the Hagley Musuem and Library', *Technology and Culture*, 44/4 (2003), pp762–77.

43 Particularly noteworthy are the diaries of Nikolai Kamanin, who managed cosmonaut training from 1960 to 1971. With the sponsorship of private publishers, his son published four volumes: *Skrytyi kosmos: kniga pervaia, 1960–1963gg.* (Moscow: Infortekst IF, 1995); *Skrytyi kosmos: kniga vtoraia, 1964–1966gg.* (Moscow: Infortekst IF, 1997); *Skrytyi kosmos: kniga tret'ia, 1967–1968gg.* (Moscow: Novosti kosmonavtiki, 1999); *Skrytyi kosmos: kniga chetvertaia, 1969–1978gg.* (Moscow: Novosti kosmonavtiki, 2001).

44 Notable collections include those of engineers Boris Chertok, Konstantin Feoktistov and Oleg Ivanovski, all of whom worked for Sergei Korolev.

45 James Oberg quoted in *Russian Space History, Sale 6516*, note 23, description for Lot 29.

46 Wilford, J N, 'Soviet space papers going on sale', *New York Times* (5 December 1993), p36; Martin, D, note 23

47 The relevant exhibit can be seen at http://www.nasm.si.edu/exhibitions/gal114/SpaceRace/sec300/sec360.htm (accessed 9 May 2005).

48 For details of the 'request for proposal', see http://prod.nais.nasa.gov/cgi-bin/eps/synopsis.cgi?acqid=115760 (accessed 7 June 2005). The project also encompasses translating two notebooks of another senior engineer from the Soviet space programme, Konstantin Feoktistov.

Martin Collins

The Iridium communications satellite: an artefact, system and history in the 1990s

'Well, Iridium was basically Bary [Bertiger's] idea. He came in with this one-line idea. [Laughter] You could describe it in one sentence, you know, about a small satellite system to effectively have a space-based cellular radio system. It was just an idea, a one-line idea...'

Kenneth Peterson, Motorola engineer and co-inventor of Iridium, NASM Oral History Interview, 2000

'This is not just a phone; it is a vision.'

Robert Kinzie, Chairman, Iridium, Inc., 1992

Introduction

Let's start with an unsurprising claim: the collecting of, display and meaning given to artefacts in technology museums is inseparable from historiography – the narratives, explanations and concepts historians employ to talk about history. But this claim of 'inseparableness' is not without its tensions – despite the fact that academically-trained historians often are those who preside over artefacts in museums. One such tension concerns the status of the artefact in history, a central question for a museum, often peripheral for the discipline of history of technology.[1] Is the artefact evidence, a material entrée into the fine-grained world of inventor, problem and creative response? Or, does it stand (primarily or merely) as reminder, an expression of authenticity, a concrete symbol of an achievement or failure, a person, or historical moment – a representation of the interplay between innovation and culture? If an artefact's value and meaning lean towards the textual, symbolic or cultural, the museum seems to lose the possibility of a distinctive, fundamental role in the history of technology as discipline. The museum and the artefact each become one more conveyor of texts in a culture defined by texts. In this view, artefacts perhaps serve the same illustrative purpose as the several pages of photographs tucked into a typical academic or general-audience history book. They are not in and of themselves as material objects a source through which the discipline creates narratives of explanation or accounts of historical change.[2]

The artefacts 'tension' suggested in this simple characterisation has two roots. One is *historiographic*: the fundamental explanatory orientation of the field has shifted. Internalist history, with its focus on discrete, material, geographically and time-bounded acts of innovation by a lone inventor or by small groups, long ago yielded to a culturally-oriented historiography. For the latter the goal has been to explain cultural change – the ways in which the specifics of innovation, and more broadly the activities of science and technology, both embody and participate in the making of culture. In the shift to 'culture' the causes and contexts of innovation seem less easily bounded.[3]

The second aspect of the problem of the artefact is *historical*: different periods of history raise different considerations on how to relate innovation, artefacts and culture. In the Cold War era and its commercial, globally-oriented aftermath, the organising concept of system has been central to many technologies, especially space technologies – the US ballistic missiles programmes and Apollo programme are well-known exemplars. This systems emphasis has deep implications for technology museums. Individual artefacts so situated derive meaning primarily in the context of the system of which they are a part. Such systems, often state-sponsored, sporting big budgets, and using skills and materials from many institutions, often have been vast cultural enterprises, explicitly composing and intermingling ideology, politics and technology. Even more, authors including Thomas Hughes, Langdon Winner and Ulrich Beck have argued, in different ways, that post-Second-World-War systems in their many interlocking manifestations define a new mode of personal and social life.[4] In this historical frame, individual artefacts thus testify to multiple and complex acts – with those that are textual often predominating (in number and importance) over those that are material or directly centred on the artefact. To the degree one might discern the discrete bounded acts of innovation characteristic of internalist historiography, they are embedded in an extended web of cultural and political choices and assumptions.

This essay is an exploration of one such system artefact – an Iridium communications satellite. The Smithsonian's National Air and Space Museum artefact (Colour plate 9) was the first of tens of Iridium satellites constructed by Motorola, a US Fortune 500 company. The satellites were and are signature components of a global, space-based cellular telephone system developed, built and orbited from the late 1980s to the late 1990s – a system still in operation into the twenty-first century. The museum satellite and its in-orbit companions bridge the Cold War era and its aftermath, a period in which private markets and corporations entered into big technology projects, complementing or supplanting state-sponsored initiatives and creating new combinations of the technical and cultural. This essay aims to trace the web of acts and meanings that link the Iridium satellite as artefact, system and culture in the 1990s. Three overlapping yet contrasting frames of reference will be emphasised: the satellite as symbol of post-Cold War culture, especially in terms of innovations in communications as a defining element of that culture; the satellite as exemplar of systems; and, lastly, as a challenge in manufacture.

Born together: Iridium and the post-Cold War moment

The Kenneth Peterson quote at the beginning of the essay suggests that Iridium came into the world via a classic act of heroic invention – at least according to Iridium lore. In 1987, three engineers at Motorola – Kenneth Peterson, Raymond Leopold and Bary Bertiger – grappled with a problem posed by Bertiger's spouse: why could you not make a phone call while sitting on the beach in the Bahamas to your office in the US (or elsewhere)? The question combined the burgeoning expectations for cellphone technology (then confined to major urban areas) as well as the emerging information-era sensibility of monitoring and controlling professional responsibilities while engaged in leisure activities. In response, the three conceived the idea of a space-based, global system of satellites to provide a cellular telephone service to any point on the Earth's surface, sketching and handwriting the concept on a couple of sheets of paper (Figure 1). In this narrative, their idea gained material expression 11 years later in 1998 through an imaginative response to a problem, perseverance, luck and timing.[5] These graphics from the mid-1990s convey two perspectives of Iridium as system – as satellite constellation (Colour plate 10) and as communications system that could act independently of and integrate with ground-based telephone networks (Figure 2).

Two aspects of the 1987 'eureka' bear mention. One is that the idea from its inception focused on a complete system – not a component or portion of a system (such as a satellite). The primary inventive act was conceptual, unrelated to any specific material, technical problem – it was oriented toward envisioning a future market.

The second aspect is contextual. The three Motorola inventors worked as part of a relatively small Systems Engineering Group situated within Motorola's Government Electronics Division devoted to contract work building electronic subsystems for military and intelligence programmes primarily, as well as for NASA projects. The division was a small slice (approximately 10 per cent) of Motorola's largely commercial portfolio.[6] The Systems Engineering Group had been created to look for new business concepts for government or commercial markets – a recognition that declining Cold War budgets already had and would continue to undermine the division's long-standing sources of support. Study and assessment of the idea took nearly three years – to articulate more precisely the system's technical aspects, as well as the market context (commercial or governmental) through which it might be developed. Not surprisingly, given the idea's origins in Motorola's government

Figure 1 Engineering notebook, signed by Iridium inventors Bary Bertiger, Kenneth Peterson and Raymond Leopold. (Motorola Museum)

unit, the group first pitched the project to the US military. But as late-Cold War budgets tended firmly downward, the group quickly began to frame the project as a commercial undertaking. The birth and early development of a proposed system for cellular global communications thus coincided with and embodied the historical moment. Iridium's emergence stood as a microcosm of the tangled interconnections among big business, big technology and the changes that roiled politics, international trade and foreign policy during the 1980s and 1990s, with the tearing down of the Berlin Wall in 1989 an iconic and practical watershed. With the end of the Cold War, the turn toward privatisation and markets that gained increasing acceptance during the 1970s and 1980s became, in the 1990s, the dominant political philosophy. From its inception, the Iridium system was invested with the multiple, sometimes conflicting, meanings and connections of this sea change in culture and politics.

During this three-year period of internal assessment, Motorola kept a low public profile on its aspirations for the project. In June 1990, Motorola unveiled Iridium to the public. Reflecting a building enthusiasm (at least in media and political circles in the US and Europe) for the beneficial transformations private markets and communications technologies might stimulate, the roll-out was splashily global. Four press events were held simultaneously – in London, Melbourne, Beijing and New York City, a nod to the project's geographic scope and the realities of generating interest in key financial, media and political circles.[7]

The New York City event was the focal point. The renowned Hayden Planetarium played host, adding a historical echo to the new venture – in 1951 the Hayden hosted the Symposium on Space Travel, a first-of-its-kind event that helped galvanise public interest in space exploration well before the launch of Sputnik in 1957. Iridium seemed a marker of a new phase in the decades-long effort to gain mastery over the space environment. The private sector, through a leading American corporation, one that notably had no tradition of spacecraft or satellite manufacture, was confidently willing to initiate the most expensive business start-up in history to create a unique infrastructure in space. The message: the market was now positioned to join, and perhaps supplant, government in the exploitation of space and, by implication, to bring individuals, as entrepreneurs and consumers, closer to the space experience. More broadly, the venture offered an exclamation point to the possibilities of the market, of an age in which entrepreneurship and technology might subsume the globe, making the control of time and distance a consumer option. These messages quickly gained amplification: within months of the Iridium announcement several other firms announced their plans to provide global telephone and data services.[8]

Technology, corporations and markets stood out as compositional elements of the global milieu of which Iridium was a part. But central to and deeply embedded in this triumvirate was the techno-cultural phenomenon of communications. At the time of Iridium's beginning, the personal computer, the Internet, the World Wide Web, cellular telephones, undersea fibreoptic cables, satellite communication (especially as it related to direct-to-home TV and immediate 'you are there' long-distance news coverage) were all nascent as technologies or as ubiquitous services or commodities. But individually and as a collective development, they had become imbued, through the 1980s and into the 1990s, with rich cultural symbolism – a symbolism that fused technological advances with the possibility of reinvigorated individual liberty and expression.[9]

Figure 2 Overview of communications using the Iridium system. (Iridium Inc.)

A press already enamoured of markets, communications technologies and their possibilities responded to Iridium with enthusiasm. More than 1400 newspapers carried the 1990 announcement – many on the front page. The *New York Times* ran it on its front page with the headline 'Science fiction nears reality: pocket phone for global calls'. In good pop-culture fashion, the announcement, too, found its way into a Johnny Carson monologue and a Batman comic strip. The Beijing event received substantial play in China, running on the evening news. Approximately 250 million Chinese viewers heard parts of the Motorola press release and saw dubbed portions of a promotional video depicting how the satellite communications system would work.[10]

Soon after the press announcement Motorola established Iridium as a separate corporation, a 'start-up' in the parlance of the time, with the parent company controlling the largest single share of the enterprise. Within a few years, more than a dozen investors joined in, representing a diverse sampling of companies and countries around the world – including, prominently, China and the former USSR, the *personae non gratae* of the Cold War years. The price tag for this global venture eventually reached close to $7 billion – the most expensive privately-financed 'start-up' in contemporary business history. The venture's scope, representation and cost led *Wired* magazine in 1998 to dub the undertaking as the 'united nations of Iridium', a new market-driven reinvention of the state-centred United Nations.[11]

Motorola – through its history and standing as a successful high-technology company – seemed as ready-made as any business for implementing a world-view in which corporations and markets were

Figure 3 Cellular beam pattern created on Earth's surface by the Iridium system. (Iridium Inc.)

central. A Fortune 500 company, Motorola was then the third-largest electronics firm in the US and the largest manufacturer of cellular equipment in the world. It had sales offices around the globe and production facilities in more than 20 countries – including China.

The project's signature technical feature was a constellation of 77 satellites in low-Earth orbit – the '77', the same as the atomic number of the element iridium, and hence the source of the venture's name.[12] The orbiting satellites served as the equivalent of cellular towers, connecting to mobile customers below, using wireless hand-held phones (see Figure 2). As one of the founding engineers noted, the constellation 'bathed the planet in radiation', enabling a completely global phone system – a seeming teleological end point to more than a century of patchwork, geographically-limited terrestrial communications and to the not-fully-global system of satellite communications initiated in the 1960s.[13] A schematic diagram of satellite-created 'cells' on the Earth's surface vividly conveys the technical achievement (Figure 3).

As Iridium got under way, its coverage in the media (primarily print and the newly-emergent domain of the Web) arced from spectacle and promise in 1990 to tragedy in 1999 and 2000 – when Iridium entered bankruptcy protection a mere nine months after its commercial launch in November 1998 and then re-emerged in late 2000 as a much smaller, much less ambitious company, with a new group of investors supplanting Motorola and its pan-national partners as owners. From this vantage, the story seemed to have a beginning, middle and end, and a second chance. It had vision, ambition, risk, luck, failure, a global stage, a cast of thousands, former enemies reconciled and shadowed connections between the military and commercial. Its rise, fall and partial resuscitation neatly bracketed the post-Cold War phenomenon, the boom and bust of communications in the 1990s.

In news accounts the Iridium origins story highlighted the Motorola engineers as exemplars of the inventive spirit and minimised the late-Cold War context of their activity. They sold the idea 'up' the corporate hierarchy over a period of nearly three years, with the newly market-oriented military division overcoming the doubts and resistance of Motorola's much larger and more important (in dollar and sales terms) commercial divisions. The 'little' guys persuaded corporate leadership to make the project a priority, which led to the worldwide announcement already described.

In the first years after the announcement, Motorola and the Iridium 'start-up' overcame a number of hurdles – gaining a series of national and international regulatory approvals for spectrum allocation and permissions to operate, acquiring several billions of dollars in financing from sources around the world, and organising and implementing, by the reckoning of the participants and the press, one of the most complicated technical projects ever attempted. Each of these steps pushed a crucial envelope of global transformation: the shift from government to private market and corporate ownership of communications services. Iridium often was at the vanguard of defining or benefiting from the creation of new legal and regulatory regimes to accommodate this transformation.[14] These challenges and their surmounting by Motorola and Iridium signalled, with exclamation marks, the market-sparked reshaping of the global landscape.

Successes in the political–media world were matched by accomplishments inside the factory. Satellites pulsed off the production line in late 1996 and early 1997 – at peak manufacture a fresh satellite appeared every five days, a radical departure from the prior industry standard of a two- to four-year cycle for producing a single satellite. During 1997 and 1998, rockets launched from Baikonur, Kazakhstan, Taiyuan, China, and Vandenberg Air Force Base, California, began to place tens of satellites into a communications constellation. A 1997 IPO (initial public offering) for common stock helped connect the enterprise to the mania for Wall Street and market wealth. The gateways – the national and regional franchises owned by international investors, sited around the world and responsible for selling iridium to real-live customers – readied for business. A worldwide advertising campaign preceded commercial service, which began in November 1998. But the target markets for the phone – primarily corporate business travellers – did not rush to buy in as expected. A slow-motion sense of collapse – historic, business-school-textbook-for-years-to-come failure – unfolded at real-time speed.[15] Phone and service sales stayed paltry compared to projections – and in a few months the result was financially catastrophic. In August 1999, Iridium filed for bankruptcy, sought to reorganise, but eventually collapsed in late 2000. Motorola planned to de-orbit the entire constellation, bringing the enterprise to a spectacular, eyes-to-the-heavens finale. A new investor edged in to buy the expensive system for pennies on the dollar – $20 million for the $7 billion system.

Iridium's collapse as a business had multiple causes, but revolved around an assumption that proved untenable. Motorola and Iridium anticipated that consumer purchase of the phone service would mirror the uptake of cellular telephones earlier in the 1990s, which displayed a substantial 'S curve' – that is, a rapid takeoff of sales in a short period of time. Bank loans made to Iridium (some of which were guaranteed by Motorola) assumed this analogy to cellphones and required substantial repayments in the first few months after initiation of commercial service. When Iridium sales fell short of the cellphone model, the banks demanded payments that Iridium could not meet, leading to bankruptcy. A mix of internal and external factors undermined the assumption of an 'S curve' model, including: a poorly organised sales effort, underproduction of cellular phones, the cost of individual phones and service contracts, the inefficiency of the gateway sales model, and perhaps above all, the maturation of ground-based cellular phone networks available at lower cost and with international coverage. Iridium's failure quickly became conflated with the 'dotcom' bust, a symbol of overreach and out-sized expectations.

A narrative thread tied this denouement to the project's beginning in the Cold War: the US Department of Defense (DoD) pushed for new ownership in the bankruptcy process and the preservation of the system. With the system's worldwide, almost-anywhere capabilities, the DoD expressed interest in Iridium from its conception, signed a multimillion-dollar contract when the system went commercial in 1998, and, in a mirror image of the commercial Iridium, had its own separate gateway in Hawaii to facilitate communications. Motorola also designed telephones for encrypted communications. The DoD renewed its original contract in 2000 to help new ownership commit to a post-bankruptcy company. In the aftermath of September 11, Iridium (now called Iridium Satellite in its reincarnated form, with all ties to Motorola and the original investors severed) has enjoyed its best financial moments, boosted by an increasing flow of military and other government business, as well as increased use by the media in covering the Afghanistan and Iraq wars.

Culture in and through the artefact

Of course, nearly all artefacts may be threaded into a larger narrative and serve as compact bearers of symbols and cultural preoccupations. Iridium, in this sense, perhaps conveys rich associations by virtue of its timing – as a venture inseparable from a broad reconfiguration of relationships among technology, culture, business and politics. It neatly captures notions of the global, the virtues of markets and the rhetoric of empowerment attached to new communications technologies – as well as concerns about the concentration of power in corporate hands

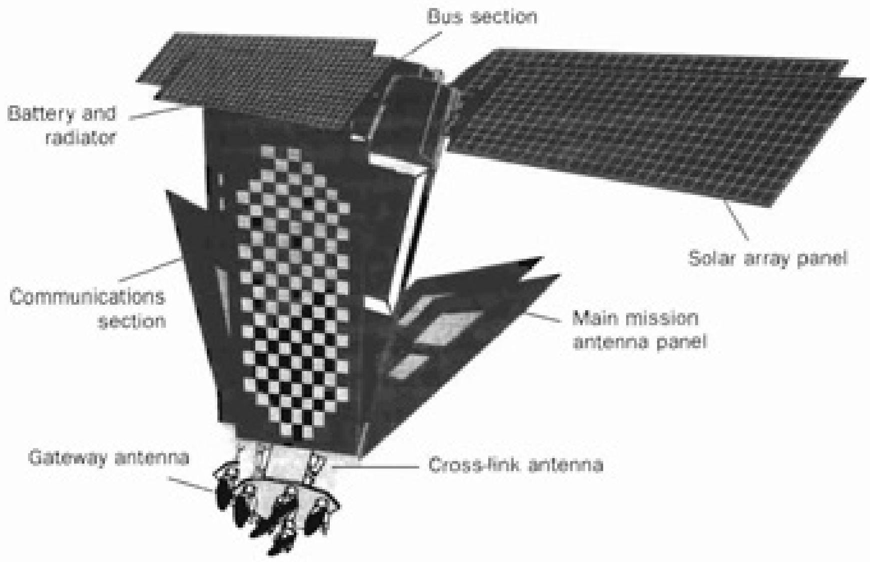


Figure 4 Schematic diagram of Motorola Iridium satellite in its deployed configuration. (Motorola)

and economic inequities on a transnational scale. As technology and artefact, though, the Iridium system – and the satellites, in particular – was more than a vessel carrying a cultural story. The satellites' design, manufacture and organisation embodied in specific ways the milieu of which they were a part.

