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The Life and Death of an Aircraft: A Network Analysis of Technical Change

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Imagine a technological project that lasts for a number of years, involves the mobilization of tens or hundreds of thousands of workers, designers, managers, and a plethora of heterogeneous bits and pieces including designs, parts, machine tools, and all the rest. Imagine that this project is developed in a constantly changing environment—that requirements, interests, and even the actors themselves change during the course of its lifetime. Imagine that not hundreds but hundreds of thousands of decisions are made. And imagine that in the end it is cancelled amid a welter of acrimony. How can we describe such a project in a way that is more than "simple" history? How can we describe it in a way relevant for the analysis of other projects and technological innovations? How can we explain the decision to close the project? How can we explain its failure? And how can we do this in a way that lets us avoid taking sides?

Despite the recent growth in interest in the social analysis of technology, few tools currently available are really useful. Our problem is that it is too simple (though it contains an element of truth) to say that context influences, and is simultaneously influenced by, content. What we require is a tool that makes it possible to describe and explain the coevolution of what are usually distinguished as sociotechnical context and sociotechnical content. In recent work we have used a network metaphor to try to understand this kind of process (Callon and Law 1989). We have considered the way in which an actor attempts to mobilize and stabilize what we call a *global network* in order to obtain resources with which to build a project. In our language, then, a global network is a set of relations between an actor and its neighbors on the one hand, and between those neighbors on the other. It is a network that is built up, deliberately or otherwise, and that generates a space, a period of time, and a set of resources in which innovation may take place. Within this space—we call it a *negotiation space*—the process of building a project may be treated as the elaboration of a *local network*—that is, the development of an array of the heterogeneous set of bits and pieces that is necessary to the successful production of any working device. We have suggested, that is, that the notions of context and content that are used as common analytical devices in the sociology of science and technology may be transcended if projects are treated as balancing acts in which heterogeneous elements from both "inside" and "outside" the project are juxtaposed.

In this chapter we push our analysis a stage further by considering the dynamics of a large British aerospace project. We consider the way in which the managers of that project sought to position their project in a global network in order to obtain the time and the resources needed to build and maintain a local network. And we discuss the way in which the shape of that project was influenced not only by the efforts of those managers, but also by events and strategies that influenced the shape of the global network. Thus we trace the strategies and contingencies that led to the creation of both local and global networks, the fortunes or the managers as they sought to shape both networks and control the relations between them, and the eventual collapse of the project when the relationship between them finally got completely out of hand.

At one level, then, our story is banal. It is the description of a large military technology project that went wrong. But although this project has considerable interest for the history of British aerospace, here our aim is not primarily to add to the catalog of accounts of military waste. Rather it is analytical. Like many others in this volume, we are concerned to develop a vocabulary of analysis that will allow us to describe and explain all attempts to build durable institutions. Analytically, the fact of the failure in the present project is best seen as a methodological convenience: controversy surrounding failure tends to reveal processes that are more easily hidden in the case of successful projects and institutions.

A Project and Its Neighbors

The TSR.2 project was dreamed up in the Operational Requirements Branch of the Royal Air Force (RAF) in the late 1950s. (TSR stands for Tactical Strike and Reconnaisance; the meaning of the 2 is a mystery.) The structure of the project and its aircraft were conceived in the course of a set of negotiations with neighboring actors. Thus, those who advanced the project sought to establish for it a shape that would allow it to survive. In some cases it was a question of securing sufficient resources from neighboring actors. In other cases it was a question of securing their neutrality for an appropriate period. In both cases it was a question of coming to appropriate arrangements—of defining the relationship between the project and its neighbors.[1]

The origin of this process can be traced to a General Operational Requirement (GOR 339) developed by the Operational Requirements Branch and to a policy for the rationalization of the aircraft industry implemented by the procurement branch of the British government, the Ministry of Supply. So far as the RAF in general was concerned, it was necessary that the end product be an aircraft. All other transactions were predicated on this assumption. That a combat aircraft was needed was not, in fact, that clear in the late 1950s. The defense policy of the United Kingdom as spelled out in the 1957 Defence White Paper was that of nuclear deterrence based on ballistic missile retaliation. So far as the Ministry of Defence was concerned, it was important that the end product not be a strategic bomber—this alternative having been ruled out by the White Paper. This suggested that the project should be a combat aircraft, and given British defense commitments as conceived by the Ministry, it was appropriate that it should be a tactical strike and reconnaissance aircraft (TSR).

