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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

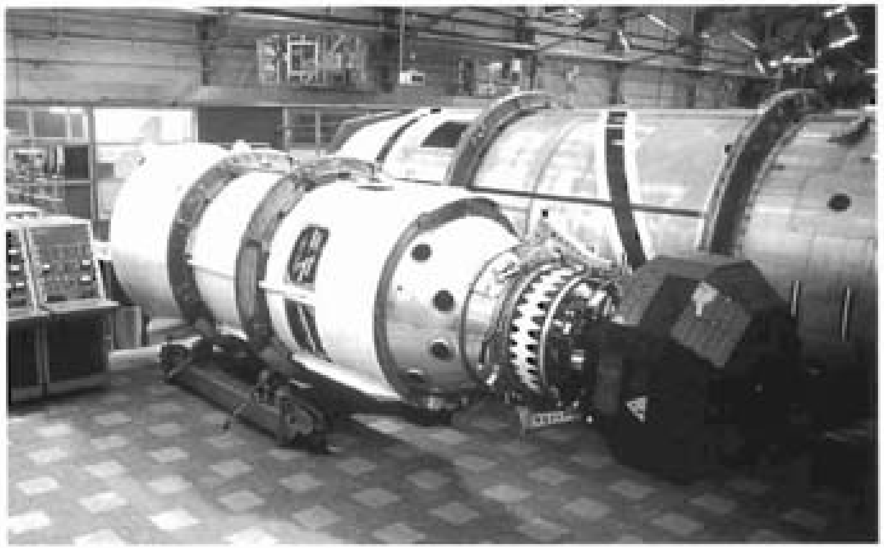

Figure 5 Black Arrow R4 at SARO, Cowes, Isle of Wight, prior to transfer to the Science Museum. The second stage (foreground) has the Waxwing apogee motor and X3 engineering model attached. (Science Museum)

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.

11 Morton, P, note 9, p499

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

23 'Anglo-French technical proposals for the development of a satellite launching system', Ministry of Aviation, London/French Air Ministry, Paris, February 1961

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

25 Dommett, R, 'Crusade, Sparta and Pillera: ballistic flight programmes at Woomera', unpublished memo passed to the author. See also Robinson, H G R, 'The ballistic test vehicle Black Knight', Technical Note No. GW 503, Royal Aircraft Establishment, Farnborough, December 1958.

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.

27 Robinson, H G R, 'Preliminary notes on a proposal for a Liquid Hydrogen/Liquid Oxygen Second stage for Black Knight', memo, 12 December 1961, p1, Panel H2 folder, RAE papers, Science Museum.

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.

33 Minutes of the fourth meeting of the Re-entry Physics Co-ordination Panel, 3 July 1963, pp3–5, RAE papers, Science Museum. © Crown Copyright/MOD. Reproduced with the permission of the Controller of Her Majesty's Stationery Office.

34 'The future Black Knight re-entry programme', draft memo, Ministry of Aviation, Guided Weapons Branch, 25 October 1962, p8, RAE papers, Science Museum

35 Note 26

36 Osbourne, I W, 'Black Knight 50,000 lb thrust motor bay', SP 598, Issue 1, Westland Aircraft, Saunders-Roe Division, September 1962, RAE papers, Science Museum

37 'A small satellite launcher based on Black Knight technology', Space Department, Royal Aircraft Establishment, April 1964

38 'Design study for a small satellite launcher based on Black Knight', Report SP 816, Westland Aircraft, Saunders-Roe Division, Cowes, February 1964, RAE papers, Science Museum

39 'A performance study of a satellite launching vehicle consisting of Black Arrow as the upper stages of Blue Streak', Blue Streak/Black Arrow Report No. D/R/1, British Hovercraft Corporation, Osborne, East Cowes, Isle of Wight, June 1968, RAE papers, Science Museum

40 Pinch, T J and Bijker, W E, 'The social construction of facts and artefacts: or how the sociology of science and the sociology of technology might benefit each other', *Social Studies of Science*, 14 (1984), pp399–441

41 MacKenzie, D A, *Inventing Accuracy: An Historical Sociology of Nuclear Missile Guidance* (Cambridge, MA/London: MIT Press, 1990), p9

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

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