But as a museum or a curator, how might one see such embodiments – of culture in the artefact and the making of culture through the artefact? A simple 'reading' of the artefact, at most, suggests questions for exploration – for example: Why was the satellite built to this size and configuration? Why was it designed with three types of antenna (phased array, cross-link, and telemetry, tracking and control)? Why do two sides of the spacecraft each sport a large aperture that remains open even in orbit (look closely at Colour plate 9 for the apertures and see Figure 4 for identification of the satellite's main components)? Answers to such questions are bound up in the notions of Iridium as a system and as an expression of 1990s culture. As with any 'big technology', though, pursuing those answers is not straightforward. In the Iridium case, project documents are voluminous and mostly inaccessible – Motorola, as with most companies, judiciously guards its corporate records.[16] The cast of characters often is large and decision-making dispersed across institutions and geographically. Also, the nature of modern corporate and technical communications leans toward the spare (think of PowerPoint briefing slides), obscuring the context in which ideas and choices develop. One partial antidote, used in this study of Iridium, is structured oral history – an approach that is a practical as well as an epistemological strategy. Participants provide a level of meaning unavailable in the written record (even if it was comprehensively available). A cross section of interviews spanning working-level engineers and a variety of managers and different institutions has been used to offer insight into the interconnections among artefact (the material expression of specific choices), system and culture, into the tacit as well as explicit characteristics of the venture.

These interviews have yielded two broad, overlapping frames of meaning for understanding the Iridium satellite as artefact and history. One is the interrelation between design choices (of the satellite and the system) and assumptions about the global. The other centres around the notion of 'manufacturability' – the ideas and techniques that informed project management. The latter concern derived from Iridium's distinctive need to produce and launch tens of satellites over a one- to two-year time frame. In the 30 years prior to Iridium, satellites were craft technologies and typically required several years to produce a single spacecraft. The 'how' of satellite manufacture loomed as a central problem, affecting the relation of design and manufacture, the ways in which Cold War techniques for project management were adapted for market-oriented big technology, as well as the norms and expectations that structured the work of engineers and managers. The NASM's Iridium satellite particularly captures this latter context: it was the first satellite produced at a specially-designed Motorola manufacturing facility in Chandler, Arizona, and served as a test of innovations in 'manufacturability'.

Iridium's design and notions of the global

As Iridium took shape in the late 1980s and early 1990s, the idea and rhetoric of 'globalism' already had gained wide currency.[17] But it was a descriptor that bundled together assumptions, corporate and market practices, and national and international policies that still were contingent, in flux, in the process of codification. Iridium was part of this process, invoking and grappling with the particulars of engineering (in both senses of the term) the global. Two senses of the global pervaded Iridium. In the foreground was that of transnational markets and the day-to-day business activities of transnational corporations. In the background was the global presence of the US government, particularly the military. Motorola saw Iridium as a response to both as categories of global business activity.

As the venture developed it maintained a careful ambiguity on whether Iridium was a global mass-market product (and, thus, as with the Internet, was a communications technology with broad implications for personal and political transformation) or pitched at a more specialised niche.[18] Indeed, Iridium was conceptualised and designed in its technical specifications to serve a very particular class of users – international business travellers, especially those from the US, Europe and Japan. The new levels of international business activity in the 1980s created, in the eyes of Motorola, a substantial and likely increasing number of business officials on the move across the international landscape, predominantly flowing from developed to undeveloped countries, and in need of improved communications options. This insight came out of the international travel experience of those at Motorola who conceptualised Iridium. In the early 1990s, the company had facilities in more than 20 countries and sales offices in tens more – its own needs seemed emblematic of the potential for mobile, wireless communication in a world increasingly defined by the pulse of international business activity.

To satisfy such travellers, the Iridium system would have to meet one seemingly quirky criterion – it would have to enable a voice transmission from inside an automobile as a caller traversed from an international airport into its adjacent city (most such airports were sited outside cities). The goal was to enable a call back to the home office or other site to coordinate global business among relevant staff. The entire technical specification of the Iridium system was designed to meet this scenario. The crucial design element was creating sufficient 'link margin' – that is, radio signals with enough power – to meet this specific, perceived service need.[19] Determining this link margin then determined every other facet of the system – the numbers of satellites, their size, their power, their antenna design, all grounded in a particular construction of how global business practice operated and would operate in the future.[20]

Adhering to this criterion resulted in a substantial redesign of the entire system. As noted above, when the system was announced in 1990 the satellite constellation comprised 77 satellites, arranged as 11 satellites in 7 orbital planes, with near-equidistant spacing, each tracking over the Earth's poles. In 1992, tests on the ground and from aircraft indicated that the initial design did not provide sufficient link margin to meet the baseline criterion – the satellite electronics and cellular antennas did not generate a sufficiently powerful signal. In this version, the satellite buses were hexagonal and the antennas integrated into the surface of the spacecraft. To generate signals of sufficient power the satellites were made larger, reconfigured to a triangular shape, and antenna panels, larger than the originals, were appended to the spacecraft. To keep the project at the same cost, the constellation was reduced in size, from 77 to 66, in a revised arrangement of 6 orbital planes, each with 11 satellites.

Satellite and system design reflected Motorola's sense of the global in other ways. In addition to the antennas used to communicate with Earth-based cellular phones, each satellite also had 'cross-link' antennas, used to communicate with satellites directly in front of or behind a given satellite in an orbital plane or with satellites in adjacent orbital planes. These antennas were integral to a distinguishing technical feature: on-board switching of communications signals – that is, routing of calls through the space system to a specified destination. Iridium, thus, could process calls in two ways: from one Iridium phone to another anywhere on the planet through the constellation (as a 'stand-alone' communications network), or by connecting an Iridium phone call to land-based (line or cellular) systems through a ground station that linked space and land-based networks.

While switching was a common element of land-based telephony, it had not been used in commercial communications satellites.[21] These satellites traditionally had been 'bent pipes' – they served as conduits positioned in geostationary orbit to relay communications from a given point on Earth to another point or region. To make communications satellites as reliable as possible they were designed as simply as possible – that meant no on-board switching capability. Significantly, Iridium's primary competitor in satellite telephony, Globalstar, followed this traditional standard. Satellites in its constellation acted as 'bent pipes', a design choice that required more than 20 ground stations to provide coverage, each of which provided the switching that Iridium performed in orbit. And given the expense of ground stations, Globalstar targeted its service to the most populous land areas, bypassing coverage over less-populated higher latitudes and over the oceans. Globalstar's design and business choices highlight Motorola's distinctive conception of the global as one embracing commercial and military activity over the entire planet.

But the ambition reflected in the Iridium system's design was balanced against the realities of the political landscape in the post-Cold War world. The constellation's on-board switching capability meant that processing calls through the system technically required only one ground station to link the network to land-based networks. Over most of the twentieth century, though, most countries controlled communications, either directly through state-run entities or through designated corporate monopolies (as with AT&T in the US). Iridium (or any communications venture) needed permission to send signals in and out of any national territory – and for a global service this meant the negotiation and arrangement of permissions on an unprecedented scale. Even with the move in the 1980s toward privatisation of communications, states carefully examined granting control over communications within their territories to foreign firms. Thus, as a matter of politics, Motorola and Iridium courted companies and state entities from nations around the world to participate – as investors to spread the financial risk of the project and as owners of gateways. The gateways served as inducements to support the venture. They acted both as technical entities that linked the constellation to ground-based communications and as business units that sold Iridium service in a particular region. In China, for example, such an arrangement was crucial to gain access to this market. The inclusion of 'not technically required' gateways greatly complicated the production of software to operate the system as well as the business structure of Iridium, each complicating the venture's possibility of success.

'Manufacturability': culture in the factory

Recall the artefact-based question posed earlier: why does the spacecraft have apertures that remain open to the space environment in orbit? A narrow, partial answer is straightforward: to allow workers ready, waist-high access to a satellite's interior to affix and test the communications payload during manufacture and checkout. But why does such a seemingly unsurprising objective have import? This and similar design and manufacturing choices in Iridium reflected a broad rethinking of the traditions and procedures for building satellites.

In the US, this tradition, 30 years in the making, developed around state-sponsored big technology. It established particular methods of project management, of the relationship between funding agency and prime contractor, of protocols for manufacture and test, and a variety of other organisational and technological assumptions. As applied to satellite manufacture, this methodology, as noted above, typically resulted in a time frame of several years for producing a single satellite. For Iridium, 'manufacturability', then, was a conceptual position that sought to question, reconfigure and adapt this prior set of practices and assumptions. More importantly, it aimed to take this reinvention and merge it with two overlapping developments of the 1980s: the methods of Japanese manufacture (especially as developed in the automobile industry) and new approaches to achieving high-quality and reliable products.[22] For the latter, Motorola codified and promoted a managerial and statistical technique called Six Sigma that was incorporated into Iridium. This hybridism was central to Iridium and yielded tension as the project applied old and new methods of management, design and manufacture.

The apertures in the spacecraft then were not just apertures. They represented materially a shift from state- to market-sponsored technology as well as a perceived imperative to respond and accommodate a new genre of market, the fluid competitive arena of the global. Motorola, as did other companies, saw these changes as a call to re-examine assumptions on a broad scale – from the organisation of a technical project on an international scale to the behaviour of workers on the factory floor.

From Cold War to post-Cold War: project, system and integration

In 1997, after several years of design and preparations, Motorola began producing Iridium satellites in its Chandler, Arizona, facility. In the parlance of the aerospace industry the factory 'integrated' satellites – a final, material expression of a years-long undertaking. 'Integration' is a term of art in the aerospace industry with deep technical and political meanings – it is the crucial activity of the project, its conceptual and managerial underpinning. As a companion to 'system' (one usually talks of systems integration), it represents a set of ideas, tools, actions that will compose a technology from a myriad of sub-technologies produced at multiple institutions, geographically dispersed and with different sets of expert knowledge and skills.[23] Integration presumes planning and control across space and time – from the initial steps of design to the end stages of manufacture. It is instrumental; each action, step and sub-step all build toward a specific technological end. Through attention to process, integration makes the production of big and complex technologies seem routine, and the remarkable social acts of organisation required seem unremarkable. What becomes 'integrated' thus encompasses institutions, disciplines, people and material things.

During the Cold War, the US military and NASA, wielding the political and financial sway of government purpose and authority, experimented with and advanced new ways of combining technological and social frameworks under the rubrics of systems engineering and the project. Early in the period, the challenges of large-scale project management – of integration – were the focus of substantial creative effort, spurred by the demands of military and NASA programmes. In the 1950s and 1960s, the media covered this innovation with regularity, marvelling at the creation of a new national capability – sometimes expressed through the sometimes optimistic, sometimes ironic question, 'If we can send humans to the Moon, why can't we eradicate poverty or cure cancer or (fill in the blank)?' By the end of the Cold War, the techniques of project management (at least in their government-oriented manifestation) had become commonplace, readily known and applied as needed, at least within the aerospace community and allied industries.

Iridium was deeply connected to this history – through its mode of organisation and through institutions and individuals. A subset of Motorola's Government Electronics Division provided the managerial and engineering expertise for defining, designing and building the system under contract to the Iridium 'start-up' business. This arrangement emulated, with a commercial, self-referential twist, the basic formulation of the Cold War project – a rough separation, at least on paper, between a project and the political and funding environment of which it was a part. But as lead investor in Iridium the corporation, Motorola controlled both sides of the institutional equation. The Motorola group thus exercised powerful influence over development of the entire effort.

In the earliest phase of the project the market-oriented question 'Will it be profitable?' was balanced with the techno-organisational question 'Could it be built?' And the basic resource in answering the latter was knowledge of the techniques and practices for implementing big technology projects – questions of management and process. Iridium connected to this prior experience through two channels. One, noted above, was the project's origins in Motorola's government service division. This division, as with similar divisions in other firms oriented toward military product lines, primarily subsisted on contract. In the case of Motorola, the Department of Defense, National Security Agency and NASA were key patrons and it was the prospect of diminishing government dollars that spurred this Motorola division to contemplate reinventing itself for the commercial world – a recurring and familiar story throughout the Cold War as the availability of contract dollars cycled through highs and lows. The other channel linking Iridium to project tradition was through personnel who joined the project – several of the key people who managed Iridium's system design, manufacturing and cross-institutional coordination and contracts came from the US Air Force as leaders of military projects, a demographic shift of expertise from the state to the market at the end of the Cold War.

But Motorola adapted this legacy in key ways – reflecting intertwined conceptions of markets, the global and the technological. The Cold War project was a creature that sought to coordinate and control geographically-dispersed, heterogeneous activity through the management of information and institutions – through techniques such as centralised control of systems design, configuration management, schedules and, of course, contracts. It was a form and a set of processes designed to coordinate institutional inputs and only secondarily to alter organisational, individual or professional conceptions of work. Iridium, in contrast, saw the values, norms and work of individuals, and in correlation the culture of the firm, as essential sites of action and experimentation.

As a commercial undertaking, though, the project was not a cross-institutional, cross-disciplinary tool to advance the state of technological art or scientific knowledge. Iridium explicitly was conceived to use underlying technologies that had proven their workability – although the system might use such technologies on a new scale (for example, on-satellite switching processors for directing calls around the network) or in new applications (such as phased-array antennas – a crucial technology in establishing cellular communications between the satellites and the Earth's surface – which had only been used in Earth-based applications previously). This was to ensure greater predictability and control over costs and schedule, and thus to reassure potential investors that the project could provide a return on capital. The history of state-sponsored Cold War projects that pushed scientific or technical boundaries proved, as Motorola and others knew, almost always to exceed expected costs and development times.

'Manufacturability': the problem of culture

One approach to gain purchase on the terrain of the 1990s and the adaptation of the Cold War project to an era of global markets is to look at the ways in which the categories of the technical and the cultural were constituted in the Iridium project and the problems and ideas that informed this process. During the 1980s, at Motorola and other firms, an article of faith took hold: that there was a correlation between the internal life of the corporation and the ability to participate in global markets. This concern derived from specific trends and experiences that occurred during the 1970s and 1980s: a shift towards deregulation in trade law and communications policy; the increasing role of transnational companies in shaping global markets; and the Japanese manufacturing challenge in electronics and automobiles – a challenge Motorola directly confronted in its semiconductor business.[24] In the US, the competitive success of Japanese firms gave rise to a simple equation that revolved around the concept of 'quality': Japanese companies produced products of superior quality; that quality derived from cultural factors – inherent in Japanese business methods and in Japanese society; US corporations produced products of lesser quality; thus, US corporations, in the context of transnational markets, had ill-adapted cultures. In anthropological terms, the missing element was a shared system of signifiers and symbols that conceptually and emotionally tied together individuals, practices, corporate goals and international markets.[25] Many large firms saw cultural ill-adaptedness as a problem to be analysed and solved. One result was an eruption of new managerial methodologies that promised remedy – Continuous Quality Management, Total Quality Management, Theory Z and more.[26]

Two features of this intellectual turn should be noted. One, it was not a critique of capitalism, but a purposive effort to insert culturally-grounded methodologies into the basic framework of profit.[27] Two, it identified an explicit relationship between the internal culture of the firm and performance in global, geographically-dispersed markets. Motorola responded to this evolving perspective perhaps more deeply than any other company. In 1986, it articulated a philosophy and set of practices it dubbed Six Sigma, designed to recast corporate culture to meet the changing relationships among markets, technology and business.[28] It conjoined several elements: a commitment to subject to analysis any and all business processes and practices (mantra: 'nothing is sacred'); an emphasis on the use of statistical methods to ground such analyses quantitatively (hence, Six Sigma – to reduce errors to a statistical variance of 3.4:1,000,000); and to train each employee – from the shop floor to managers – to use the method and then charge them to reshape their immediate work environments. In theory, all employees had one beacon: to uncover, and then improve, defects in products and processes, technical and non-technical. The Six Sigma way was a blend of analytical rigour, empowerment ideology and symbolism – the core of a corporate language intended to fuse together business strategy, technical practice and individual behaviour and commitment. Terminology reinforced the notion that individuals and work teams were the foundation of a larger corporate and international market culture; for example, Six Sigma adepts were designated 'black belts' as an analogy with the martial arts and a rhetorical echo of the Japanese challenge.

This interest in and commitment to notions of culture in the corporate setting found expression in another crucial way. In 1989, Motorola established Motorola University as a central component of this endeavour. Its mission was to thoroughly integrate and sustain Six Sigma in the life of the corporation. The university was one, notable instance of a larger trend: over a decade, from the mid-1980s to mid-1990s, more than a thousand corporate universities were created in the US – all of which were a response, in one fashion or another, to the perceived culture problem.[29] Iridium, conceptualised over the period 1987–90, was an inextricable part of this context. Indeed, the perception of the project as globally revolutionary reinforced this notion that a self-reflexive, adaptive corporate culture generated effects that rippled outward across the world stage.

One might view these developments through the long-running discussion beginning with Weber, Veblen, Frederick Taylor and Henry Ford on the relationship among workers, managers, bureaucracies, markets and states, on the striving of modern institutions for rationalisation and efficiency. The difference, perhaps, is that in the 1970s and 1980s many disciplines and social groups began to invoke culture as a descriptive and analytical category.[30] Frederic Jameson, in a seminal 1991 book, observed that for authors committed to the idea of a postmodern condition, culture had become a 'veritable second nature'.[31] By the mid-1980s, Motorola came to a similar point of view – but framed in terms of the technical, organisational and business interests of the corporation. Culture and the rhetoric of culture became a strategic tool to create new ways of corporate life.

In Iridium, this focus on cultural rather than discrete technological problems may seem odd. Iridium was a sprawling technological system, with many 'first' features and problems – ranging from designing a global communications system and optimising its thousands of components to developing software to run customer billing operations that accounted for the telecommunication policy idiosyncrasies of every country in the world. But unlike many of the state-sponsored examples of Cold War big technology, Motorola did not have to overcome a set of critical 'make-or-break' technical problems to realise the end system – systems managers and engineers, as a design strategy, chose only technologies that were well behaved or at least previously tested. The key challenge was management: organising and motivating the many actors involved – Motorola, contractors, subcontractors, and financial and political sites around the world – to build and integrate the system within specific money and time constraints.