So far as the Treasury was concerned, it was important that the end product be cheap. Given this perspective, which was based on its perceived need for economies in defense spending, the Treasury tended to doubt the need for any aircraft at all. At most support could be found for a single combat aircraft. This meant that the aircraft would have to fulfill all the possible combat aircraft requirements of the RAF. Accordingly, there was pressure for a versatile aircraft—a requirement fulfilled by the TSR definition—and also one that might be sold overseas, thereby cutting its unit cost.

So far as the Navy was concerned, it was also necessary to overcome a high degree of hostility. The Navy was purchasing a small tactical strike aircraft called the Buccaneer, and was anxious to persuade the RAF to buy this same aircraft because this would cut unit costs for the Navy and relieve pressure on the arms procurement budget overall. The response of the Operational Requirements Branch was to propose a large, supersonic, precision-strike, long-range aircraft that was quite different from the Buccaneer. Although this response was not what was sought by the Navy, it was intended to neutralize the (Treasury-assisted) attempts by the latter to impose the Buccaneer.

So far as the Ministry of Supply was concerned, it was important that the aircraft project be consistent with a policy for rationalizing the airframe and aeroengine industry. There were upward of a dozen airframe manufacturers in the United Kingdom in the late 1950s. The Ministry felt that there was room for two or three at most. Accordingly, the project was conceived as an instrument for bringing a large and powerful industrial consortium into being: it would not be awarded to a single firm.

These transactions shaped and helped to define the project. Let us note a number of important characteristics of this process.

The TSR.2 project displayed what we may call variable geometry: it represented different things to different actors. In other words, it possessed a high degree of "interpretive flexibility." For the Ministry of Defence and the RAF, it was not a strategic bomber but a tactical strike and reconnaissance aircraft. For the Treasury it was relatively (though insufficiently) cheap. For the Navy it was a successful competitor to the Buccaneer, and for the Ministry of Supply it was an instrument of industrial policy.

At the same time, however, it was also a relatively simple object to each of those other actors. Though our account is, of course, schematic, most of the complexities of the aircraft and its project were also invisible to these outside actors. But the simplification involved in bringing this project into being was reciprocal: the outside actors were, in turn, simplified from the standpoint of the project. Thus the Treasury was (and is) a highly complex bureaucracy with a wide range of policy concerns and procedures. From the standpoint of the project most of these were irrelevant. The Treasury was a "punctualized" actor—an actor that was reduced to a single function, that of the provision of funds.

This process of reciprocal simplification has several consequences. One is that from the standpoint of both its neighbors and an outside observer, the project can be treated as a series of transactions. Some of these took the form of economic exchanges: in return for the provision of funds the project would provide accounts, progress reports, and, ultimately, a working aircraft. Some were political in character: in return for a demonstrated need for a large and complex aircraft, the objections of the Navy to the project would be overruled. Yet others were defined technically (the General Operational Requirement, and the more specific Operational Requirement that followed it) or industrially (the provision of contracts in exchange for a rationalization of the aircraft industry). In an earlier paper (Callon and Law 1989) we referred to what is passed between an actor and its neighbors as *intermediaries*, and we will adopt this (deliberately general and nonspecific) terminology here to refer to what passes between actors in the course of relatively stable transactions. And, as indicated earlier, we will use the term *global network* to refer both to the set of relations between an actor and its neighbors, and to those between its neighbors.

It is also important to note that transactions leading to reciprocal simplification shaped not only the project itself but also the actors that entered into transactions with it. Again, this shaping operated through a variety of mechanisms: often the formulated *interests* of existing actors were redefined. In 1957 the Ministry of Defence did not "know" that it needed a TSR aircraft. It simply knew that it did not need a strategic bomber to replace the existing V bomber force because ballistic missiles would fulfill this role. In the process of interacting with the Operational Requirements Branch, the ministry was persuaded or became aware of its interest in a TSR aircraft. A similar process overtook the RAF. At the beginning of the process it knew only that it wanted a new combat aircraft, and that there were important obstacles to this ambition. By the end it perceived its interests in terms of the TSR.2. A similar but even more dramatic process overtook the airframe manufacturers. They started out with a general interest in obtaining contracts to produce new aircraft, and ended up finding that it was in their interest to merge with manufacturers that had previously been rivals to design and manufacture a TSR aircraft. So profound was the process in this case that they were not simply reshaped—they were turned into new actors in their own right.