In pursuing the project, Motorola viewed this new Six Sigma-based culture as its crucial asset. Most of the leaders of the Iridium project had worked on company defence and intelligence contracts for communications subsystems. They had no commercial experience, no experience in executing large, complex technical systems. Their advantage, they believed, was the Six Sigma way of looking at the world, the value of which the market and competitors had begun to ratify. During this period, Motorola's cellular products and services were dominating the market. Within this context, Iridium project managers had a significant insight: that after more than 30 years of organised effort, spacecraft systems, particularly communications-satellite systems, were well understood. Each new project need not be viewed as an R&D effort, requiring a multi-year process of design, development, tests, manufacture and more tests.[32] The technical and management knowledge associated with state-sponsored big technology could be translated, rationalised and subsumed into the Motorola framework and reconstituted as market-oriented big technology.

Such thinking informed the initial formation of the project. Motorola selected Lockheed and Raytheon as partners in the Iridium project – the former to build spacecraft buses, the latter the spacecraft phased-array antennas. Motorola performed system design and overall integration, thereby controlling the project, and also contributed the communications payload, their in-house technical forte. One part of the price of admission was a commitment to accept and thoroughly adopt Motorola's idea of project culture, based on Six Sigma. Over the period 1991–95, the company took a series of formal and informal steps to indoctrinate contractors and subcontractors – to create a lived commitment to a way of thinking, working and interacting. The goal was to identify and realign assumptions, processes and social boundaries to harmonise the established knowledge on developing space-based systems with market requirements for meeting schedule and cost estimates, product reliability and global scope. An outline of the results of this process can be seen in a series of graphics prepared by project designers as they described and promoted their methodology to contractors, potential investors and professional and academic audiences.

The notion of the virtual factory (Figure 5) encapsulated the Motorola approach. The trope of virtual-ness was not meant to convey that these heterogeneous, geographically-dispersed institutions were linked via contract, or in a computer-age sense, via information umbilici. Rather the project's likeness to a factory was that all its elements – from Chandler, Arizona, to Baikonur, Kazakhstan, and Taiyuan, China, shared a common set of technical practices. These practices, employee behaviours and commitments, and a market-oriented view of the world, constituted a project way of life. The virtual-ness of the factory was that this way of life could

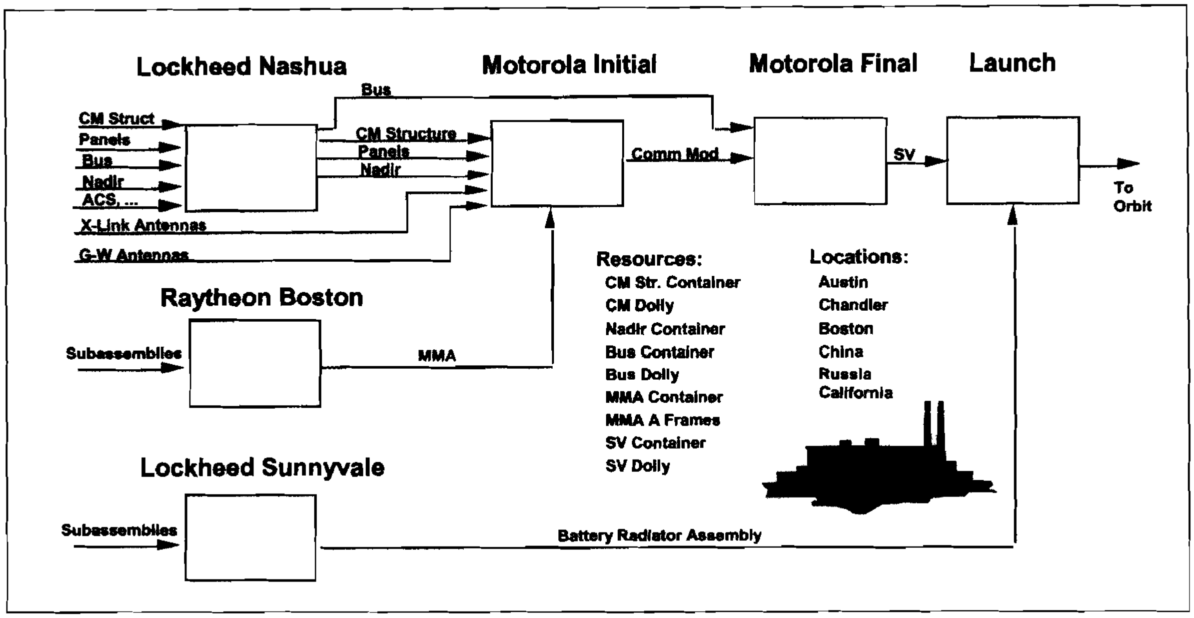
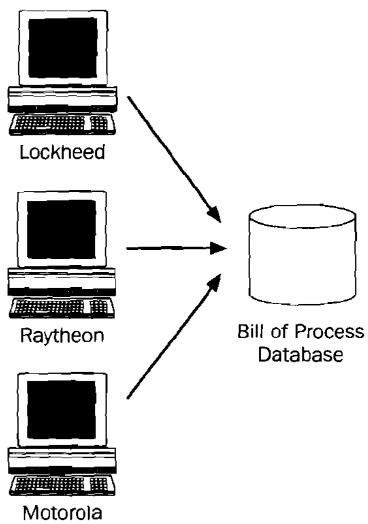


Figure 5 The virtual factory. (Andrew Feller)

be transported and replicated, albeit with difficulty, to disparate institutions and cultural sites. The trope of the factory performed work too. It strengthened the idea that the project established new social boundaries, drawing in and redirecting elements of other institutions, into a new, substantive community.

The emphasis on process – that is project actions analysed, broken down into constituents, reconfigured for the market ends of cost, schedule and quality, a cycle iterated again and again – was the key departure from state-oriented project management (see Figure 6, which shows the core idea of this approach, a complete database of thousands of discrete process steps, and Figure 7, an 'exploded' view of one process activity). And it was through this emphasis on process that the individual – from low-level subsystem tester to project manager – became fundamentally integrated into the project culture.[33] In Figure 6, note that individual names (in project terms 'ownership') are attached to each process step.

The attention to process and culture was a mutually supporting enterprise. The process emphasis allowed a connection between a set of technical practices and a symbolic frame of shared values and commitments – a frame that served to define work life at local sites and connect it to the instrumental transcendent ethic of the 1990s market: that you could do well and do good, make a profit and spur a liberal democratic remaking of the world. Motorola, and other firms, tailored the concept of culture to meet the perceived challenges of global markets, a strategy that only intensified with the collapse of the Soviet Union. In Iridium, this concept of culture associated with Six Sigma led to a new methodology of project execution, a new



IRIDIUM SPACE VEHICLE BILL OF PROCESS

Sequence Level	Process Name	Cycle Time	Location	Person - Process
5790	Pack and Prep Battery	4	Sunnyvale	Kevin Bilger
6000	LAUNCH SITE HEADER PAGE	0	Launch Site	JORDAN
6057	Transport SV/Dispensor to Launch Complex	8	Launch Site	Jeff Finan
1280	Thermal Cycle	52	Boston	Paul Babbit
5070	SV Liveness Test	6	Chandler	Hyrie Bysal
6020	SV Confidence Test	4	Launch Site	John McBride
1210	Attach Velcro Strips to Panel	0.7	Boston	Richard Russo
1040	Dispense Adhesive & Assemble Patches	.575	Boston	Richard Russo
1060	Assemble and Bond T/R Modules	.57	Boston	Richard Russo
1230	**Lay Thermal Blanket Over Panel Back**	**0.2**	**Boston**	**Richard Russo**
229.1	COM MODULE, Propulsion System-Weld	5.75	Austin	Machine Operator
239.1	BUS MODULE, Propulsion System-Weld	4.95	Austin	Machine Operator
1050	Attach Patch Hold Down Fixture	0.2	Boston	Richard Russo
1230	Lay Thermal Blanket Over Panel Back	0.2	Boston	Richard Russo
5800	Ship From Sunnyvale	168	Sunnyvale	Jordan Snyder
6035	Receive Flight Battery Radiator Assembly	2	Launch Site	John McBride
1260	Element Test	18	Boston	Paul Babbit
1070	Bond and Assemble Drive Modules	1.4	Boston	Richard Russo
1090	Bond and Assemble Power Regulators	3	Boston	Richard Russo
243	BUS MODULE - Propulsion System Purge and Seal	0.91	Austin	Assembler
1290	Calibration Verify	16	Boston	Paul Babbit
6120	Charge Batteries	10	Launch Site	John McBride
1330	Clean Panel and Pack	1.0	Boston	Richard Russo
4110	CS Functional Test - Station 8	48	Chandler	Mike Monteith
5030	Propellant Line Connection	7	Chandler	Hyrie Bysal
5031	Propellant Line Connection - Welding	7	Chandler	Hyrie Bysal
1130	Attach R.F. Cables and Flex's to T/R modules	7.0	Boston	Richard Russo
1140	Assemble P/R Flex	0.5	Boston	Richard Russo
1100	Cure & Remove Fixture	168	Boston	Richard Russo
2780	Ship CM Structure to Comm Space	1	Austin	John Tiernann
1900	Ship MMA to Comm Space	24	Boston	Paul Babbit
220	NADIR-Receiving	3.26	Austin	Certified Assemble

Figure 6 Schematic diagram of a 'bill of process' database. (Andrew Feller; document redrawn)

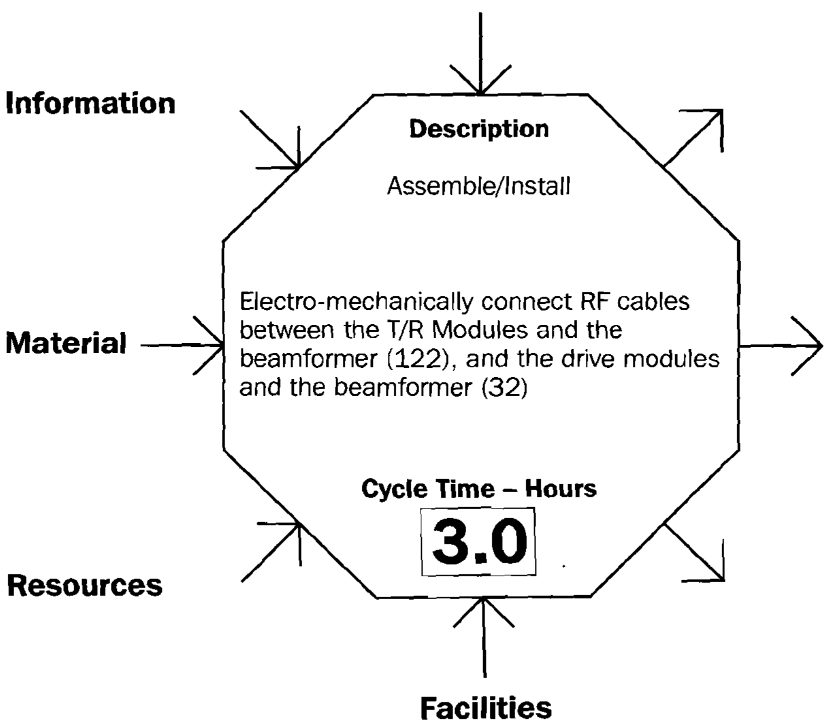


Figure 7 Schematic diagram of a 'process icon'. (Andrew Feller; document redrawn)

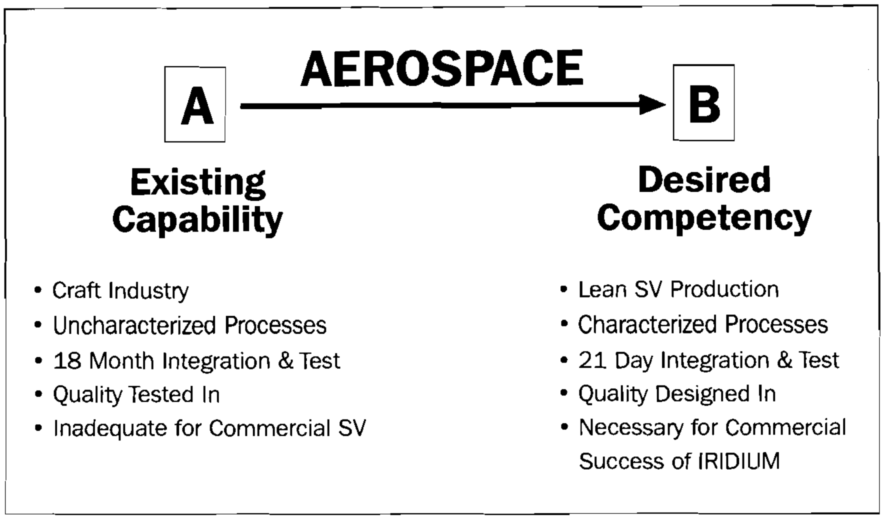


Figure 8 Leading an industry transformation. (Andrew Feller; document redrawn)

means to create large-scale technology. While this had commercial ramifications, it also exemplified new configurations of military–industry collaboration. The project had deep and ongoing relationships with the US military from its inception, and the military was one of first and best customers of this satellite telephone system. Motorola's methodology for achieving quality provided a clear alternative to more than 40 years of military practice and opened up new possibilities for defining the military–corporate relationship in the age of the market. (For a stripped-down Motorola view of this connection see Figure 8.) Lastly, the move to culture signalled the continuing elision and shifting over the decades of the Cold War and after of a variety of conceptual and social boundaries, including those relating to academia and industry, and markets and states. Through these elisions and shifts, history and business have come to an odd mirror-image juncture: they now are methodological companions, both actively seeking to comprehend the manifold interplay of technology and culture.

Conclusion

Part of the argument of this essay is not new – indeed in the context of the science and technology studies literature it is well worn: that culture and technology are produced in concert.[34] Iridium as technological system and as satellite artefact may be offered up as exemplars, creations distinctive of the mixing of markets, globalism, corporations, big technology and military interests at the end of the Cold War. While co-production may be viewed as utilitarian and metaphorically evocative for history, it is problematic for the museum. The multi-causal perspective and the attempt to explain cultural and technological change within a layered narrative simply are an ill fit for the concision required of exhibitions and for the progress-oriented stories with which museum administrators and visitors seem most comfortable. The challenges of explaining big technologies only intensify this history and museum mismatch – they expand the scale and complexity of the narrative.

In turn, the artefact, the museum's trump, seems to offer, at least for space-age technologies, a modest return for history. Though it is rarely evidence in explaining historical change, the artefact, in addition to providing a culturally-situated marker of visitor values, perhaps best serves as a concrete pointer – a call to look more closely at the institutional and technical matrix from which it was produced, to see it as real-world untidy material and conceptual problem. As in the case of the Iridium satellite, the artefact, in the technical choices it presents, may point to specific lines of inquiry that open the world behind the object. Perhaps in this way the museum can find common cause with history as a discipline.

Notes and references

1 For a discussion of the relationship of artefacts to the history of technology see, for example, Corn, J, 'Tools, technologies, and contexts: interpreting the history of American technics', in Leon, W and Rosenweig, R (eds), *History Museums in the United States: A Critical Assessment* (Urbana/Chicago, IL: University of Illinois Press, 1989), pp237–61.

2 For a more in-depth discussion of artefacts and historiography, see the introduction to this volume.

3 As one marker of the near totality of this shift, see Jasanoff, S, *et al.* (eds), *Handbook of Science and Technology Studies* (Thousands Oaks, CA: Sage Publications, 1995).

4 See for example Hughes, T, *Human-Built World: How to Think About Technology and Culture* (Chicago, IL/London: University of Chicago Press, 2004); Winner, L, *The Whale and the Reactor: A Search for Limits in an Age of High Technology* (Chicago, IL/London: University of Chicago Press, 1986); and Beck, U, *Risk Society: Towards a New Modernity*, trans. Ritter, M (London: Sage Publications, 1992).

5 In 1998, *Aviation Week and Space Technology*, in recognition of their role as inventors of Iridium, awarded the three its Laureates Award.

6 For an overview of Motorola in the 1980s and 1990s see Steinbock, D, *Wireless Horizon: Strategy and Competition in the World Wide Mobile Marketplace* (New York: Amacom, 2003), Chap. 8.

7 Bradshear, K, 'Science fiction nears reality: pocket phone for global calls', *New York Times* (26 June 1990), ppA1, D7

8 As costs and regulatory complications arose, all but one of these efforts gradually folded their tents over the 1990s. The one remaining competitor was Globalstar, backed by Loral, an aerospace industry stalwart. Globalstar succeeded in financing and building its system, but always trailed along behind Iridium's vanguard. Globalstar, like Iridium, went through bankruptcy before achieving some measure of stability.

9 A useful overview of literature on the idea of an information society, the multiple meanings attached to the concept of communications, and their relation to capitalism and postmodernism is Webster, F, *Theories of the Information Society* (London: Routledge, 1995).

10 These events in China are related in Gercenstein, M, Oral History Interview, Iridium Oral History Project, NASM. Gercenstein was Iridium's representative in China at the time of the press announcement.

11 Bennahum, D, 'The United Nations of Iridium', *Wired*, 6/10 (October 1998), pp134–8, 194–201. By 1998 the investors, in addition to Motorola, included Bakrie Group of Companies (Indonesia); Saudi Binladin Group (Saudi Arabia) – an entity that gained notoriety after September 2001 through its familial connection to Osama bin Laden; Vebacom (Germany); Inepar SA (Brazil); BCE Mobile Communications (Canada); Ilapeca (Venezuela); Kyocera Corporation (Japan); Industrial Development Bank of India; Krunichev State Research and Production Center (Russia); SK Telecom (Korea); Telecom Italia; Sprint (USA); Lockheed Martin (USA); Raytheon (USA); UCOM (Thailand); Pacific Electric Wire & Cable Company (Taiwan); and China Aerospace International Holdings.

12 As design of the system evolved over the next few years the number of satellites in the constellation was reduced to 66 – the atomic number of the element dysprosium. The relation of this design change to Motorola's conception of the global is discussed below.

13 Motorola and Iridium couched this claim as 'nearly' global coverage. The signal could not penetrate buildings. Structures in dense urban areas and canopies of trees might shade, obstruct or diminish satellite signals.

14 Although not covered in this paper, the creation of new national and international regulatory regimes friendly to communications was a central part of the Iridium story and of international trade in the 1990s. The Federal Communications Commission, analogous regulatory bodies in other countries and the International Telecommunications Union played crucial roles in facilitating Iridium through revised frameworks for allocating spectrum and providing guidelines for international communications. Similarly important were new regimes of international trade contained in the World Trade Organization, which paid particular attention to communications.

15 Iridium already has become the subject of business-school case studies. See, for example, McCormack, A, and Herman, K, 'The rise and fall of Iridium', Report 9-601-040, Harvard Business School, 2001.

16 The author has, however, had extensive access to Iridium corporate records. These contain a broad range of communications from Motorola, including those relating to design, manufacture and project management.

17 The literature relating to the global is vast. Crucial for the discussion here are Albrow, M, *The Global Age* (Stanford, CA: Stanford University Press, 1997) and Robertson, R, *Globalization: Social Theory and Global Culture* (London: Sage Publications, 1992).

18 Or more precisely, Iridium's rhetoric was populist and its business plan aimed for the 'cream' of the market. From the beginning, estimates for phone prices ranged from $2000 to $3000 and per-minute charges were around $3 – both above cellular standards of the early to mid-1990s.