However, the actors shaped by the project were not, in all cases, influenced by operating on their perceived interests. Thus the expressed interests of the Navy with respect to the project remained unchanged in the following years: it was hostile and wished to see it cancelled. However, because of the definition of the aircraft described above and a series of bureaucratic political ploys that will not be detailed here, the project and those whose support it enlisted (notably the RAF itself) boxed in the Navy. The latter was hostile, but it was also unable to press its hostility home. In this case power plays and bureaucratic strategems acted to shape the Navy. The neutrality of the Treasury was secured in part by similar means.

We are emphasizing this process of mutual shaping because it is important to understand that actors are not simply shaped by the networks in which they are located (although this is certainly true), but they also influence the actors with which they interact. In one way this is obvious, for the latter class of actors are themselves located in and shaped by a global network. However, the point is worth making explicitly because it breaks down an abstract distinction common in social analysis between (determined) actor and (determining) structure, or between content and context. Neighbors do indeed shape new actors as they enter into transactions with them, but they are in turn reshaped by their new circumstances.[2]

Finally, we should note that financial resources, a set of specifications, the tolerance of certain neighbors, and the neutralization of others offered the project managers the resources to go about fulfilling their side of the explicit and implicit bargains that they had entered into. In short, like many of the other cases described in this volume, the project had created for itself a time and a space within which it might deploy the resources it had borrowed from outside. It had, accordingly, achieved a degree of autonomy, a "negotiation space." We will now consider some of the transactions that took place within this negotiation space.

Designing a Local Network

By the autumn of 1957 the negotiation space for the project managers was quite limited. In general they were obliged to adopt a step-by-step approach: for instance, no funds would be forthcoming unless they produced intermediaries in the form of clearer ideas about the design of the aircraft, its likely manufacturers, the costs involved, and the probable delivery date. The first stage in this process was to specify the design features of the aircraft more fully. Thus GOR 339 was quite general, specifying the kind of performance required rather than detailing the design of an aircraft. The latter would be necessary if such skeptics as the Treasury were to be convinced that a consortium of manufacturers was indeed capable of producing the proposed aircraft within budget. Accordingly, the process of giving shape to the project continued. Now, however, the focus of the project managers turned inward: they started to try to elaborate a network of design teams, design features, schedules, and contractors. They started to create and mobilize actors in what we will call a local network.[3]

The first step in this process was to ask the British aircraft industry to submit outline designs in the autumn of 1957. This posed no particular problem, for the firms in question were hungry for work and readily mobilized. In all there were nine submissions (Gardner 1981, 25), though here we will mention only the three most relevant to our story (Williams, Gregory, and Simpson 1969). Vickers offered two possibilities. One was for a small single-engine aircraft that was relatively cheap but diverged considerably from GOR 339. The other was for a much larger aircraft that conformed closely to GOR 339. Both proposals advocated a "weapons systems" approach to design with an integrated approach to airframe, engines, equipment, and weapons (Wood 1975, 156). Although this represented a departure from traditional methods of military aircraft procurement in which airframes were designed, built, and tested first, and weapons and equipment were added afterward, the approach was well received in Whitehall, in part because of an extensive selling exercise by Vickers and in part because it accorded with Ministry of Supply thinking and recent American experience.

Nevertheless, although the general philosophy of the submission was clear, well articulated, and closely argued, Vickers were not able to do all the necessary design work and saw themselves going into partnership with another firm, English Electric, which had designed and manufactured the successful Canberra light bomber and the Lightning supersonic fighter. However, English Electric had made its own submission, code-named the P17A, which was a detailed aerodynamic and airframe design for a 60,000 to 70,000 lb. delta-winged Mach 2 strike bomber with twin engines and two seats (Hastings 1966, 30; Williams, Gregory, and Simpson 1969, 18; and Wood 1975, 155). Though the P17A met many of the specifications of GOR 339, it lacked an all-weather capability and a vertical or short takeoff capacity (Williams, Gregory, and Simpson 1969, 18). English Electric countered the latter deficiency by arguing that short takeoff was not the most urgent requirement (which was, in their view, the replacement of the Canberra), but suggested that this could be provided at a later date by a platform that would lift, launch, and recover the P17A in the air. This platform was to be designed and built by Short Brothers, which submitted a preliminary design (Hastings 1966, 29; Williams, Gregory, and Simpson 1969, 18; Wood 1975, 155).

With the airframe manufacturers mobilized and a set of submissions in place, the second stage in the elaboration of the local network started—consideration of what design or combination of designs would best fulfill the various requirements negotiated with neighboring actors. Though the small Vickers design was favored by the Treasury because it was likely to be relatively cheap, the large submission was particularly attractive to the Air Staff, the RAF, and sections of the Ministry of Defence. This was because it strengthened the commitment of the Air Staff both to a short-takeoff aircraft (which would have to be large because it would need two powerful engines) and to a weapon systems approach. The staff, the Ministry of Defence, and the Ministry of Supply were also impressed by the integrated design philosophy advocated by the company and were persuaded that Vickers had the management capacity to control and integrate a complex project (Wood 1975, 158; Gardner 1981, 33). However, they were also impressed by the English Electric submission, which was generally conceded to be "a first class design" (Wood 1975, 155), was the product of wide experience with supersonic aircraft, and also had the advantage that it could use existing avionics equipment in the short run. In addition, though contact between the two firms had been limited (with English Electric contractually tied to Short Brothers), Vickers had indicated its wish to have English Electric as its partner. Accordingly, the Air Staff came to the conclusion that a combination of the large Vickers-type 571 and the English Electric P17A would be both appropriate and capable of being used to mobilize actors in the global network.[4]

Accordingly, with a putative design and potential contractors in hand, the Air Staff returned to the global network in June 1958. Specifically, they went to the Defence Research Policy Committee (Gardner 1981, 32). This group was responsible for the overall control of defense procurement and as part of its role assessed and allocated priority to the projects put to it by user services and the appropriate supply departments (Williams, Gregory, and Simpson 1981, 32). Cabinet-level approval was ultimately obtained, and GOR 339 was replaced in early 1959 by a tighter, more technical and definitive requirement, Operational Requirement (OR) 343 (Gardner 1981, 33; Wood 1975, 158), and an associated Ministry of Supply specification, RB 192 (Gunston 1974, 41).[5] All was now in place: a preliminary network of local actors had been mobilized and had contributed to creating the intermediaries needed to satisfy the global actors or turn their objections aside. The design for a local network of firms, technical components, management procedures, and the rest had been approved. Intermediaries would start to flow from the global network in order to mobilize a more permanent local network.

The Creation of a Local Network

Vickers and English Electric did not wait for contracts to be awarded formally. In late 1958 they set about the difficult task of building a permanent local network of designers, designs, production teams, management, and subcontractors that would bring about the construction of a TSR.2 within the time and budget permitted by neighboring actors. The first step was to try to integrate and take control of two quite separate industrial organizations and designs. Several problems had to be overcome in this process of designing and mobilizing a local network. First, the designers who had previously worked in two teams some 200 miles apart had rather different approaches to design. Thus the Vickers team, which was based in Weybridge in Surrey and near Winchester in Hampshire, had concentrated on electronic systems, on airborne systems in general, on fuselage design and on short takeoff and landing (Williams, Gregory, and Simpson 1969, 29). The English Electric team was based on Warton in Lancashire and had concentrated on supersonic aspects of the design, the implications of low-level flight, and had, as we have noted, submitted the more detailed airframe design. The process of getting to know one another and settling down to collaborative work was difficult but generally successful in the end (Beamont 1968, 137; Beamont 1980, 134; Williams, Gregory, and Simpson 1969, 47), and a joint team of fifty designers undertook a detailed study of the technical and design problems raised by GOR 339 by the early months of 1959. Following this a division of labor evolved that reflected the relative skills of the two teams: the Weybridge group worked on systems including cost-effectiveness and weapons, while the Warton team worked on aerodynamics (Wood 1975, 164).

But the local network was not composed of people alone. For instance, the problems posed by the differences between the two designs were at first considerable. The most fundamental of these arose out of the different requirements suggested by supersonic flight and a short takeoff capability. High-speed flight suggested a small wing with low aspect ratio, a low thickness-to-chord ratio and a high leading edge sweep—all features of the P17A. A short-takeoff capability suggested the need for a low wing loading, which in turn implied that the wing should be large, and it also suggested a high thickness-to-chord ratio and a low leading edge and trailing edge sweep. Sir George Edwards, head of Vickers and later of the merged British Aircraft Corporation, is reported to have said at one stage, "The Vickers STOL study and the English Electric machine with a tiny low level wing ... seemed irreconcilable" (Gunston 1974, 44). The team wrestled with these different requirements and eventually resolved them in a single solution by: a. providing very large flaps that increased both the thickness-to-chord ratio and the angle of attack; b. forcing high-pressure air over the flaps in order to improve lift at low speeds by preventing the breakup of airflow over the top surface of the wing; and c. increasing the thrust-to-weight ratio by specifying two extremely powerful engines (Gunston 1974, 46; Williams, Gregory, and Simpson 1969, 25, 39; Wood 1975, 165).