19 Link margin was dependent on two factors: the power of the signal generated from the satellite and the efficiency of a ground antenna in receiving the signal. The critical variable was the strength of signal generated by the satellite.

20 On the clear connection between system design and perceptions of global business practice, see Hillis, D, Oral History Interview, Iridium History Project, NASM. Hillis was a pivotal figure in Iridium. As the project was initiated, he was a key manager in Motorola's defence unit and was the person most responsible for shepherding the idea from embryonic stage to support by Motorola management. He then served as head of the project and was instrumental in shaping the project's engineering and organisational culture.

21 Switching technology was tested on NASA's Advanced Communications Technology Satellite (ACTS) launched in the late 1980s. ACTS was the last in a long-running series of NASA experimental spacecraft intended to assist the communications-satellite industry in evaluating new technologies. Significantly, Motorola received the contract to develop the switching technology for ACTS, an experience that directly influenced the company's decision to use the technology in Iridium. Concurrently, the military began to develop switching technology for use in its MILSTAR satellites that began deployment in the late 1980s.

22 The Japanese manufacturing challenge, especially in automobiles, gave rise to a number of responses and studies. MIT conducted a seminal analysis that had a deep impact on US manufacturers, published as Womack, J P, *et al.*, *The Machine That Changed the World* (New York: Rawson Associates, 1990).

23 It is important to distinguish Hughes's original notion of 'system' from the Cold War concepts of the project and integration. While there are important similarities, there is a key difference. System as developed in Hughes's seminal work *Networks of Power* was an accretive process – an effort extending over time in which the articulation and build-up of a technological complex was contingent on advocates securing markets and, as needed, political accommodations. As a product of entrepreneurship, markets and capitalism, system started from the bottom and worked up – its end point was never pre-determined or foreordained. In the Second World War and the Cold War, this formula largely was reversed. The large-scale system, in concept, existed from the start. The political authority and funding capability of the state enabled the translation of concept into something concrete – first as an active project organisational structure, a system of contracts and perhaps eventually a technological complex. The material and political dynamics of the project and integration thus are fundamentally different from Hughes's original concept of system. Hughes himself seems not to have highlighted this difference – in his work on Cold War subjects, system is approached in the same way as in pre-Second World War examples. On the early Hughes see Hughes, T P, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, MD: Johns Hopkins University Press, 1983); for treatment of Cold War systems see Hughes, T P and Hughes, A C (eds), *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After* (Cambridge, MA: MIT Press, 2000).

24 On the origins and development of the deregulation and markets-over-governments movement, see Yergin, D and Stanislaw, J, *The Commanding Heights: The Battle Between Government and the Marketplace That Is Remaking the Modern World* (New York: Simon & Schuster, 1998).

25 For an analytical discussion of definitions and characteristics of culture see Williams, R, *Sociology of Culture* (Chicago, IL: University of Chicago Press, 1981).

26 A useful overview of these developments is Waring, S P, *Taylorism Transformed: Scientific Management Theory Since 1945* (Chapel Hill, NC: University of North Carolina Press, 1991). For a critique of this movement see Jackson, B, *Management Gurus and Management Fashion: A Dramatistic Inquiry* (London: Routledge, 2001)

27 At the same time, a different but related business work culture was emerging: the egalitarian commune-esque style of computer start-ups. Explicit concepts of culture were important here, too, but rationalisation of process was not one of its primary characteristics. For an in-the-trenches example of this culture see Kidder, T, *The Soul of a New Machine* (Boston, MA: Little, Brown, 1981).

28 Over the 1990s, Six Sigma spread to other large firms such as General Electric and became the preferred tool for corporate cultural reinvention, spawning a substantial 'how-to' literature. The bible is: Pande, P S, *et al.*, *The Six Sigma Way: How GE, Motorola, and Other Top Companies Are Honing Their Performance* (New York: McGraw-Hill, 2000).

29 For an overview of this trend from a policy perspective see Cunningham, S, *et al.*, *The Business of Borderless Education* (Canberra: Commonwealth of Australia, Department of Education, Youth, and Training, 2000).

30 For a comic, often polemical and sometimes accurate account of the relationship between academic cultural studies and business uses of culture, see Frank, T, *One Market Under God: Extreme Capitalism, Market Populism, and the End of Economic Democracy* (New York: Doubleday, 2000), Chap. 8.

31 Jameson, F, *Postmodernism, or, the Cultural Logic of Late Capitalism* (Durham, NC: Duke University Press, 1991)

32 A good account of the history of government-sponsored project management is Johnson, S B, *The Secret of Apollo: Systems Management in American and European Space Programs*

(Baltimore, MD: Johns Hopkins University Press, 2002).

33 The importance of process as a strategy in recent business is developed in Pisano, G, *The Development Factory: Unlocking the Promise of Process Innovation* (Boston, MA: Harvard University Press, 1997). As implied above, the attention to process derived principally from the Japanese model of 'lean production'. For an account of the application of lean production outside Japan, see Delbridge, R, *Life on the Line in Contemporary Manufacturing: The Workplace Experience of Lean Production and the 'Japanese' Model* (Oxford/New York: Oxford University Press, 1998).

34 For a useful overview of the strengths and shortcomings of the historiography of science and technology studies, see Pestre, D, 'Thirty years of science studies: knowledge, society and the political', *History and Technology*, 20 (2004), pp351–69.

Cathleen S Lewis

The birth of the Soviet space museums: creating the earthbound experience of space flight during the golden years of the Soviet space programme, 1957–68

Introduction

Very few people have experienced space flight, or ever will. Out of a world population of more than 6 billion, fewer than 500 people have flown in space. The vast majority of humanity can only imagine the experience of space flight by viewing public displays of artefacts and models of hardware. Aviation and space museums in the United States and those in the former Soviet Union have presented this experience in strikingly different ways, despite the apparent parallels between the space programmes of the two Cold War competitors.

In the early 1960s, the United States quickly embraced the idea of publicly displaying its space achievements throughout the country. From its inception, the National Aeronautics and Space Administration (NASA), the civilian face of the US space effort, embarked on a campaign to publicise and support such exhibitions. Within a few years, the century-old Smithsonian Institution, through its National Air Museum, situated on the National Mall in Washington DC, would become the premier site for US space displays through an exclusive artefact transfer agreement with NASA. Other American museums, particularly those specialising in the history of technology and transportation, also began to mount space-themed displays.

In the Soviet Union, there was a much more complex and timid evolution of the presentation of space flight. In the Soviet case, two parallel exhibition strategies appeared during the 1960s – public displays in museums throughout the Soviet Union and in state-sponsored exhibitions sent to foreign venues, and private, corporate displays intended only for the benefit of those in the space community. The effect of this approach was to separate the collection and preservation of real, flown objects from the activities of public display and education. Corporate and official entities retained tight control over the artefacts of space flight and jealously guarded their in-house displays to prevent public access. Given their limited, but educated, audiences, such displays typically did not include interpretative labels

– in contrast with standard museum practice in the US. Displays at spacecraft, rocket and other aerospace manufacturers served as legacy exhibits, in institutions such as RSC Energia (the legacy facility of Sergei Korolev), JSC Zvezda (spacesuit manufacturer) and Khrunichev (engine and launch-vehicle manufacturer). Public displays in the USSR also eschewed interpretation, but for a different reason: to focus on space as a celebratory symbol. The end result was two distinct styles of display – progress-oriented, non-public museums (that still exist in Russia today) and public establishments that emphasise slick, packaged 'edutainment' and rely on models and projections of future space flight.

The themes and approaches of exhibits on the USSR space programme also followed distinct geographical tracks. Exhibitions in cities such as Moscow and travelling exhibitions intended for international audiences often were nearly identical in content, including identical objects and descriptive components. However, public museums located outside major urban centres often had their own distinct identities and included a wider range of materials. There was thus a greater diversity in content among the domestic public displays than between the state-sponsored travelling shows and large public exhibitions.

Early displays: exhibitions without artefacts

From their inception, public space museums in the USSR mounted displays that echoed the popular press celebrations of Soviet mastery of rocket technology. The exhibits were not intended to explain the technology or institutional context of space flight, but to celebrate national accomplishments in the mastery of technology. The first space exhibition in the Soviet Union on record was a small commemorative display featuring stamps and buttons (*znachki*) that opened at the Moscow Planetarium in the years that followed the launch of Sputnik in October 1957. The exhibition included the space-related stamps, postcards, *znachki* and commemorative coins that had been issued before the February 1961 opening. The coins and stamps featured highly-stylised representations of the spacecraft that executed the much-celebrated space firsts of the Soviet Union. None revealed technically-accurate details of the space hardware, nor were they meant to do so. Instead, the Moscow Planetarium director, V K Litski, conceived the exhibition as an encouragement for established collectors, most likely adults, to expand their traditional philately and numismatic collections to include space subject matter.[1] Stamp and coin collecting was considered a pursuit of the intelligentsia in the USSR, not a child's hobby.

The objects selected for this first exhibition were remarkable in a crucial respect – none represented authentic hardware from the space programme. All were objects that first the Russian and later the Soviet state had traditionally presented to individuals or groups to reward accomplishment or to popularise a state-sponsored activity. Stamps, for example, had a long history of promotional use within first Russia and then the Soviet Union. Under Tsarist rule, stamps were issued as a substitute for travel abroad, which was expensive and suspected to facilitate the spread of liberal ideas. Under Bolshevik rule, stamps were designed and circulated to encourage interest in and support for state projects such as Soviet Arctic exploration and the development of nuclear energy. Pins or *znachki*, too, represented a long and established Russian tradition whose origins can be traced back to ancient Rome. During the Soviet period, the symbolism attached to *znachki* shifted from rewarding accomplishment to acting as souvenirs of national celebrations. Finally, the commemorative coins minted at the *montenyi dvor'* (mint) offered the opportunity to create a new class of symbolic objects related to the nascent space programme. At first, these coins occupied the *znachki*'s former role and were awarded ceremoniously at the conclusion of projects. During the space programme, production of the coins proliferated; they began appearing as diplomatic gifts and were struck as often to honour anniversaries of past events as to note recently completed projects. Eventually, the coins joined the ranks of collectables.

During the decade after the 1961 Moscow Planetarium show, hundreds of space-themed public and private museums, large and small, sprouted up across the Soviet Union, including those that could make any claim to fame related to space flight. The development of these exhibitions provides an interesting perspective on the space programme and its role in post-Stalinist Soviet society and culture. The museums were housed in buildings ranging from nineteenth-century houses to well-known Stalinist monuments; they varied in size and scope from table-top classroom exhibits, through single-room shrines dedicated to the lives of individuals, to the heroic-scale celebrations of hardware. As the size and scope of the exhibitions varied, so too did the audiences. In some cases, the exhibitions invited the public to glimpse a vision of the promised post-Second World War Soviet abundance and technological prowess. In other cases, semi-private exhibitions sought to affirm the work and potential rewards of life within the closed worlds of post-Second World War technology centres, or modern-day *sharaga*s (scientific and technical prison camps), which continue to serve as legacy centres today.

The 1961 Planetarium show was obviously an expedient way to mount an exhibition and also fulfilled that institution's mandate to promote scientific awareness. Planetariums throughout the Soviet Union had served to lure the religious and superstitious from churches to new temples of scientific worship. However, since they had been built around a projection dome and designed with limited exhibition space, they could not accommodate large-scale Soviet technology. Plans for a full-size space museum on the scale of what was to become the Smithsonian Institution's National Air and Space Museum began very early in the Soviet Union, pre-dating NASA's earliest exhibitions and NASA's relations with the Smithsonian. Yuri Gagarin laid the cornerstone for a large space museum on 13 June 1961 in the city of Kaluga, home of Konstantin Tsiolkovski, the intellectual founder of Soviet space flight, in whose honour the museum would be named. Sergei Korolev, the chief designer of the space programme in the mid-1960s, also played a driving role in establishing the museum in the rocket pioneer's adopted home town. Plans for the museum were subject to architectural competitions. The team of Boris S Barkhin, Evgeniy I Kireev, Nataliya G Orlova, Valentin A Strogy and Kirill D Fomin won the honour of designing a building that went on to win the State Prize. Korolev did not live to see the building open, however; it took more than six years to complete and formally opened on 3 October 1967, nearly two years after Korolev's death and close to six months before Gagarin's.

Evolution of a space exhibition icon: the Kosmos Pavilion

During the 1960s, as work on the geographically-remote Tsiolkovski museum proceeded, the Exhibition for Economic Achievements (*Vystavka dostizheni narodnogo khoziaistva*, VDNKh) in Moscow was the national centre for exhibitions on Soviet space achievements. It established the tone and scope of state-sponsored space exhibitions. When the Soviet Union began a parallel and equally active programme of international exhibitions, they resembled those at VDNKh.

The Exhibition of Economic Achievements in Moscow has long been held as a barometer of official pride in Soviet agricultural, scientific and technical accomplishments. The exhibition first opened in 1939 as the All-Union Agricultural Exposition, a celebration of the fruits of Stalinist collectivisation. The purpose of the 1939 exhibition was to demonstrate that there was no famine in the country, only abundance resulting from collectivisation and mechanisation of agriculture. The park has been characterised as an effective forum in presenting state propaganda to the entire Soviet population in the early Stalinist period.[2] It conveyed the message that the abundance represented in the displays was more real than the scarcity experienced in daily life. The themes and architecture of the park date from that early, high-Stalinist period. A prominent feature was and is Vera Mukhina's sculpture *Rabochi i kolkhoznitsa* (worker and woman collective farmer) – a representation of the *smychka*, or union between the emergent industrial populations of the USSR and the dominant agrarian tradition. The original exhibitions highlighted the dominant role of agrarian life in the Soviet Union. They featured produce, apple groves and garden plots in their scientific displays and included exhibits on folk art and culture from all over the vast country. The celebrations of folk culture and agricultural accomplishments gave way to demonstrations of Soviet industrial accomplishments only after the post-Second World War reconstruction of the exhibition halls.[3]

The Mechanisation of Agriculture Pavilion at the exhibition had a long history. The architect, Viacheslav Oltarzhevski, originally designed the structure with four wings extending from the central axis of the exhibition. A statue of Stalin stood at the centre. Construction of the original design was never completed – perhaps because of accusations that the construction was shoddy and the design resembled a swastika when viewed from above.[4] The final version of the pavilion was built as a large domed structure with only two small wings branching off a grand hallway. This high-Stalinist monument did not officially become the Space Pavilion (or, as it is more affectionately known, the Kosmos Pavilion – the name more commonly used in the US) until 1966. However, displays of space flight first appeared in that building in 1958, edging out the tractors and combines. In that year models of the first three Soviet spacecraft – Sputnik, Sputnik 2 and Sputnik 3 – moved from the main entrance hall of VDNKh into a 100-square-foot exhibition area a year after the original spacecraft accomplished their historic flights.[5] The models of Sputnik (the first man-made satellite), Sputnik 2 (the spacecraft that carried the dog Laika into space) and the heavily-instrumented Sputnik 3 attracted a steady stream of visitors – even though they lacked detailed explanatory exhibitry and were not authentic hardware.[6] The models were the first three-dimensional representations of the real objects available to the public and supplemented the earlier announcements and celebrations in the Soviet press. Muscovites (and Western journalists) were hungry to see the material evidence of the USSR's accomplishments in space.

Space exhibits at VDNKh grew slowly in the first few years of the 1960s, mirroring the slowness with which the Soviet Union revealed its space secrets. A model of Vostok, the spacecraft that carried Yuri Gagarin into space, had its first public display on 29 April 1965, within the Mechanisation of Agriculture Pavilion, alongside the three Sputniks.[7] The model's unveiling was given as the main reason for the transfer of the previous space displays to the pavilion building.[8] As had been the case with previous displays, the purpose of the exhibit was not to conduct a technical discourse on the engineering of the spacecraft, but to draw visitors to pass by the object and worship the accomplishments of Soviet science and technology. In this way, the display differed from other demonstrations of technological prowess at the exhibition, which was notorious for its vast moving and lit scale models of combines and hydroelectric dams. The 1965 VDNKh Vostok model served its purpose well by not revealing too many technical details but still attracting visitors.

The case of the Vostok display and its use are particularly interesting to a museum curator. Instead of revealing information about the history and technology of a historic accomplishment, the display of the Vostok model represented a deliberate effort to conceal the actual details of the human space-flight programme in the Soviet Union. The display at the pavilion and subsequent ones carefully camouflaged elements of Vostok's design legacy and its technical characteristics. The *New York Times* reporter who first wrote about the Vostok model interviewed Konstantin Feoktistov, the chief spacecraft designer, and received only the most cursory description of the spacecraft from that knowledgeable engineer and cosmonaut. At the time of his interview with the *New York Times*, Feoktistov was better known as the flight engineer of the first Voskhod spacecraft that carried three men into orbit on the first multi-man mission in October 1964. It is possible that the reporter did not know about Feoktistov's role as designer, in which case he would not have had reason to ask him pointed questions about the design of early Soviet spacecraft. In his recent memoirs, Feoktistov acknowledges that his flight on board the Voskhod was in fact a reward for redesigning the Vostok interior to accommodate three men.[9] Given his intimate knowledge of the spacecraft, Feoktistov was remarkably guarded in his interview about Vostok and the model on display. The engineer limited his remarks to technical specifications, such as the gross weight and external dimensions, and made no attempt to describe the workings of the spacecraft. This meagre information was not enough for serious comparisons to be made with the flown Mercury capsules that already had been on display throughout the United States and the world.[10]

Another model of the Vostok soon appeared at the 26th Salon International de L'Aéronautique et de L'Espace at Le Bourget Airport during the Paris Air Show in June 1965.[11] At that time, the Soviet portrayal of the craft was even more deliberately dishonest about its technical details. Yuri Gagarin accompanied the exhibition prop to the Paris Air Show and asserted that the Vostok and Voskhod craft were 'of entirely different design', a lie that the Soviet space establishment would perpetuate for another generation.[12] The Vostok at the Paris Air Show served as a decoy, hinting to the world that great technical advances separated the displayed Vostok from the still shrouded Voskhod. Years later Soviet engineers conceded the designs of Vostok and Voskhod were identical, and Feoktistov admitted the high level of risks taken in refitting a one-man craft to carry three.

These first displays of quasi-realistic models of Vostok were revelations, albeit minor ones. Until 1965 the few published photographs of Vostok itself were of the protective conical shroud that covered the spacecraft through its launch and until its entry into orbit, revealing no more than the external dimensions of the craft. Before then, previously-released drawings deliberately included inaccuracies in the representations of the spacecraft and its function.[13] This trail of misinformation served to hide not one, but many secrets about the first human space flights. The USSR was engaged in a Cold War against the United States, and a culture of secrecy prevailed. Despite the fact the Americans were displaying flown Mercury spacecraft throughout the world, it surprised no-one that the Soviet Union adhered to secrecy at that time. The tradition of secrecy was compounded by the fact that the human and science space programmes were an ancillary part of the ballistic-missile programmes of the Soviet Union and not separate from the military – unlike NASA in the US. The USSR had no buffer agency to protect its even more dear military and strategic secrets than the design of spacecraft. Beyond the military culture of secrecy, the Soviet Union feared the technical comparison with the American Mercury and Gemini spacecraft. NASA had taken an active role in displaying and publicising their hardware. Given the quality of Soviet intelligence, there is little doubt that Soviet engineers and managers were well aware that their hardware was less technologically sophisticated than NASA's.