Although this was the most fundamental design decision—for given the Operational Requirement, many other decisions about engines, moving surfaces, undercarriage, and integral fuel tanks were seen by the team to be foreclosed—other and somewhat separable design difficulties also arose. One of these concerned the location of the engine. The necessity for thin, uncluttered wings suggested that these should be located within the fuselage, as in the English Electric design. Vickers were skeptical about this, worrying about cooling problems and the risk fire. However, in the end the English Electric view carried the day (Wood 1975, 163). Another concerned the short-takeoff capability of the aircraft. In 1959 the Air Staff were hoping for this, but the designers quickly concluded that the proposed aircraft was too heavy, and they sought—and were given—permission to build an aircraft that would take off instead from half runways and rough strips (Gunston 1974, 41).

In March 1960 the wing position was moved by three inches as a result of these and similar deliberations (Hastings 1966, 40; Gardner 1981, 105), but after this the design was changed little in concept, and a brochure and drawings were issued to the workshops in 1962 (Wood 1975, 165).[6] A putative local network of technical components had been specified. All that remained was to turn these from paper into metal.

Integrating their designs and their design teams were not the only problems of integration and control confronted by the two firms. There was also a question about how the production work should be allocated. Although the contract from the Ministry of Supply stated that the two firms were to share the work equally, it was also made clear that Vickers was the prime contractor and would exercise overall mangement control (Hastings 1966, 35; Williams, Gregory, and Simpson 1969, 22). This led to some ill feeling in English Electric, which felt that it should have received its own contract directly from the ministry. The problem was exacerbated by the commitment to a development batch approach. The prototypes and development aircraft would be built on the production line for the main series rather than being built by hand, separately. The location of the production line had, therefore, to be determined early on, and negotiations were difficult (Gardner 1981, 32).

Relations between Global and Local Networks

While the design and creation of a local network went ahead, there were continuing difficulties in the interaction between the local network and the global network that had brought it into being. As we have already indicated, in principle the Ministry of Supply was committed to a weapons systems approach to procurement—the whole machine including all its avionics, armaments, and other subsystems should be conceived as a whole. In the view of the Ministry, this approach had implications for management:

> Since the failure of only one link could make a weapons system ineffective, the ideal would be that complete responsibility for co-ordinating the various components of the system should rest with one individual, the designer of the aircraft. (*Supply of Military Aircraft* 1955, 9)

The approach thus implied centralized control. It suggested that a single locus should shape and mobilize the local network *and* that this locus should have control over all transactions between the local and global networks. It should, in short, become an *obligatory point of passage* between the two networks.

As we have indicated, Vickers was indeed appointed prime contractor and was responsible in principle for controlling the entire project (Hastings 1966, 35; Williams, Gregory, and Simpson 1969, 22). In practice, however, the Ministry of Supply (later Aviation) did not vest all responsibility for control in Vickers. Rather, the project was controlled by a complex series of committees on which a range of different agencies were represented, and no single agency was in a position to control all aspects of the project. The failure of the management of the newly formed British Aircraft Corporation to impose itself as an obligatory point of passage led to a number of complaints by the latter about outside interference. These fell into two groups:

1. Actors in the global network were able to make (or veto) decisions that affected the structure of the local network:

a. Many of the most important contracts were awarded directly by the Ministry; the contract for the engines provides a case in point. The design team took the unanimous view that this should be awarded to Rolls Royce. This recommendation was based on the belief that a reheat version of the RB 142R offered the thrust-to weight ratio necessary for the aircraft, was lighter, and had more potential than an alternative enhanced Olympus engine made by

Bristol Siddeley (Hastings 1966, 41; Wood 1975, 164). However, the Ministry of Supply had other views, apparently deriving from its concern to pursue an industrial policy of merger, and despite this recommendation awarded the contract to Bristol Siddeley (Clarke 1965, 77; Gardner 1981, 29; Gunston 1974, 41; Williams, Gregory, and Simpson 1969, 21). In fact, overall, the BAC controlled only about 30 percent of the project expenditure itself (Gunston 1974, 67; Hastings 1966, 40).

b. The Air Staff tended to make decisions without reference to the BAC. The problem here was that the RAF continued to develop its ideas about the ideal performance and capabilities of the TSR.2. This tendency to upgrade specifications was encouraged by the fact that contractors would often talk directly to the Air Staff and the Air Ministry. Sometimes such discussions would lead to changes in the specification of equipment whose specifications had already (or so the BAC thought) been fixed. One result was that, at least in the view of the BAC, progress toward freezing the design of the aircraft was impeded (Hastings 1966, 144; Gardner 1981, 101; Williams, Gregory, and Simpson 1969, 49).

2. Given the number of global actors that had a right to express their views in the committee structure, arriving at a clear decision was sometimes difficult.

a. It was often impossible to get a quick decision from the various government agencies. Hastings (1966, 160) describes the case of the navigational computer that was the responsibility of a firm called Elliott Brothers. The specification for this computer was very demanding, and Elliott concluded that the only way in which this could be met within the time allowed was by buying the basic computer from North American Autonetics. The Ministry resisted this because it had sponsored basic research on airborne digital computers in 1956–57. The Ministry ultimately accepted Elliott's view, but the equipment required was complex and the price was high. This brought into play Treasury representatives, who insisted that the decision be reviewed after a year. The whole argument delayed the development of the computer and (or so Hastings argues) added £750,000 to the cost.

b. On a number of occasions the Treasury used its position to try to cancel the project, or at least reduce its cost, and there seems little doubt that an initial delay in issuing contracts was in part a function of Treasury reluctance. When the committee structure was further elaborated in 1963, the opportunities for discussion about costs became greater still. Indeed, the Projects Review Committee, which included Treasury membership, had no representatives from industry (Hastings 1966, 38; Williams, Gregory, and Simpson 1969, 82).

c. The technical committees often made decisions with relatively little thought of cost, whereas those committees concerned with costs had little information about, or ability to determine, the technical necessity of the tasks they were examining (Hastings 1966, 35; Williams, Gregory, and Simpson 1969, 22). Certainly it appears that the RAF sought optimum performance in a way that was relatively cost-insensitive. (Hastings 1966, 59–60). The Air Staff tendency to delay was strengthened by the weapons systems philosophy and the development batch approach to procurement, both of which reinforced the RAF desire to be sure that the design was absolutely right before it was frozen, because it was so difficult to introduce modifications once this had occurred (Williams, Gregory, and Simpson 1969, 53).

Difficulties in Mobilizing a Local Network

We have described the reaction of the British Aircraft Corporation to the fact that outside actors refused to let it serve as an obligatory point of passage between the project's global and the local networks. However, the growth of mistrust between the Ministry and the BAC was two-way. The Ministry came to believe that the prime contractor was failing to exercise adequate management control (Hastings 1966, 157; Williams, Gregory, and Simpson 1969, 54). In particular, it was suggested that there was no single "iron man" at the BAC to direct the project (Wood 1975, 172), and at one point the ministry felt obliged to represent this view very strongly to the firm. Thus, although the Ministry's point of view has not been as well documented as that of the BAC, it is pretty clear that for much of the period after 1959 *neither* acted as an obligatory point of passage between local and global networks, and there was continual "seepage" as local actors lobbied their global counterparts, which influenced and in some cases impeded the smooth running of the project.

Indeed, the construction of the local network presented many problems. Perhaps the most serious of these concerned the engines. It is clear in retrospect that neither the Ministry nor Bristol Siddeley knew what they were letting themselves in for when the contract was awarded. The Ministry specified the engines in very general terms, and it was at first thought that their development would be a fairly straight-forward matter of upgrading an existing type, the Olympus (Williams, Gregory, and Simpson 1969, 27, 52). It turned out that this was not the case. The engine that was developed had a much greater thrust than its predecessor and operated at much higher temperatures and pressures. When it was first proved on the test bed, it turned out that its cast turbine blades were too brittle, and it was necessary to replace them with forged blades at considerable cost in both time and money (Hastings 1966, 42; Gardner 1981, 104).

This was not the only difficulty experienced by Bristol Siddeley. Serious problems arose with the reheat system, it proved impossible to install the completed engine in the fuselage, and there was also a weakness in the joint between the main engine and the jet pipe. However, the most serious problem appeared only late in the process of development. After proving the engine for over 400 hours on the test bed (Hastings 1966, 43), it was installed beneath a Vulcan in late 1962. On December 3 this aircraft was taxiing during ground tests at the BSE works at Filton in Bristol when the engine blew up, "depositing," as Wood (1975, 174) reports it, "a large portion of smouldering remains outside the windows of the company press office." The aircraft was reduced to burning wreckage, and although the crew was saved, a fire engine that approached the flames without due caution was caught up in the inferno (Gunston 1974, 56).