There was a significant technical secret that the Russians guarded very closely. It was one that threatened their role as a generator of space firsts. The Vostok, as designed and flown with a human inside, was incapable of decelerating sufficiently to land safely on the ground. Parachutes could not slow the spherical re-entry capsule from its critical velocity of 27,500 km/h to below a survivable speed of well under 100 km/h. Yuri Gagarin and all five subsequent Vostok cosmonauts had ejected from the spacecraft at an altitude of 20,000 feet and parachuted separately to Earth. Gagarin had not accomplished the first orbit of Earth to the precise specifications of the Fédération Aéronautique Internationale (FAI), which required him to land with his spacecraft.[14] The shiny representation of the Vostok in orbit that was placed on display at VDNKh did not betray the secret of the craft's landing condition. The actual, flown spacecraft would have revealed to the world the used ejection hatch in the same way that the flown Mercury spacecraft revealed that the astronauts depended on recovery crews to disembark from their own spacecraft. Its near-shattered condition would have revealed the fatal velocity at impact.

Beginning in the summer of 1965, the exhibition contents in the Mechanisation of Agriculture Pavilion gradually shifted from combines to spacecraft. In 1966, the pavilion was officially renamed the Kosmos Pavilion (Figure 1), and became known as Moscow's permanent space exhibition.[15] Direct administrative control of the pavilion was under the Soviet Academy of Sciences Council on Exhibitions, which had directed the content of the scientific, industrial agricultural and ethnographic displays at the VDNKh since its rededication in 1959. However, the greater part of the Kosmos Pavilion was not devoted to displays on Soviet accomplishments in human space flight. Only the rear, domed portion of the hall featured the activities of humans in space. The majority of the exhibits represented scientific activities

Figure 1 The Kosmos Pavilion, at the Exhibition for Economic Achievements, Moscow. The Vostok launch vehicle has replaced the statue of Stalin. (Editorial Press of the VDNKh, USSR)

in space flight through high-quality full-scale models of spacecraft, starting with the 1958 model of the Sputnik 3 satellite, thus reflecting the interests and expertise of the Academy of Sciences. The pavilion relied on guides to explain the displays to visitors, reputedly conducting 150 tours per day.[16]

When the pavilion was renamed, changes were also made outside the building. A Vostok rocket was placed in an area vacated when a statue of Stalin was removed in the early 1950s.[17] This was a simple and direct indication that a new icon had replaced a powerful symbol of the past. Space was the new focal point of the state. As Stalin had presided over the mechanisation of agriculture, a proud product of collectivisation and industrialisation, now anonymous rocket engineers and their product, the Vostok rocket, represented the Soviet mastery of Cold War-era technology. As though there could be any doubt of this interpretation, later that year, a 350-foot titanium-covered stylised rising rocket was erected just outside the entrance to the park to commemorate the 'Conquerors of Space'. The monument firmly tied public memory of explosives experts from the Revolution to the contemporary activities of the USSR's engineers and technicians. These engineers and technicians gathered every morning near the base of the monument outside VDNKh to wait for buses that would carry them to work at the space design bureaus. It was commonly known, even during the period of relative secrecy, that the well-made apartment blocks in the area of VDNKh and the botanical gardens had been built to house the growing aerospace community in Moscow. It was less well known before 1966 that the apartments had been built around Sergei Korolev's existing single family home, where he lived until his death.[18] Almost 15 years later, in 1981, the Memorial Museum of Cosmonautics was built underneath the base of the 'Conquerors of Space' obelisk.

As these aerospace engineers went to work, they witnessed a very different set of museum displays, ones not open to the public crowds that the Kosmos Pavilion claimed to receive. These isolated private museums housed the remnants of the actual spacecraft and equipment that had flown or was designed to support human life in space. Each design bureau and enterprise jealously guarded its own collection of objects that represented the material legacy of its contribution to space flight. After much of the flown hardware was lost to destructive post-flight testing, what remained rarely left the factory of origin. It remained under the supervision of a single individual who would collect and arrange the exhibits for the edification of his own colleagues in the form of a legacy display. The purpose of the legacy display was both to reassure old-timers of their accomplishments and to educate newcomers about the heritage of their mission.

Existing in conjunction with the Kosmos Pavilion and the private museums was a world of small museums that sprouted up during this period, each fulfilling a specific demand from an audience or a patron. For example, the display that in 1967 became the Gagarin Spaceflight Training Centre Museum was initiated through the advocacy of Yuri Gagarin. He envisioned the museum as a repository for the gifts that cosmonauts received over the years from local and foreign admirers. The museum took on a decidedly personal tone when Gagarin died in 1968. At that time, the Commandant of the Cosmonaut Corps, Nikolai Kamanin, decreed that everything there associated with Gagarin be gathered to form a memorial museum. Kamanin oversaw the re-creation of Gagarin's office on the site of the museum in Star City.

World's fairs: a tale of two spacecraft

In November 1928 representatives from 31 countries met in Paris to sign the convention that established the International Exhibitions Bureau (BIE), the governing body for the World's International Exhibitions, also known as World's Fairs. The USSR was an original signatory, yet has not hosted a single fair. The United States waited until 1978 to sign the treaty, but had been chosen as the site for the last World's Fair held before the Second World War. The New York World's Fair of 1939, 'The World of Tomorrow', was officially labelled a 'general exhibition, category two', because of the United States' status as a non-signatory to the convention.

While the members of the Academy of Sciences' Council on Exhibitions and the space and science communities created separate styles of space exhibitions within the USSR, the academy formulated a unified version of space-flight exhibits for dissemination abroad. Between 1958 and 1967, there were three official general exhibitions of World's Fairs, one *ad hoc* bilateral exposition exchange and a single American unilateral 'World's Fair'.[19] First was the USSR exhibition at the World's Fair in Brussels in 1958. That World's Fair led to a US and Soviet agreement to hold joint expositions in Moscow and New York the following year. Seattle in 1962 was the third venue at which space accomplishments were offered for direct comparisons. The fourth venue was the New York World's Fair in 1964. And the last exhibition with space themes was the 1967 World's Fair in Montreal. It was the only exhibition in which US and Soviet space achievements could be compared directly. The Soviet Union did not participate in all of these fairs, but space flight was the topic of the time and featured prominently at each fair, with or without models of Sputnik and Vostok.

The World's Fair in Brussels, which opened in April 1958,[20] was greeted with much anticipation. The fair's theme was Atomium, conveying the optimism of a renewed faith in science and technology, the rejuvenation of Europe after the Second World War and the hope that nuclear power would be used for peaceful purposes. This was in spite of the fact that the USA and USSR, former allies in the Second World War and the world's two nuclear powers, were actively involved in their Cold War rivalry. The Iron Curtain had already been established, and just months before the start of the Brussels World's Fair the competition between the two nations had entered the new arena of space. Each side claimed dominance in science and technology – an assertion that each side used to explain victory in the Second World War and geopolitical prowess in the Cold War years. The international public expected to see such claims reflected in each country's exhibitions. Comparisons and competitions were inevitable at the Brussels World's Fair.

The United States had just launched its first successful space mission, Explorer 1,[21] too late to make space the focus of its World's Fair

Figures 2 and 3
The USSR pavilion at the 1958 World's Fair in Brussels. A statue of Lenin oversees the spacecraft centrepieces of Soviet technological progress. (Rudolph Nevi)

exhibition. Instead, the major theme of the massive, circular American pavilion was the 'American way of life'. There were examples of the latest calculating machines, including state-of-the-art voting machines and IBM's latest computer.[22] A circular screen, the 'Circarama', showed a projected overview of life in the United States every ten minutes.[23]

The Soviet pavilion (Figures 2 and 3) conveyed a future-oriented theme, anticipating life as yet to come in the USSR. It featured exhibits of cars not yet in production, a model of the first two Sputniks and a scale model of a solar-powered space station.[24] The interior of the massive Soviet building created a strange atmosphere – the centrepiece was a heroic sculpture of Lenin surrounded by scale models of commercial aircraft, giving the impression of heading forward in the same direction.[25]

At the conclusion of the 1958 fair, the United States and the Soviet Union announced plans to send their respective displays to Moscow and New York in acknowledgment of the popular interest in each country that the pavilions in Brussels had created.[26] Today, the more famous of the two 1959 displays is the American exhibition in Moscow. It was inside the famous Whirlpool-sponsored kitchen in Moscow that Vice President Richard Nixon and Nikita Khrushchev held their improvised 'kitchen debate' in July 1959. The less-well-remembered Soviet exposition in New York was opened by Vice President Richard Nixon and Soviet First Deputy Premier Kozlov on 29 June 1959, on the top two floors of the New York Coliseum. In his opening statement, Kozlov made a direct connection between the Soviet's nascent space programme and the legacy of the Second World War, a legacy which explained the theme of the 1958 USSR Pavilion in Brussels:

> Despite tremendous losses, the Soviet People found the strength not only to eliminate in a short period of time the aftermath of war but also made big strides along the road of economic and technical progress. A vivid expression of the outstanding successes of our country is the launching in the Soviet Union of the first artificial satellites of the earth and Sun.[27]

Figure 4 John Glenn's Friendship 7 in Seattle in 1962 on the final stop of its world tour. (University of Washington Libraries, Special Collections)[29]

However, in this exhibition, as at VDNKh in Moscow, the USSR featured the social significance of the Soviet accomplishment of space flight rather than the technical details. As before, the models of the three Sputniks revealed little of the Soviet space programme or Soviet society.

Seattle World's Fair in 1962

The Seattle World's Fair established the practice of looking toward the future for all American World's Fairs for the rest of the century. The fair (originally dubbed the 'Century 21' fair) was originally planned as a revitalisation effort for downtown Seattle. The city had not benefited from the post-Second World War economic boom on the west coast of the United States, and local planners hoped the fair might lure Californian businesses northward. Such intentions notwithstanding, the conjunction of the first human space-flight successes and the dominance of the Boeing Corporation in the local economy transformed the aim from the 'Century 21' goal of promoting tourism and redevelopment in Seattle into the theme of 'America's Space Age World's Fair'.[28]

After its flight in February 1962 John Glenn's Mercury capsule, Friendship 7, toured 17 countries before arriving at the World's Fair in Seattle in July 1962 (Figure 4).[30] This was in marked contrast to Yuri Gagarin, who immediately after his flight personally toured as many countries as possible, but whose spacecraft, Vostok 1, never went on public display – it remained on semi-closed view at the Energia Rocket and Space Corporation, where it remains today.

Figure 5 The NASA and Department of Defense Space Park at the New York World's Fair in Flushing Meadows, 1964. (Courtesy NASA)

New York World's Fair in 1964

The theme of the third international space-age fair, the 1964 New York World's Fair, was 'Man's Achievements on a Shrinking Globe in an Expanding Universe'. At the time the Soviet Union appeared to be winning the space race, yet again decided not to participate in an American fair.[31] This decision provided NASA with an important opportunity to display its achievements. NASA planned a full display, including material on the Apollo effort to land a man on the Moon by the end of the decade. In preparation for the Fair, Hugh Dryden, the NASA Administrator, was appointed to the 14-person Time Capsule Selections Committee, chaired by former Smithsonian Secretary Leonard Carmichael and including such luminaries as Andrew Wyeth, Vannevar Bush and Ralphe Bunch.[32] With the advice of NASA historian Eugene Emme, Dryden chose to include portions of actual space artefacts in the capsule that was to be sealed for 500 years. The committee selected material from the heat shield of Scott Carpenter's Aurora 7 Mercury spacecraft, a solar cell from the Vanguard satellite, a piece of balloon material from the Echo communications satellite, as well as microform copies of technical and historical accounts of the American space programme.[33]

NASA's preparations for the time capsule were a minor prelude to the World's Fair itself. The US Space Park at the World's Fair (Figure 5) was a two-and-a-half-acre collaboration between NASA and the Department of Defense (DoD).[34] The park displayed 31 exhibits on the history and future of American rocketry and space flight. To present the exhibits' messages, NASA and the DoD jointly offered two weeks' training to the 35 park tour guides.[35] The US Space Park featured the flown Mercury Aurora 7, a model of the Gemini spacecraft, and other models of flown scientific, military and international spacecraft. But the displays pointed to the future as much as the past. The Apollo programme occupied a good portion of the park. A model of the aft end of the Saturn IC launch vehicle was a centrepiece – this rocket was part of the system being designed to carry astronauts to the Moon. Mock-ups of the Apollo Command and Service Modules and the Lunar Excursion Module were also on display.[36]

Though it may seem that all this effort was excessive for a temporary exhibition at a World's Fair, NASA anticipated that the US Space Park might become part of a permanent exhibition in New York. On 6 September 1964, NASA Administrator James E Webb gave a speech at the dedication of the Hall of Science, another fair pavilion adjacent to the Space Park. This pavilion was designed and conceived as a permanent monument to the era the fair celebrated, giving NASA hope that Space Park also might be made permanent. Webb closed his address by saying, 'It is no accident that the US Space Park is located adjacent to the Hall of Science. It is a great credit to the wisdom of Robert Moses and his associates that the permanent structure designed for retention after the fair is the building we are here to dedicate.'[37]

But planning for the New York site was only to be a temporary measure. Even after the 1962 success of dominating the Seattle World's Fair, NASA was well aware of the expense for the maintenance of these major exhibits. The Century 21 organisation had raised between \$200,000 and \$500,000 to cover the administrative and construction costs for NASA's exhibit there. NASA only agreed to full participation at the New York Fair with approval of a federal appropriation through the Department of Defense, Commerce Department and NASA, specifically for the exhibit. NASA would soon be out of the travelling exhibition service.[38] The Smithsonian National Air Museum in Washington DC had begun to incorporate space themes in its own exhibits, including the intrepid Friendship 7 spacecraft. Museum director Paul Johnston saw that space flight offered an opportunity to expand the scope of the National Air Museum (NAM) and could do much to promote plans for a new museum.[39]

Expo '67 in Montreal

During the latter half of the 1960s, the Soviet Union maintained official secrecy surrounding its space programme. It never officially acknowledged that it had a programme in competition with the US to send men to the Moon and provided few technical details on the programmes that did receive publicity. The 1967 World's Fair in Montreal, Expo '67, 'Man and his World', offered an opportunity for the Soviet Union to display genuine spacecraft and celebrate their programme in a way similar to the US presentations in New York, or to continue to use models to carry its message of mastery of science and technology. Not surprisingly, the USSR chose the latter. A *New York Times* reporter described the 140,000-square-foot hall packed with technical models, including those of unflown spacecraft and a light show that simulated a Moon landing, as designed to 'overwhelm the visitor'.[40]

Conclusion

Despite the Soviet state's deliberate attempt to recreate the Stalinist illusion of abundance in the post-Stalinist, post-Second World War Soviet Union, its representation of space flight in museums fell short of this goal, since it did not match the didactic technical displays of the previous generation. There were no working models of spacecraft on display that were similar to the model hydroelectric dams of the 1950s, and visitors did not leave the exhibits with greater technical knowledge than they brought with them. Space-flight exhibitions during this period adopted a very narrow and precise focus – they promoted national interest and celebration, but consistently sought to obscure information and guard state secrets. Through space displays, the Khrushchev government promised abundance it could not deliver. As was true during much of his tenure, Nikita Khrushchev had promised far more than he had been capable of delivering. Little is revealed of the actual spacecraft, but their models are frequently paired with models of ambitious plans for the future. Exhibitions of the golden age of Soviet space flight promised the continuation of Soviet achievements in space without revealing how the first feats were accomplished.

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8 Note 7
9 Feoktistov, K, *Kosmicheskaia tekhnika: perspektivy razvitia* (Moscow: Izdatel'stvo MGTU im. N E Baumana, 1997)
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12 Note 11
13 Note 11, p162
14 The FAI is the international world air sports federation founded in 1905 that sets and documents all aviation and space-flight records throughout the world. In order to comply with FAI mandates, the USSR submitted fraudulently ambiguous paperwork to document Gagarin's flight as the first space flight.
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16 This claim is somewhat doubtful, as it coincides with claims of 8–9 million visitors per year. That would mean that as many as 24,000 visitors would make the pilgrimage to the pavilion per day, far more than the 10,000-square-metre facility could comfortably accommodate. Bazykin, V, note 15.
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David DeVorkin

The art of curation: collection, exhibition and scholarship

Introduction

Artefacts on display in museums can be described as congealed culture,[1] mute testimony to the cultures in which they were produced, used and finally conveyed to posterity. But in fact they are far more. They symbolise the power and authority of the exhibiting institution, and often are used to attract support, both public and elite. They are the medium through which national museums such as the Smithsonian Institution define and assert particular views of culture.

These assertions, naturally, breed tensions over ends and means within national museums among administrators and curators. The focus here is on curators – their role in collections and exhibition, and these activities' interplay with scholarship, in the context of a particular institution, the Smithsonian's National Air and Space Museum. My goal here is to suggest the texture of the curatorial experience through a personal account of two intimately-connected undertakings: building a collection of artefacts documenting astronomy in the space age and creating the permanent exhibition 'Explore the Universe' (opened in 2001).

One can argue that developing any exhibition story dealing with a concept, an event or an era is influenced by how the curator views the subject matter, the resources available and the topics deemed acceptable by the institution and prevailing culture. All these factors influence the exhibit, and hence the act of collection. But such factors also may come into play well before an exhibition is created. Aerospace museum curators identify and select all sorts of bits and pieces of the material legacy of space travel, and turn them into artefacts. The choices they make may be shaped by social, political and economic forces as much as by intellectual priorities.[2] As Oxford historian Jim Bennett has observed of all forms of curation, therefore, 'museum collections [...] show you not what there was but what was collected'.[3] Stating the obvious, yes, but in fact this observation has profound implications worth pursuing; specifically, what factors inform, in this case, the collecting of space artefacts? How do scholarly judgments intersect with political and economic influences? Whatever the answer, for each curator, for each and every institution concerned, collections may illuminate, and in turn affect, scholarship.

The curator and his or her working milieu thus compose an important nexus: this conjunction literally creates the stuff of history.

'Explore the Universe'

In the 1990s I became part of a hybrid curatorial/scientist team tasked with replacing an existing astronomy gallery, 'Stars' – an initiative set in motion in 1988 by the arrival of a new Director, astrophysicist Martin Harwit. I had long wanted to improve sections of 'Stars' in association with my curatorial colleague Robert Smith. But the new Director called for a completely new gallery, one that had a strong scientific voice, to state 'what we know and how we know it' about the universe. He wanted visitors to understand the scientific process, to discover for themselves how scientists work and think about things, but relying on interactive displays rather than artefacts to achieve these ends – all in a 4600-square-foot gallery. Initial responsibility was entrusted to a newly-formed infrared astronomy group established by Harwit, rather than the curatorial Space History Division. During this initial planning, the museum became embroiled in a controversy over an exhibition on the end of the Second World War featuring the *Enola Gay* B-29 bomber. This controversy led to Director Harwit's departure, the dissolution of the infrared astronomy group and the return of gallery planning to the curatorial department and to me as curator.[4] With this change, artefacts assumed a prominent role in the gallery's conceptualisation, and the gallery, in turn, offered a crucial opportunity to build the collection, as described below.

But with Harwit's departure, I felt that a new Director might not assign a high priority to an astronomy exhibition. To build support, I accepted a suggestion by a former exhibitions chief, Nadia Makovenyi, that we form a core exhibition team consisting of curator, designer, scripter, fundraiser and educator. This organisational technique did create 'grass roots' interest in the exhibition that transcended the curatorial department. Inadvertently, the *Enola Gay* controversy facilitated this support: an exhibition on astronomy was considered to be 'safe' – far away from politically-sensitive issues (a proposed exhibition on the air war in Vietnam also was cancelled during this period). Our major challenge, which we accepted, was to compete for financial backing as the Development Office focused on fundraising for a new facility at Dulles (now the Stephen F Udvar-Hazy Center).

The new gallery theme emphasised galactic and extragalactic astronomy and cosmology (though we were not encouraged to use that word, as it was feared there could be confusion with the practice of beauticians). These themes posed a range of conceptual hurdles, including aspects of cosmology and evolution that the museum's visitors might regard as controversial.

We knew that two areas of modern astronomy had to take centre stage in this new gallery, entitled 'Explore the Universe': the search for the remnant structure of the big bang, and the search for the large-scale structure of the universe. And because the initial planning phase for this new gallery was unusually long, by the mid-1990s we also knew that we could not ignore a key and exciting new area of astronomical research, the question of dark matter. As curator, I needed to consider how artefacts could tell these stories.

By the mid-1990s, the outline of the gallery was well established: the organising theme was that the application of new technologies to astronomy tended to reveal new universes – in other words, each time science changed the way it looked at the universe, using only the eye, then the telescope, and then adding new detection devices to telescopes, science encountered a fundamentally different universe. Exhibition areas devoted to visual sky astronomy, to telescopic astronomy, to photographic and then spectroscopic astronomy (Colour plate 11) take the visitor from the eleventh century through to the twentieth, from the geocentric to the heliocentric, to a stellar universe, to a universe composed of galaxies and finally to an expanding universe set approximately in the mid-1950s. Institutions from around the world loaned historical artefacts, including William Herschel's original 20-foot telescope wooden tube and an 18.5-inch speculum mirror, Mount Wilson's original 100-inch Newtonian cage used by Edwin Hubble, and Lick Observatory's Brashear radial-velocity spectrograph. We also acquired significant contemporary ground-based artefacts for the collection, including Palomar's prime-focus spectrograph – from 1950 until the early 1980s the fastest spectrograph in the world sitting on top of the largest telescope in the world. This spectrograph/telescope technology symbolised William Herschel's classic dictum that the purpose of large telescopes was to increase the 'power of penetrating into space'.[5] Herschel's point of view is reflected in the gallery's choice and arrangement of artefacts: from Tycho's equatorial armillary sphere (Colour plate 12), a Huygens lens, the Herschel 20-foot reflector, to Mount Wilson's 100-inch reflector and the prime-focus spectrograph from the 200-inch. The latter artefact highlights that astronomy's ability to 'look' into space also can be the result of increasing the efficiency of the detector – a point that introduces the final section of the exhibition, the 'Digital Universe'.

This section was originally called 'Space Astronomy', to reflect an institutional mind-set at the museum which had looked to NASA as the primary stakeholder. But we were able to broaden the scope of this section and rename it as we secured additional funding from the National Science Foundation, as well as corporations such as Kodak, Corning and TRW, some of which had invested heavily in ground-based instrumentation. This change allowed for an exhibition organised mainly along parallel scientific and technological lines, mapping revolutions in thinking about the universe with changes in technology. This parallel, though not particularly profound to the specialist historian, was met with happy smiles and even surprise by contemporary scientists and our technology-oriented patrons.[6]

The 'Digital Universe' section departs, however, from the linear parallels and firm conclusions of the first four sections. As it deals with the present, I chose not to offer conclusions on scientific views of how our understanding of the universe has changed as a consequence of digital technology, though some possibilities are presented. This section takes a thematic approach, examining broad categories of cosmological questioning: the origin of the universe, the evolution of the universe, the large-scale structure of the universe. Most of the objects exhibited here are new accessions, from a variety of sources: the Hubble Space Telescope back-up mirror; flown and retrieved Hubble instruments; COBE engineering instruments, an early computer-controlled photometer and an image-tube spectrograph as examples. Some were chosen because they demonstrate key paths of development. The original '4-Shooter' CCD camera from Palomar, for example, proved the concept embodied in the wide-field planetary camera on Hubble.

The primary criterion guiding these acquisitions was to identify and collect instruments responsible for changing science's view of the universe. The image-tube spectrograph (acquired from the Carnegie Institution) is the one built and used by Vera Rubin and Kent Ford to determine the rotational dynamics of spiral galaxies and sense dark matter unequivocally. The development of our understanding, over a period of decades, of the existence and structure of the cosmic background radiation, the 'fingerprint' of the big bang, is explored through a series of artefacts: George Gamow's original YLEM bottle, Robert Wilson's pigeon trap, Robert Dicke's radiometer, COBE hardware and various higher-resolution successors. The evolution of structure in the universe is represented by the twice Shuttle-flown Hopkins Ultraviolet Telescope, by WFPC-1 hardware from Hubble and finally by the Smithsonian Astrophysical Observatory's 'Z Machine' from Mount Hopkins, the central instrument used by John Huchra and Margaret Geller to create a survey that revealed large-scale structure in the contemporary universe.

The most challenging portion of 'Digital Universe' deals with missing matter. If the exhibition had opened in 1995, it is unlikely that issues such as dark matter or dark energy would have been included. Parts of this section, such as the faint-object spectrograph (FOS) retrieved from Hubble, or a 20-inch photomultiplier from the original Kamiokande II detector that took part in measuring the neutrino flux from supernova 1987A, were originally planned for a treatment on 'exotic' or 'extreme' objects such as supernovae and black holes. However, in the ensuing years it became clear that these instruments could be linked in the search for dark matter. Starting with Vera Rubin's spectrograph (detection of the mass anomaly), the Kamiokande detector and the FOS represent aspects, along with elements of X-ray telescopes, of the search for missing baryonic matter. Not covered at all is the growing field of astroparticle physics that is devoted to the search for non-baryonic matter. This is an area for future attention.

Our growing recognition of the importance of the search for the dark side of the universe influenced other parts of the 'Digital Universe' section. We began the section displaying the known electromagnetic spectrum using as many graphic illustrations and interactives as we could fit in. Our purpose was, first, to show how small the optical spectrum is compared to the full spectrum, and, second, to introduce a major display of electronic analogue and digital detectors designed to study the full spectrum, as well as the high-energy particle flux called 'cosmic rays'.

The detector collection in the 'Explore the Universe' gallery ranges from a loan of Dicke's original radiometer, which confirmed the big-bang cosmic background radiation, to an IRAS focal-plane element, the first semiautomated photoelectric photometer at Kitt Peak, prototype and back-up X-ray area detectors from ROSAT and Chandra, an element of the scintillation chamber from the Compton Gamma Ray Observatory and the original flown ionisation chamber Victor Hess used to establish the vertical profile of cosmic rays. The point of this display is to show the vast variation in detector designs required to sense the known universe. The subtext is that, even with all this effort, science only has limited understanding of the universe because, as astronomers finally accepted, their detectors have only been able to detect a very small portion of what is out there. This treatment introduces the visitor to the gallery's last section and the theme of the dark universe.

Presenting history in a museum context

During the time I was developing 'Explore the Universe', the Space History Division was rethinking its collections rationale. In the early 1990s, the division changed the basis of the collections rationale to emphasise clear, broad goals rather than catalogues of specific artefacts. Working in the former mode, I had developed a two-dimensional taxonomy to highlight the important correlation between detectors and spectrum in the development of astronomy. This led to the acquisition of a suite of X-ray, ultraviolet, visual and infrared detectors representing some 40 years of developmental effort by the Navy and Air Force, as well as by NASA/Goddard, universities and industry. But I also realised that this 'Noah's Ark' approach had real practical and intellectual limits. I did want to demonstrate that a diversity of real and perceived uses propelled development, and that goals, objects and techniques changed with time. I recognised that my collecting responsibilities had to encompass a broad range of possible future interests, ranging from preserving technical details of the hardware to preserving 'institutional goals and styles, national goals and priorities, [and the] scientific goals of those who lobbied, designed, built and then used the hardware'.[7]

But a profound change was taking place within the division, reflecting disciplinary trends. Other members of the staff expressed a growing sympathy for a stronger historical approach: that 'the objects in our collection are more meaningful and significant as historical artefacts than they are as examples of clever or effective engineering or as sources of specific kinds of information'.[8] We explored arguments in material-culture studies that centred on the importance of experiencing the 'real thing' as a means to illuminate history and draw attention to historical events.[9] But overall we knew that doing so required a significant shift in regarding why and what we collect.

This shift therefore provided a new context in which to consider not only what I collected but how I presented artefacts to the public. In particular, it encouraged the use of contextual constructions such as three-dimensional dioramas to illustrate such themes as the changing relation of the human observer to the machine. This decision was also confirmed by a series of formative (pre-exhibition) evaluations in which we brought artefacts to the public, with test labels and graphics, and studied their response: how they reacted to the objects and what they needed to enhance their understanding.[10] An early evaluation of the Palomar prime-focus spectrograph provided an important finding. The object was a mystery to visitors unless we showed clearly where it fitted into the telescope, and how a human observer actually used it. This relational and contextual approach proved to be the best way to 'uncongeal' an artefact for the casual visitor: to present the artefacts not as ornaments, but as characters on a living stage, making them the centre of the action. We wanted our visitors to understand how the experience of doing astronomy developed in concert with changes in instrumentation. To do this, we needed to put the visitors and the instruments in the right display context.

But we had neither the space nor funds to build extensive dioramas in the gallery's floor area of less than 5000 square feet. Our goal, by necessity, was more limited: to create mini-dioramas that placed an artefact, especially those associated with transformative historical developments, in its immediate technological and historical context. The gallery uses this technique for showing Tycho's 'hands-on' use of an equatorial armillary sphere (Colour plate 13); William Herschel's method of sweeping the heavens in his back yard, standing on, and hence within, his telescope, but exposed to the open air (Colour plate 14); Hubble's direct manipulation of the 100-inch telescope within a dome (Colour plate 15); and the Old Mills radial-velocity spectrograph at Lick Observatory (Figure 1), mounted in a

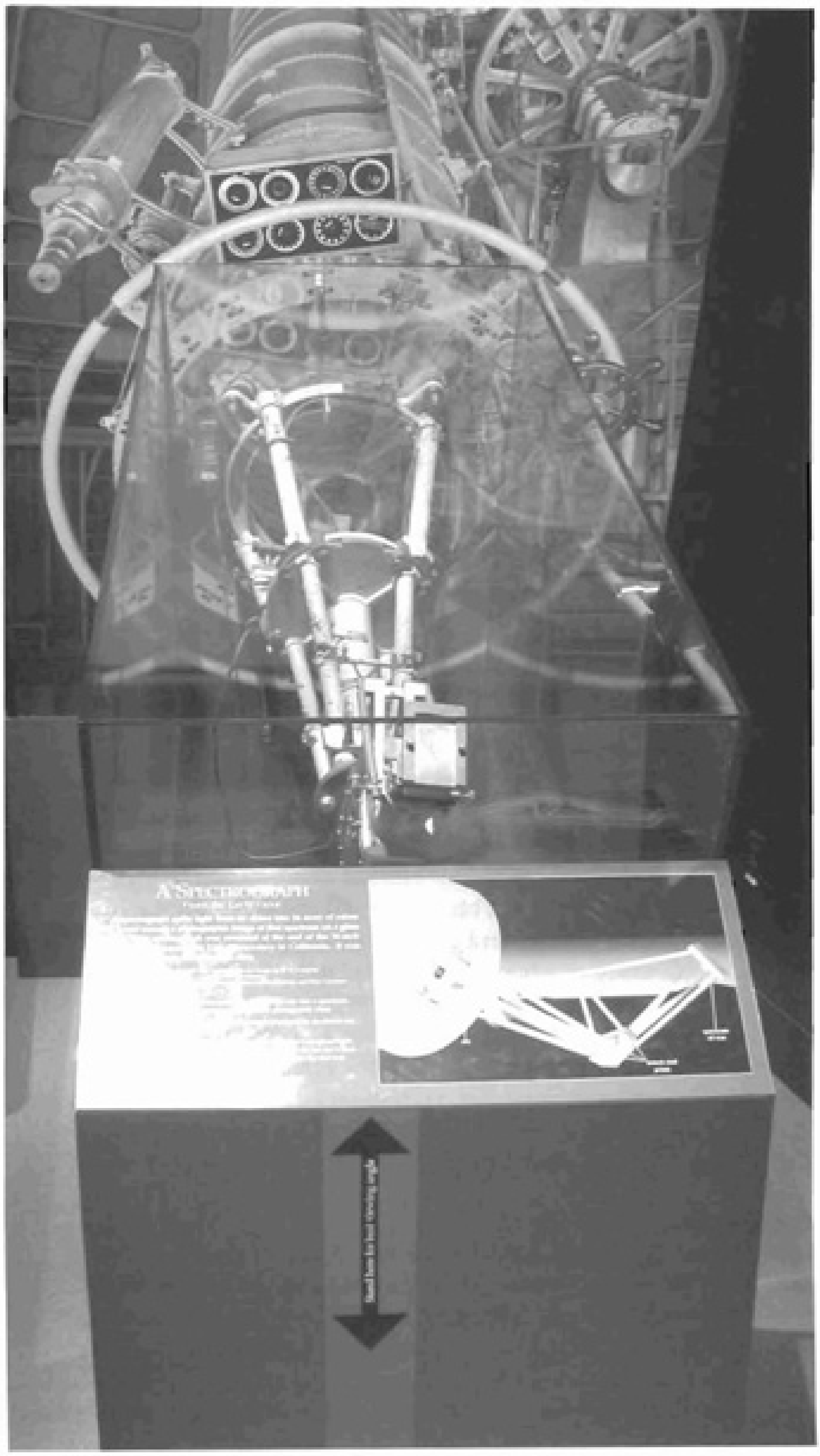

Figure 1 Direct view of the Lick spectrograph, showing it in its proper relationship to the 36-inch refractor, dome and slit. (David DeVorkin)

photographic diorama illustrating its relationship to the telescope. I would have loved to place the Palomar prime-focus spectrograph within its actual observer's cage, but that would have taken up a large chunk of the gallery. We found an elegant compromise by situating the instrument at the vertex of a blue cone of light representing the beam from the 200-inch mirror, and using photographs and digital media to tell the whole story of where the instrument sat within the telescope and how the observer used it, and, finally, how the astronomer processed the data. In the 'Digital Universe' section, we highlight a historic transition in the human–machine relationship: the gradual removal of the human observer from the telescope, both on the ground and in space, largely through the application of electronic and now digital means of detection, imaging and remote control (Figure 2).

Figure 2 The 'What's New' section invites visitors to 'observe' at electronic kiosks, in the same way that the astronomer depicted in the picture on the right is observing remotely using the 4-metre Mayall telescope at the National Optical Astronomy Observatory. The 'observing sessions' reveal where various satellites are in space at the moment and also offer other interactives. (Eric Long/Smithsonian National Air and Space Museum)

Conclusions

In each of these dioramas, the presence of the original instrument engaged in discovery promotes a sense of experiencing an actual event in history, an event validated by the survival of the physical artefact itself, as well as by the survival of knowledge about its role in the process of exploration and discovery that helped to shape our understanding of the universe. When the instruments survive, they attest to these achievements, in ways that are still being uncovered as historians continue to search for new forms of analysis and interpretation.[11]

One extensive post-opening evaluation of 'Explore the Universe' has been conducted. In that survey, 55 per cent of visitors interviewed after exiting the gallery understood the primary theme: 'How astronomical tools have changed our view of the universe'.[12] Although an interactive thermal-infrared imaging camera was the most popular single item mentioned by visitors, the exhibition attributes that most enhanced visitor experience (85 per cent) were 'Telescopes and other objects'.[13] One visitor expressed amazement at the sheer size of the Herschel telescope, whereas another visitor interviewed for the project expressed his frustration generally with the necessary precautions one has to take in exhibitry: remarking about an aircraft engine, he wanted to rip off the plastic cover and actually feel the pieces. An engineer visiting the museum wanted to 'see some of the real items that had actually gotten into space and had some historical significance. I wanted to see them for myself.' And another visitor preferred direct experience 'rather than looking at them in a book or having someone tell me about them. I just want to see stuff.'[14] This evaluation was not designed to determine if seeing the 'real thing' was important to our visitors, but these examples suggest that the actual artefacts lent impact and authority to the displays.[15]

Overall, however, this exercise convinced me that fully-contextual exhibits do require three-dimensional dioramas that place artefacts in their historical settings. This, again, is nothing new in the museum field, but it is a reminder that the direction many museums are taking today, from explanatory labelling, graphics and video to the use of electronic simulations and immersion, might not be an effective educational strategy if the artefacts of the enterprise are abandoned or reduced to mere ornamentation.

This observation directly impacts how and what we collect. It also creates a challenge that, in purely economic terms, is not easy to meet. That is, when considering an instrument or object for collection, it is not enough to collect only the object itself without also collecting, in some form or another, as much information about its surrounding frameworks: those that brought it into being and those required to make it work. This leads to a specific collecting method: to collect the key object, in my case the detector, and then as many elements of its context as possible – the instrument of which it was a part, the satellite bus and the infrastructure that enabled the creation of the detector and its associated systems.

Few, if any, of the environments that surrounded these detectors have been preserved. Laboratory space in any scientific institution is valuable property, quickly cannibalised once a project is completed. The effort required to reconstruct them, and indeed to be sure that the pieces are authentic, is enormous and prohibitively expensive.

Possibly the only complete environment preserved in the Smithsonian collections pertaining to astronomical history is the workshop of Henry Fitz from the mid-nineteenth century.[16] This does not mean that the situation is hopeless. Far from it. Very effective means have been developed to preserve detailed graphics and textual descriptions, either from original sources or through structured oral and video-history interviewing.[17] As the capability of simulation improves, indeed, this medium may help to recapture the feeling of being there. But the link with the past will only remain solid if an undeniably clear material record survives. And since icons breed myth and legend, only full contextual display should be the goal of the art of curation.

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Brian Durrans

Space is the place

Overview

My argument is that both public and scholarly understanding of space is poorly served by technological bias. To advance such understanding, social context needs to be brought into the picture. By 'social context' I mean not just the setting in which space science is practised – its funding, organisation, personnel, and so on – but also how space and related concepts are used in the practice of most people's everyday lives. By 'related concepts' I indicate those ideas, principles or points of reference, such as God or heaven or spirit world or fate, which space partly incorporates or overlaps with, but which it never completely or even remotely displaces. In this looser, operational sense, space resembles much that has preceded it and that continues alongside it. This sort of space is as much about 'in here' as about 'out there'. It is also as implicit in action as explicit in thought.

Although trained scientists are a social minority, there is widespread adherence to certain precepts taken to be scientific. Trained scientists may have custody of scientific traditions, but not everything they do is scientific. In any setting, some people are more concerned than others to explain things, and some are more relaxed than others about inconsistency, cheerfully adapting their behaviour and (when they can be bothered to provide them) explanations to different or changing contexts. Such disparities can parallel those between indigenous peoples and their Western counterparts. None of these contrasts is final or fixed, however, and what people have or do in common is often more interesting than their differences.