Within forty-eight hours it was clear that the failure had been caused by primary failure of the low-pressure compressor shaft. What was not clear, however, was what had caused this failure. Bristol Siddeley hypothesized that it might be due to stress and ordered that the thickness of the shaft be doubled. At the same time it ordered an exhaustive series of tests—a further, elaborately mobilized network of actors—to investigate the reasons for the failure. These led to further unpredictable and unexplained explosions. Finally, in the summer of 1964 the cause of the problem was diagnosed. In the original unmodified engine, the low-pressure shaft had turned on three bearings. However, the design team had become concerned that the middle of these three bearings might catch fire at the high operating temperatures; this bearing had therefore been removed and then, to provide the shaft with sufficient rigidity, the diameter of this shaft had been increased (Beamont 1968, 139; Hastings 1966, 43; Wood 1975, 174). Under certain unusual circumstances, the air between this shaft and its high-pressure neighbor started to vibrate at a frequency that corresponded to the natural frequency of resonance of the low-pressure shaft. When this happened, disintegration quickly followed. However, even with a diagnosis at hand, a solution was going to require further time and money.[7]

Not all of the local network problems concerned the engines. It also proved very difficult to control the subcontractors. As we have indicated, same subcontractors appealed over the head of the BAC to the ministry in order to obtain favorable decisions about costs (Hastings 1966, 36; Gardner 1981, 101). Others colluded with the air staff to specify equipment that was unduly sophisticated. Again, from 1959—and more so from 1962, when the political climate began to undermine the project—many subcontractors doubted whether the aircraft would actually fly. This feeling was a function of another kind of seepage between the local and global networks—specifically the knowledge that the project had powerful opponents in government. The subcontractors thus sought to protect themselves (and recover their costs in full within each contract) by charging high prices, and they also tended to give the work low priority (Beamont 1968, 143; Gardner 1981, 102; Williams, Gregory, and Simpson 1969, 28). In addition there was a tendency to charge a wide range of development work to the TSR.2 because it was the only advanced military aircraft project in Britain (Gunston 1974, 53; Gardner 1981, 102). In any case, much of the work was not amenable to precise costing in advance (Gunston 1914, 60; Williams, Gregory, and Smith 1969, 27, 51). Although the aim of the ministry and the BAC was to issue fixed price contracts as this became possible, this goal was not achieved for many of the most important areas of work because unanticipated technical problems arose or the specification of the equipment was altered.

The Global Network Reshaped

The consequences of the failure to build a satisfactory local network made themselves felt in a number of ways. The RAF had been promised that the TSR.2 would be available for squadron service by 1965, but it was clear, with the engines still unproved in the middle of 1964, that this deadline had substantially slipped. The Ministry of Defence had likewise been promised a vital weapon with which to fight a war in Europe or the Commonwealth by 1965. This was not going to be available. The Treasury had been promised a cheap and versatile aircraft. Though it is true that some of the blame for the cost overrun can be laid at the door of the Treasury itself, by 1963 the estimated cost of the aircraft had nearly doubled. The Navy, which had been hostile from the outset, saw the project swallowing up more and more of the procurement budget. By 1963, then, all the relevant actors in the global network, whether sympathetic to the project or not, saw it as being in deep trouble. It was simply failing to deliver the intermediaries to the global network that it had promised when it had been given the go-ahead. Thus, although the data in table 1.1 are calculated on a variety of bases and are not in all cases strictly comparable with one another, they sufficiently illustrate this general trend.

However, although these difficulties were serious, they did not necessarily mean that the project was doomed. If the necessary intermediaries could be obtained from the global network, it would be able to continue: funds from the Treasury, expertise and support from the RAF, political support from the Ministry of Defence, and specialist services from such departments as the Royal Aircraft Establishment—these would allow it to continue. The RAF and the Minister, though not necessarily the whole of the Ministry of Defence, remained strong supporters of the project. With the government committed, it was not possible for the Treasury, the Navy, or indeed, the hostile sections of the Ministry of Defence, to stop the project. Accordingly, the funds continued to flow. However, armed

Table 1.1
Estimated costs and delivery dates of TSR.2

Date of estimate	Development estimate	Production estimate	Total
January 1959	£25–50m	up to £200m	up to £250m
December 1959	£80–90m (for 9 aircraft)		
October 1960	£90m	c. £237m (for 158 aircraft)	c. £330m
March 1962	£137m		
January 1963	£175–200m		
November 1963			£400m (overall, Ministry of Aviation)
January 1964	£240–260m		
February 1964			£500m (overall, Ministry of Defence)
January 1965			£604m (overall, Ministry of Aviation) £670m (overall, contractors) (R&D and production of 150 aircraft)

with the knowledge that came from their participation in the cat's cradle of government and industry committees, the skeptics were in a strong position to undermine the project by indirect means. This involved taking the fight into a wider arena.