The key conclusion is that museum presentations about space need to break the spell of technological enchantment if they are to promote genuine and widespread understanding in this field.

The enchantment of technology

In 2002, on a visit to the Rose Center at the American Museum of Natural History (AMNH) in New York, I sat through a show in the Hayden Planetarium called *Are We Alone?*. This was written by Ann Druyan and narrated by Harrison Ford, both well qualified for their roles. Ann Druyan adapted the late Carl Sagan's novel *Contact* into the movie of the same name, and was earlier involved with him in the Voyager project.[1] Harrison Ford in the *Star Wars* series played the same sort of risk-taking entrepreneur as in the *Indiana Jones* films, although not so committed to the enlargement of knowledge. Such credentials raised expectations for the Planetarium show, but the result was disappointing.

The problem with the show epitomises how space science itself has been represented, not just in the media and in museums, but also in wider discourse, at least since the advent of space travel. The problem is the enchantment of technology, which has drained the field of social content.

Any planetarium screening involves impressive technology. But when your theme is hypothetical life beyond the Earth, there is nothing much for the impressive technology to show except places where life may be possible. In our own Solar System, two options seem to be Mars (at least below the surface) and Europa, one of the moons of Jupiter. For both of these places some striking images are available. For more distant stellar systems, where there may be a better chance of life, we just don't have good pictures, so in this case the less interesting photos were jazzed up with graphics. Those responsible for the programme were presumably so enthralled by their subject and the means for presenting it that they couldn't imagine it might get boring.

The interest in the search for ET is its *human* interest, which raises questions such as how to justify expenditure on a search that might not be successful, and what actual contact might mean for us or our successors in theory and in practice. Part of the human aspect of the story is what human beings imagine alien beings to look like.

In 1997, Kurt Andersen in *The New Yorker* identified from movies and TV exactly six types of space creatures:[2]

1. More or less normal-looking people (*Starman*, *3rd Rock from the Sun*)
2. Hulking humanoids with enormous bald heads (*Star Trek*, *Mars Attacks*)
3. Small, grey, hairless, chinless, big-eyed waifs (*Close Encounters of the Third Kind*, *The X-Files*)
4. Comic-relief plush toys (Chewbacca and Ewoks from *Star Wars*)
5. Swamp creatures (ET, Yoda from *Star Wars*)
6. Really, really big shellfish and insects (*Predator*, *Men in Black*, *Starship Troopers*)

He also identified a trend towards hybrids and other combinations of these types, and a growing wetness or sliminess of extraterrestrials: it seems that cinema audiences flock in to be grossed out.

It might have been interesting to hear Harrison Ford tell us why aliens might not look like any of these or how media representations are often followed by reports of similar entities being seen, and

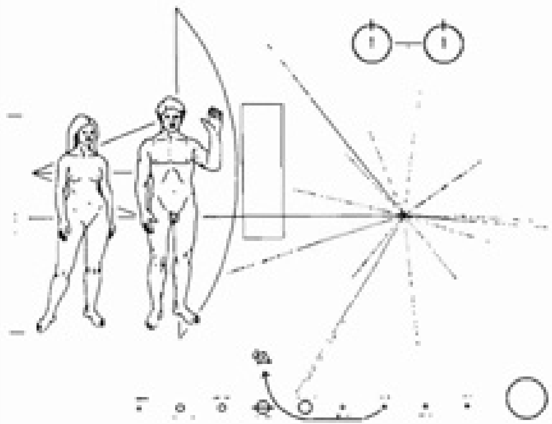


Figure 1 The graphic message to alien intelligences designed by Carl Sagan and Frank Drake for Pioneers 10 and 11, launched in 1972 and 1973 respectively. (NASA/Science & Society Picture Library)

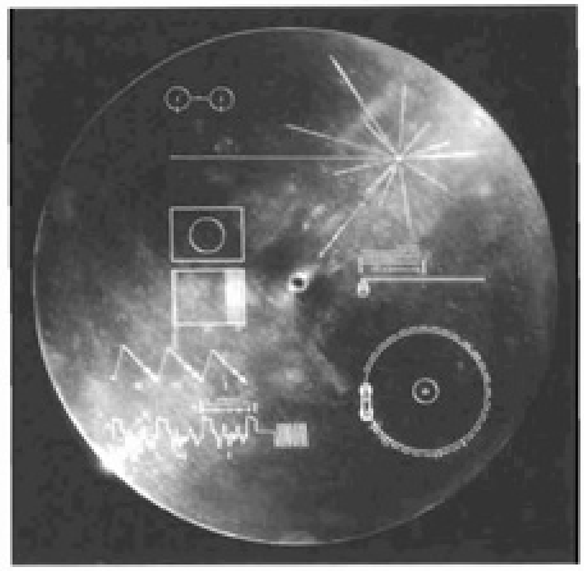


Figure 2 The more ambitious message carried by Voyagers 1 and 2, both launched in 1977, took the form of phonograph discs containing images, spoken greetings and other sounds. (NASA/Science & Society Picture Library)

sometimes abducting Americans, but again the opportunity was missed. (I'll return to space aliens again at the end of the chapter.)

The Planetarium might have shown good images of several spacecraft launched in the 1970s which, if not designed to seek out intelligent life, at least carried deliberate messages for any intelligence that might chance upon them. The Pioneer 10 and 11 and Voyager 1 and 2 space probes are by far the most travelled man-made objects in the universe. Each of them carries information that tries to explain who we are (Pioneers 10 and 11 bear a simple graphic panel, Figure 1; Voyagers 1 and 2 carry a phonograph record, Figure 2). Pathetically inadequate though such messages may be for their intended purpose, they nevertheless speak of human achievements, fears and aspirations. The *Are We Alone?* show is not alone in ignoring such human elements in its scientific presentation. In the superbly-illustrated Time-Life book on *The Far Planets*[3] – part of a series called *Voyage Through the Universe* – mention is made of the spacecraft that took many of the best pictures included, but there is not a word on the quirky messages they carried along with their cameras.

In August 1989, Voyager 2 was drawing close to Neptune, 12 Earth years away from home. To celebrate the occasion, the team of scientists and engineers who had designed and controlled the vehicle from Pasadena threw a party at the Jet Propulsion Laboratory. Chuck Berry (the only – then – living American composer represented on the phonograph record Voyager took with it) gave a live performance of 'Johnny B. Goode', a song now headed for the stars. Following that, Carl Sagan delivered what was called a 'benediction', referring to the event as a 'rite of passage' for Voyager 2. He did not speak of searching for extraterrestrial intelligence, but only of the possibility of 'beings who might encounter [the spacecraft]' in 'the great, dark ocean of interstellar space' (note the humanising 'who').

Sagan's main emphasis, however, was on the importance of overcoming problems we have on Earth, of using an outside perspective to help focus on home. There is something of the same idea in much of the message-sending that he and many others have organised, whether locked onto the distant future or deepest space. Like the prospect of death, the idea of a distant destination concentrates the mind wonderfully on here and now.

Perhaps the SETI (Search for Extraterrestrial Intelligence) lobby has become wary of ridicule, just as the space-science community is having to adapt to an increasingly militarised budget and policy. This could help explain the uninspiring character of the *Are We Alone?* show. No technology needs enchantment more than military technology – enchantment in the sense of obscuring its dependence on socially-framed decisions about the ends and means of production, and to that extent evading criticism. What is interesting about all this, however, is hearing, in the context of scientific activity, not simply terms such as 'benediction' and 'rite of passage', but others like 'the future' or 'deep space', used to focus attention on immediate or proximate concerns. Such metaphorical usage comes very close to how people in most parts of the world handle ancestors or spirit beings or gods of various kinds, which is to say pragmatically and through engaged activity rather than being overly theoretical about it.

This is the sort of stuff to pack them into the Hayden Planetarium: science as human endeavour, warts and all, and with technology itself as part of the story but not as the whole of it. Short of such a large-scale improvement, what else might the *Are We Alone?* show have included to be a bit more inspiring?

Perhaps something about SETI?[4] We could have had a summary of the history of this interest, such as the founding of the Planetary Society in 1980 and perhaps NASA's adopting the SETI programme in 1992 only to abandon it a year later, and the reasons for that. SETI had made progress of sorts since the 1970s and has continued, though with reduced funding, following the NASA cold shoulder.

NASA adopted SETI on the 500th anniversary of Christopher Columbus's discovery of the Americas. In his 1989 'benediction' for Voyager 2, Carl Sagan anticipated, as many other protagonists for the manned space programme have done before and since, an eventual colonisation of other parts of the Solar System and ultimately beyond. Especially in the world's leading space nation (though less so among Native Americans), the European conquest of the Americas which Columbus set in motion endorses contemporary 'new frontier' thinking. How can the negative as well as the positive lessons of that experience serve an interplanetary endeavour? Possible life on Mars or Europa might not be 'intelligent' (assuming it takes one to know one), but what kind of intelligence are we talking about? The intelligence of beings capable of developing powerful technologies? The intelligence of HAL or Deep Blue? The intelligence of people with an intimate understanding of their local ecosystems? The wisdom of children or of sages? If there is no sign of life, or of intelligent life, then do we assume it's acceptable to visit, and possibly stay?

Why should anyone care whether there is life elsewhere in the universe? Why should we be encouraged to think of it as, of all possibilities, a kind of person? These questions can't even be framed outside a concern about the social context of science. They have to do with responsibilities and relationships, and are therefore about morality. A line-up of both benevolent and malevolent aliens on our TV and cinema screens may imply not only that there is a market for both, but also that people are anxious about others, whether co-citizens or from further afield. What did the Planetarium show imply about the value of space exploration and its current level of funding? The lead sponsor of the show is the risk- and capital-management transnational Swiss Re, whose guiding principles include '[anticipating] the nature of risk' and [combining] 'global perspectives with local forms'.

These are questions to engage lively minds. For school students, space science could even be integrated with the English curriculum. From *Star Trek* we have the celebrated split infinitive, 'to boldly go'; from Sagan's benediction, the grammatically traditional 'to venture forth' – but the latter is prefaced by an injunction to 'cherish the Earth'. Or it could be linked to the politics or history curriculum: which view is more in tune with the twenty-first century, or at least with the leading space nation of the twenty-first century? Discuss.

The Planetarium show might also have featured the beautiful Arecibo radio telescope in Puerto Rico and perhaps a dramatised reconstruction of the spine-tingling moment, memorably recounted by Frank Drake,[5] when the assembled scientists and technicians first heard – not the intelligent signal all these people are trying to find – but simply the background mush against which they hope one day to distinguish it. Something might have been said about the SETI@home project in which at least one million computers, in offices, labs or homes, are hooked up to flash on their screensavers the very iconography of contemporary science – shifting, vivid-hued, jagged peaks and troughs – in a collective number crunch to catch that first, elusive, deliberate signal among the background noise coming in from Alpha Centauri or wherever by way of (when I last looked) the

University of California at Berkeley. Twice during the show, however, Harrison Ford asked us to imagine whether there might be someone (that was precisely the word used) on another planet in another galaxy wondering, as we were, whether there was any other life in the universe. The idea was that if we were thinking of them, they might be thinking of us. That much, at least, was an echo of Carl Sagan from 1989 in the very different setting of 2002. Such reflections on the often eccentric career of space science are not only part of its story, and interesting; they are also reminders that science does not stand outside emotion or controversy or human values, and as such they can help attract new audiences to what scientists have to say about the world – or about other worlds.

The Rose Center by any other name

Despite the literal and symbolic transparency of its glass-box architecture, for the Rose Center the human dimension of space as a resource for a multitude of uses, rather than as somewhere to see and understand only in physical terms, is evidently a closed book. I wonder whether most visitors left as glazed over as I did?

This was just a particular instance of a larger museological truth. Transmitters don't always consider receivers – provided they exist and are switched on, that's all that matters. The main business is to refine the message, to make it as accurate as possible. The problem here is another kind of technological enchantment, this time an obsession with communication technology. If you are still failing to engage with audiences, there is a whole arsenal of further technological or at least presentational solutions available: go for maximum impact – a striking architectural flourish (such as the Rose Center, the Wellcome Wing at the Science Museum in London, or the Great Court in the British Museum); or for son et lumière, multimedia, IMAX, 3D movies, installation art, audio guides, gallery talks, work-in-progress sessions with curators, audience participation, hands on, movement, aromas, argument and debate, surprise. Run the risk of critics calling your museum 'dumbed down' and of a significant proportion of your interactive equipment being out of commission at any given time.

There is nothing new in any of this, of course, but none of it begins to address the real issue. A display on the theme of space has to find some way of referring to space in human terms. That means grasping contemporary popular attitudes towards space – not necessarily approving of them, nor playing down to them, but taking them into account, and knowing that such attitudes have changed in the past, are inconsistent now, and will probably be no less so in the future. This implies an awareness of fragmented or reconfigured mindsets, of the compartmentalisation of experiences which elsewhere and in the past tend or tended to be more integrated and differently valued than they are among most contemporary museum-goers. It means (of course) teaching new things, and helping people reject false information and misunderstanding; but also encouraging them to recognise as valid much of what they already know or are familiar with from their own experience. I have no formula for how to do this – I only suggest that it should be done.

Space as a cultural resource

Not only is space a theme with almost limitless connotations of novelty and the future for all of us currently living in technologically-complex societies – and indeed most strikingly for many millions of people elsewhere – but it is not a new theme at all.

First we should dispose of the trivial, naive or stock-evolutionist sense in which the history of interest in space tends to be expressed in textbooks and in some museum displays: space displaces heaven; theology makes way for astronomy or cosmology, or whatever it is called; the cosmos is a screen on which we and our ancestors have always projected hopes and fears for other worlds, better or worse. This formula is invalid in two respects. First, it doesn't describe what space actually means to most people now, and, second, it doesn't describe what space meant to almost everyone in the past.

Instead, we should be thinking of space as a cultural resource, part of the cultural world 'in here', whatever it is discovered to be 'out there'. Space is a product of the Space Age, of the exciting era that began with Sputnik and ended (if it did end) – when? With the moon landing? Are we still in that era, although largely preoccupied with other things? But space is a label attached to something – a category – that existed for people to think about and operate with, long before the Space Age, and this category still exists across the world as a familiar non-technological point of reference. How scientists work and what and how they think tends to be richer and messier, more dynamic, interactive and imaginative than is suggested by its outcome in a more accurate description of some aspect of the world. And this is as true of space scientists as of any others. In the same sense, how anyone or everyone lives and thinks is never quite captured by generalisations of how they do so. Such generalisations deteriorate easily into unchallenged fact or stereotype. No history book is ever completely free of such guff.

One widespread popular use of space exploits the immunity from empirical verification which it offers to certain unusual claims or experiences, which may seem plausible by virtue of their sincerity. Some spirit possession cults, for example, provide marginalised individuals with a socially-sanctioned medium through which obliquely to express their needs and concerns when overt declarations would offend prevailing values. UFO sightings and alien encounters may fall into a similar category. What is at stake here is not necessarily truth but appropriateness.

Because of its characteristic rings, Saturn is the most familiar of the model planets to be seen from well outside the glass-walled architectural statement of the AMNH's Rose Center. This more than anything else signals that the business of the Rose Center is astronomy. A recent bestselling book uses a classical Mediterranean metaphor for an essentialist assertion about human gender difference: *Men Are from Mars, Women Are from Venus*. Attractive though it is, very few people claim to be from Saturn (what gender would they be?), but one who did was Herman Poole 'Sonny' Blount, a.k.a. Sun Ra, a prolific and remarkable pianist and leader of the Arkestra, who died in 1993 aged 79. I want to use the example of Sun Ra briefly to explore the useful fuzziness of space as a concept.

From an output of over 100 records, one issued in 1972 was called *Space is the Place*. This could have been an alternative name for the Rose Center, and many of Sun Ra's tracks and albums refer, as his own name does, equally to space as a place in the sense of a *physical location* and as a place in *the socialised, but heavily imaginative, sense of home* – in this case, narrowing the familiar African reference of black America to a conventionalised ancient Egypt in particular. As well as being a master musician, Sun Ra also had a sense of humour, but his take on space as an exotic theme or metaphor in some ways calls to mind the place of other worlds in the cosmological systems of tribal and non-Western peoples. Some critics are reported to have been 'uncertain about his seriousness', as travellers to other countries might have been unable or unwilling to take local people's world-views seriously, to the extent that they engaged with them at all.

To literate outsiders, and especially to Westerners, other people's ideas of what is question-beggingly called 'the supernatural' often appear not so much bizarre as *indeterminate*. People are rarely rigorous about what they believe, or at least they can be inconsistent in how they convey this to others. Yet such schemas provide a rationale for living meaningful lives, and the one which underpinned Sun Ra's career and reputation was not only meaningful in its own right but was perhaps also a mockery of naive criticism. Claiming a Saturnian origin might even have been a tax dodge if he were better off, but he was less wealthy than his talents deserved. Compare Harrison Ford. Here is a man who over many years and for huge audiences has pretended to fly spacecraft. Not only has his career not suffered from uncertainty about his seriousness, but he has made a fortune out of it. Or take Steven Spielberg, who according to at least one of his collaborators (quoted by Kurt Andersen) is an alien himself. Sun Ra was a professional musician and, like Ford and Spielberg, a space entrepreneur. More than either of them, he imaginatively exploited the indeterminacy of space, but in the end got less out of it than they did. Asking why confronts a socially-embedded value system and associated issues of taste, production and social division.

Professionals and amateurs

While the history of European exploration of the rest of the world is being rewritten in the light of increasing knowledge of the earlier movements and explorations of non-Europeans themselves, and of their role in the mutual encounters which European 'discovery' always entailed, on several continents auxiliary travellers also made tracks for others to follow. Exploring tended to be subsidiary to their main line of business. Such individuals or small groups tended to be remote in social terms from the more 'noble' explorers officially recorded in history books (and from belatedly-recognised indigenous leaders). This parallels the contribution of lay people in earlier phases of scientific endeavour from which they are now excluded largely by the need for expensive training and equipment, but also by an image of 'big science' as inaccessible because it is professionalised.

One of the main exceptions to this image is astronomy as democratic participation: the idea that more or less anyone can contribute something through systematic observation of the night sky, or through good luck, using inexpensive equipment. Such activity doesn't of course dilute or criticise the hi-tech infrastructure of professionalised astronomy; on the contrary, it reinforces and draws inspiration from it. It is also clear that SETI plays very differently for its 'big science' and amateur enthusiasts.[6] Parallels from the cultural domain include those amateur contributors (or would-be contributors) to the Royal Academy's Summer Exhibition in London, who imitate their more famous professional counterparts; or – perhaps a closer parallel – the more ambivalent case of amateur metal-detectorists in the context of professional field archaeology. All categories of amateurs, whether in sport, art, archaeology or astronomy, are internally differentiated. Professionals respect and patronise the more serious among them while finding more marginal groups embarrassing, annoying or simply a waste of time. For 'big science', including space science, one reason for these attitudes is a growing recognition that it continues to depend, if problematically, on public opinion. Another may be that across the world, and back through history, it is more closely allied with lay enthusiasm and prejudice than its present self-image can comfortably admit.

Space aliens again

Whatever else they might be about, space aliens or UFOs are a site of convergence between professional and amateur (or perhaps high and low) science practices. The equivalent category for high or big science is called exobiology or bioastronomy. Another, non-congruent but overlapping, category is what might be called the critical practice of science, which of course has adherents across many fields. In all such domains, ideas of what science can't explain, or what political control of science prevents it from explaining – and therefore any number of discourses about freedom, constraint and imagination – find powerful metaphorical expression. Some professionals, among them a number of eminent public figures, pursue serious research in exobiology, the legitimacy of which, in the eyes of at least some of their colleagues, is subverted by its attractiveness to an easily-dismissed (but less easily interpreted) 'lunatic fringe'. This might not be cutting-edge space science but, because it is where values and contradictions are often conspicuous, it is certainly at the cutting edge of a historically-informed understanding of space science as an inescapably cultural phenomenon.[7]

Consider what is involved: projection or recognition beyond normal experience/appearance; a conceptually-rehearsed unification of humankind against an imagined external threat, or at least its calibration against an external point of reference; a challenge to existing assumptions and authority structures where 'big science', like 'big government', may be too myopic or rigid to react appropriately. Such hypothetical encounters need not necessarily be with volitional beings; consideration continues to be given to assessing the risk posed by interplanetary material approaching the Earth (anxieties exploited by, for example, the two 1998 movies *Deep Impact* and *Armageddon*). Nor did the Hale–Bopp comet pass by safely for everyone. Because extraterrestrial intelligence is an imaginative projection before (and hypothetically also after) its potential, empirical, confirmation, the SETI enterprise raises not only philosophical issues[8] but also sociological ones, such as why such concerns arise where and when they do, and take some forms rather than others. This plays into more nebulous nervousness about future fortunes and survival itself: a compelling domain with enormous potential to engage public attention and help make a difference in a world that needs just that.

But for explicitly alien encounters, there are basically two models that unfortunately don't fit Kurt Andersen's six-pack schema of alien types. In the first model, there is a large-scale or apocalyptic invasion for which advance warning is possible and to which response is hi-tech and from centralised authority. The second model, which obviously has wider appeal, is a personalised or random encounter with one or more isolated aliens, or a succession of them, to which the response is low-tech and local, and typically invisible to, or disbelieved or even repressed by, central authority.

While model 1 views all aliens as hostile, the second comes in two forms, what we might call 2a, involving malevolent beings, and 2b, with benevolent ones. Both 1 and 2(a+b) would be recognised by most indigenous communities, for example, in a wide arc from northeast India through Indonesia into the northern Philippines, where the good and bad spirits that affect people's lives are manipulated, collectively or individually, through ritual offerings which for us might be paralleled by sitting in the dark with lots of other people eating popcorn. This, by the way, is a perfectly serious suggestion. Leisure analysts cannot explain why the cinema is so popular when home entertainment is so widely available, of constantly improving quality, and cheaper. And why is popcorn favoured in cinemas?

The issue for us is not whether model 1 or 2 is more plausible than the other, nor whether 2a is more popular than 2b, nor indeed whether there are any further models we might devise. Neither, on the basis of the more popular model 2, does it matter much whether changes in the pattern of what reported aliens are supposed to look like, or the timing and scale of reported UFO sightings themselves, match fluctuations in climate, social trends or media coverage of such phenomena or anything else. In late 2004, Harrison Ford was reported to have signed up for a movie on the taking of Falluja, Iraq, by US Marines, another reminder that *Star Wars* was never just a film title, and making it still more difficult for visitors to the Rose Center who might be interested in hypothetical life in space to dissociate the narrator's voice from all-too-definite death on Earth.

Museums need note only that space serves as a medium for expressing a range of social, corporate and personal interests, and that this happens both despite and because of space science, and always in close association with it.

Notes and references

1 Sagan, C *et al.*, *Murmurs of Earth: The Voyager Interstellar Record* (New York: Random House, 1978)

2 Andersen, K, 'The origin of alien species', *The New Yorker* (14 July 1997), pp38–9. See also Weinstock, J A, 'Freaks in space: "extraterrestrialism" and "deep-space multiculturalism"', in Thomson, R G (ed.), *Freakery: Cultural Spectacles of the Extraordinary Body* (New York: NYU Press, 1996), pp327–37.

3 *Voyage Through the Universe: The Far Planets* (Amsterdam: Time-Life, 1990)

4 Drake, F and Sobel, D, *Is Anyone Out There? The Scientific Search for Extraterrestrial Intelligence* (London: Pocket Books, 1997)

5 Drake, F and Sobel, D, note 4

6 Fricke, A C, 'Professional, amateur, commodity: instruments of identity in SETI, the Search for Extra-Terrestrial Intelligence', paper presented at the American Anthropological Association annual meeting, Chicago, IL, 18 November 1999; 'Information, technology, noise: cultures of/by design in SETI, the Search for Extra-Terrestrial Intelligence', paper presented at the Society for the Social Study of Science annual meeting, San Diego, CA, 30 October 1999

7 The Science Museum's 'The Science of Aliens' exhibition, which opened in October 2005, sets scientific speculation on the possibilities for extraterrestrial life against popular narratives that dominate the subject, but never quite escapes cultural associations. It does, however, eclipse the Rose Center's choice of environments: instead of 'red planet' Mars we get the 'golden' Aurelia; and much better than pallid Europa is Blue Moon ('now I'm no longer alone'), a welcome touch of human awareness.

8 For example, Baird, J C, *The Inner Limits of Outer Space* (Hanover, NH/London: University Press of New England for Dartmouth College, 1987); Fricke, A C, 'Philosophical perspectives on the problem of extraterrestrial signal detection', paper presented at the San José meeting of COSETI, 2001, abstract available at http://www.coseti.org/4273-14.htm.

Brian Nicklas

A select international listing of museums featuring space exhibitions

The incorporation of space exhibitions in museums, and the establishment of facilities dedicated to the subject, is intimately linked to the development and geography of the history of space flight. The former Soviet Union and the United States, as leading centres of space flight, a circumstance initially spurred by Cold War rivalry, have created the vast majority of space artefacts. Europe, too, collectively and through individual national programmes, within and beyond the Cold War framework, has been a prominent creator of space hardware. A broad spectrum of nations – from China and Japan to Brazil and South Africa – also have, in varying ways, pursued space initiatives. These national efforts have overlapped with international organised efforts (such as Intelsat) and, in recent decades, private commercial undertakings. While Soviet and US human space exploration garners much of the public interest, space-based science and applications (such as communications and environmental monitoring) also are recognised for their prominent role in contemporary society (think of global warming debates and news reporting from Iraq). In contrast, the enormously well-financed domain of military and intelligence space activity (primarily a US phenomenon) largely exists below the 'radar'.

This history and range of activity is imperfectly mirrored in exhibitions and museums. The majority of space-themed presentations and institutions are in the US and the former USSR, with fewer examples in other countries. This mapping also has been shaped by profound differences within the US and between the US and former USSR in policies for channelling space artefacts to museums. In the US, the civilian National Aeronautics and Space Administration (NASA) pursued an active public programme of distributing its space artefacts, in concert with the Smithsonian Institution and its National Air and Space Museum. The result has been a wide availability of *civilian* space artefacts within the US and in other countries. US military and intelligence agencies concerned with space, though, have not adopted such a policy and their important and extensive history as represented by artefacts is largely inaccessible. The USSR, in comparison, regarded (as essays by Cathleen Lewis and Asif Siddiqi highlight) nearly all space artefacts as military and intelligence products requiring limited public exposure and created a museum system that embodied this position.

The goal of this listing is to provide a selection of international museums that feature space artefacts, with emphasis on those that regard space flight as a significant part of their mission and have a large regional or national profile. Left out here are the many smaller, but still important, museums (with many examples in the US and former USSR) whose focus may be on specific individuals or local contributions. Unfortunately, there is no handy world directory of space museums that can direct the reader to institutions not included here. For additional examples, readers are encouraged to consult the membership lists of national museum associations.

Australia
Powerhouse Museum, 500 Harris Street Ultimo, PO Box K346, Haymarket, Sydney NSW 1238

Belgium
Euro Space Center, Rue Devant les Hetres, 1 – B-6890 Transinne

Canada
Ontario Science Centre, 770 Don Mills Road, Toronto, Ontario M3C 1T3
H R MacMillan Space Centre, 1100 Chestnut Street, Vancouver, British Columbia V6J 3J9

China
Shanghai Science and Technology Museum, No. 2000 Century Avenue, Pudong, Shanghai 200127

France
Musée de l'Air et de l'Espace, Aéroport du Bourget, BP 173, F-93352 Le Bourget Cedex
Cité de l'espace, Avenue Jean Gonord, BP 25855, F-31506 Toulouse Cedex 5

Germany
Deutsches Museum, Museumsinsel 1, D-80306 München
Deutsches Museum, Flugwerft Schleißheim, Effnerstraße 18, D-85764 Oberschleißheim
Hermann-Oberth-Raumfahrt-Museum eV, Pfinzingstraße 12–14, D-90537 Feucht

Hong Kong
Hong Kong Space Museum, 10 Salisbury Road, Tsim Sha Tsui, Kowloon 852 2721 0226

Japan
The Japan Science and Technology Corporation, National Museum of Emerging Science and Innovation, 2-41, Aomi, Koto-ku, Tokyo 135-0064
Space World, Yahata Higashi, Kitakyusyu city, Fukuoka

The Netherlands	Nationaal Luchtvaart-Themapark Aviodrome, Pelikaanweg 50, 8218 PG Lelystad Airport (EHLE) Space Expo, Postbus 277, 2200 AG Noordwijk
New Zealand	Museum of Transport and Technology, PO Box 44 114, Point Chevalier, Auckland
Norway	The Norwegian Museum of Science and Technology, Kjelsåsveien 143, 0491 Oslo
Russia	The Konstantin E. Tsiolkovsky State Museum of the History of Cosmonautics, #2 Korolev Street, 248650 Kaluga Central Museum of Aviation and Cosmonautics, Krasnoarmeiskaya 4, 125167 Moskva Memorial Museum of Cosmonautics, Pr. Mira, d. 111, 129164 Moskva For additional guidance on museums in Russia and the former USSR see: Association of Space Museums (AMKOS), Khilkov per., 3-13, 119034 Moskva
Switzerland	Swiss Museum of Transport, Lidostrasse 5, CH-6006 Lucerne
United Kingdom	Science Museum, Exhibition Road, London SW7 2DD Museum of Flight, East Fortune Airfield, East Lothian EH39 5LF National Space Centre, Exploration Drive, Leicester LE4 5NS The Museum of Science & Industry in Manchester, Liverpool Road, Castlefield, Manchester M3 4FP World Museum Liverpool, William Brown Street, Liverpool L3 8EN
United States	National Air and Space Museum, Smithsonian Institution, PO Box 37012, Washington, DC 20013-7012 National Museum of the US Air Force, 1100 Spaatz Street, Wright-Patterson AFB, OH 45433 National Museum of Naval Aviation, 1750 Radford Blvd, Suite C, Pensacola, FL 32508-5402 Museum of Flight, 9404 E. Marginal Way South, Seattle, WA 98108 San Diego Aerospace Museum, 2001 Pan American Plaza, Balboa Park, San Diego, CA 92101 California Science Center, 700 State Drive, Los Angeles, CA 90037 The Pima Air and Space Museum, 6000 East Valencia Road, Tucson, AZ 85706 The Franklin Institute, 222 North 20th Street, Philadelphia, PA 19103-1194 Fernbank Science Center, 156 Heaton Park Drive, N. E., Atlanta, GA 30307

United States

Cradle of Aviation Museum, One Davis Avenue, Mitchell Field, Garden City, NY 11530

Museum of Science and Industry, Chicago, 57th Street and Lake Shore Drive, Chicago, IL 60637

Space Center Houston, Nasa Road 1, PO Box 580653, Houston, TX 77258-0653

US Space and Rocket Center, One Tranquility Base, Huntsville, AL 35805

Kennedy Space Center Visitor Complex, Mail Code DNPS, Kennedy Space Center, FL 32899

Virginia Air & Space Center, 600 Settlers Landing Road, Hampton, VA 23669

Kansas Cosmosphere, 1100 N. Plum, Hutchinson, KS 67501

Armstrong Air & Space Museum, PO Box 1978, Wapokeneta, OH 45895-0978

North Carolina Museum of Life and Science, PO Box 15190, 433 Murray Avenue, Durham, NC 27704

Roswell Museum and Art Center, 100 West 11th Street, Roswell, NM 88201

New Mexico Museum of Space History, PO Box 5430, Alamogordo, NM 88311-5430

Michigan Space and Science Center, Air Zoo, 6151 Portage Road, Portage, MI 49002

Air Force Space and Missile Museum, 191 Museum Circle, Patrick AFB, FL 32925-2535

US Naval Academy, Armel-Leftwich Visitor Center, 52 King George Street, Annapolis, MD 21402-5034

NASA Ames Research Center, M/S 226/1, Moffett Field, CA 94035-1000

NASA John H. Glenn Research Center, At Lewis Field – Visitor Center, 21000 Brookpark Road, Cleveland, OH 44135

StenniSphere, NASA Stennis Space Center Visitor Center, Stennis Space Center, MS 39529

NASA Goddard Visitor Center, 8800 Greenbelt Road – Code 130, Greenbelt, MD 20771

NASA Wallops Flight Facility Visitor Center, Bldg J-17, Wallops Island, VA 23337

The following Internet sites may prove useful:

Encyclopedia Astronautica, http://www.astronautix.com/
Virtual Space Museum, http://vsm.host.ru/
My Little Space Museum, http://www.myspacemuseum.com/

Colour plate 1 The Astris exhibit as part of the space gallery of the Deutsches Museum in central Munich (page 9). (Archives of the Deutsches Museum)

Colour plate 2
The Europa II exhibit at the Deutsches Museum's Flugwerft Schleissheim branch museum, consisting of Blue Streak, Coralie and Astris rocket stages and a test satellite. These very artefacts were planned to be launched on flight F12, which was abandoned after the disastrous explosion of the launcher on test flight F11 (page 9). (Archives of the Deutsches Museum)

Colour plate 5
John Glenn's Friendship 7 Project Mercury capsule in the National Air and Space Museum, Washington DC (page 50). (Smithsonian National Air and Space Museum)

Colour plate 3 Black Arrow R4 as displayed in the 'Exploration of Space' gallery, 1986–2000. The rocket's orange payload faring, the shape of which was derived from the US Polaris missile design, was prone to damage in this constricted gallery thoroughfare (page 30). (Science & Society Picture Library)

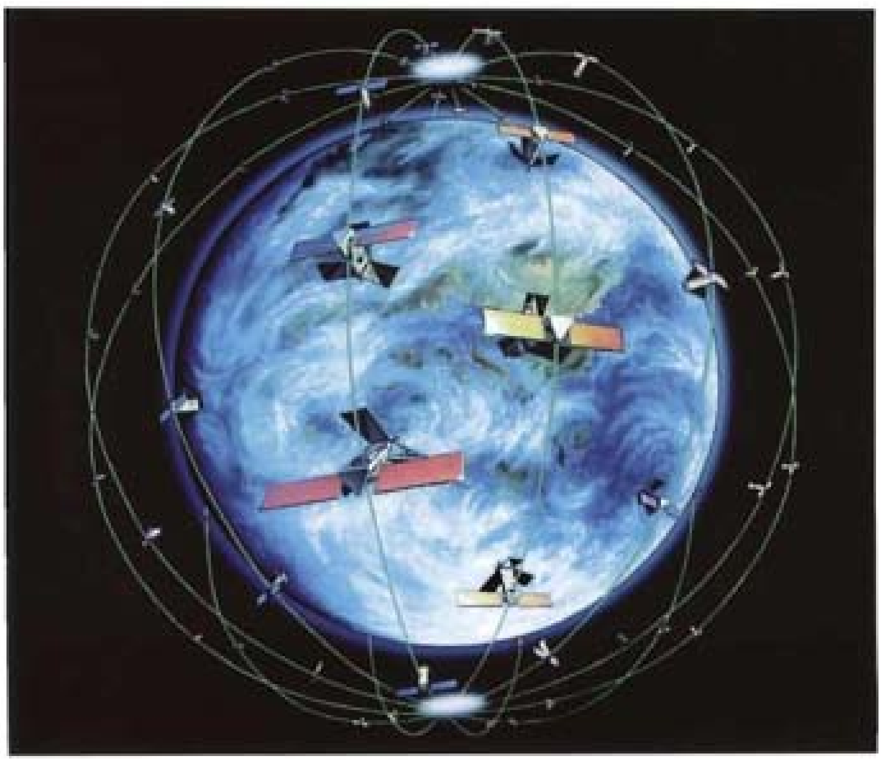
Colour plate 4 Black Arrow R4 as displayed in the 'Space' gallery, 2000 to present. The display represents (although not accurately so) the 'staging' of a rocket as it ascends – a three-dimensional diagram that utilises real artefacts (page 32). (Science & Society Picture Library)

Colour plate 6
The Woomera Heritage Centre Rocket and Missile Park in 1993. Displaying a selection of the rockets, missiles and other weapons launched and tested at Woomera, the park is one of the town's tourist attractions. A Black Arrow launcher is its most prominent artefact (page 79). (Kerrie Dougherty)

Colour plate 7
The Wresat Redstone as it was found by the recovery team in 1990. Despite the fact it had broken up on impact with the ground, the rocket was otherwise in a good state of preservation, although its original white exterior livery had disintegrated under the harsh desert sun (page 81). (Roger Henwood)

Colour plate 8 Models of the American Saturn V and the Soviet N-1 superboosters, side by side at the National Air and Space Museum in Washington DC. The N-1 booster was considered a state secret for nearly 30 years, until the Soviets revealed its existence in the late 1980s (page 105). (Smithsonian National Air and Space Museum)

Colour plate 9
Motorola Iridium satellite on display at the Smithsonian National Air and Space Museum, Washington DC (page 117). (Smithsonian National Air and Space Museum)



Colour plate 10
Artist's conception of the 66-satellite Iridium constellation (page 118). (Iridium Inc.)

Colour plate 12
(opposite) The 'Visible Sky' section of the 'Explore the Universe' gallery includes a full-scale replica of Tycho's equatorial armillary sphere and a progression of visual devices representing continually-increasing positional accuracy (page 161). (Eric Long/Smithsonian National Air and Space Museum)

Colour plate 11 General view of the 'Spectroscopy' section of 'Explore the Universe', showing the 200-inch prime-focus spectrograph on the left, with graphics and the conical converging light beam identifying its connection to the telescope. The Lick spectrograph is centre right, set within a photographic diorama (page 161). (Eric Long/ Smithsonian National Air and Space Museum)

Colour plate 13 Detail of the armillary sphere diorama, showing how the observer manipulated the double-slit mechanism for reducing parallax error (page 164). (David DeVorkin)

Colour plate 14
Diorama depicting William Herschel observing at the top end of his 20-foot reflector and Caroline Herschel (who is just visible) seated in a window in their home taking notes (page 164). (David DeVorkin)

Colour plate 15
Diorama of Edwin Hubble observing at the Newtonian focus of the 100-inch Mount Wilson telescope. The dome and chamber are typically darker than depicted here (page 164). (Eric Long/Smithsonian National Air and Space Museum)

Index