The project had been conceived and shaped within the context of a limited number of global actors. Government departments, the armed services, the aerospace industry—these were the relevant actors that had given life and shape to the project. Though sections of the specialist press had some knowledge of the project, public statements by ministers had been very limited, and until 1963 it had had a very low profile. Gradually, however, this started to change as new actors first learned about the project and then indicated their opposition to it.

The most important of these was the Labour Party, which had declared its opposition to "prestige projects" such as Concorde and TSR.2 and had promised to review them if it was returned to power in the next General Election. Labour views about the TSR.2 had been unimportant in the early days of the project, and indeed were unformed. However, by 1963 this was beginning to change. The Labour Party was riding high in the opinion polls, and a General Election was due by October of 1964 at the latest. Whispering in government and by other insiders and a series of admissions from the Ministries of Aviation and Defence about delays and escalating costs led the TSR.2 to became an object of political controversy from 1963 onward. This process was reinforced by a highly controversial setback to the project—the failure to persuade the Australian government to purchase the TSR.2 for the Royal Australian Air Force. In a blaze of publicity, the Australians opted for the rival F111, an aircraft built to a similar specification by the American firm, General Dynamics.

Thus, although supervision of the project remained in Whitehall, the number of actors, including critics, involved in its surveillance multiplied in 1963. The cost of the project was officially given as £400m. in November 1963. However, the Labour Party Opposition argued that this was a gross underestimate and put the figure closer to £1,000m., an estimate that was fiercely disputed by the Government (*The Times*, Nov. 12, 1963, p. 5). Furthermore, the Opposition argued that cost was one of the major reasons for the failure to procure the Australian order, a charge angrily rejected by the Government, which claimed that the constant carping of critics in the United Kingdom had led the Australians to doubt whether the aircraft would ever be produced (*The Times*, Dec. 4, 1963, p. 7).

Other critics suggested that the aircraft had become too expensive for its role and too expensive to be risked in combat, *The Times* suggesting that at £10m. per machine, it was "the most expensive way yet devised of blowing up bridges" (Sept. 28, 1964 p. 10).

Further political disagreements centered around the role of the aircraft. The cancellation of the British ballistic missile Blue Streak in 1960, followed by the 1962 cancellation of the American Skybolt, which had replaced Blue Streak, had led certain commentators to speculate that it might be possible to use the TSR.2 in a strategic nuclear role. This suggestion (which had always been seen as a possibility within government) was picked up by the 1963 Defence White Paper (Omnd. 1936) and attracted criticism both from those who felt that the aircraft was neither fish nor fowl, such as *The Times* and *The Economist*, and the left wing of the Labour Party, which was committed to a policy of unilateral nuclear disarmament. Yet others including Denis Healey, the Labour defense spokesmen, concluded that this "strategic bonus" did not so much represent a change in the specification of the aircraft as an attempt by the government to persuade its backbenchers of the soundness of its nuclear defense policy (*The Times*, March 5, 1963 p. 14). Controversy also surrounded the continued delays in the first test flight. Healey highlighted the symbolic importance of the maiden flight when he claimed in Parliament at the beginning of 1964 that the BAC had "been given an order that it must get the TSR.2 off the ground before the election, and that (this) was a priority" (*The Times*, Jan. 17, 1964, p. 14). However, though he was much too professional a politician to let the Conservative government off lightly for its alleged incompetence, he was also much too agile to foreclose his own options by promising to cancel the project if the Labour Party were to win the General Election.

Endgame

By the autumn of 1964 the project was at a crucial stage. The local network was practically in place: the TSR.2 was almost ready for its maiden flight, albeit very much behind schedule and over budget. But the structure of the global network had altered. Disagreement was no longer confined to the Treasury and the Navy and the RAF, the Ministry of Defence, and the Ministry of Aviation. (Indeed, some of these agencies were starting to alter their views of the project.) The dispute was now public, and the Conservative Government had committed itself firmly and publicly to the TSR.2, while the Labour

Opposition, though reserving its position, was generally highly critical of the cost and utility of the project. The future of the project thus depended on two factors. First, it was important to demonstrate the technical competence of the project, and the best way to do this was for it to have a successful first flight. This would reinforce the position of those who wished to see the project through. At the same time, the outcome of the General Election was also vital. Conservative success would probably assure the future of the project. Labour victory would call it into question.

The maiden flight took place just eighteen days before the General Election. Roland Beamont, the test pilot, describes the rather subdued group of engineers, technicians, managers, and RAF personnel who assembled at Boscombe Down before the flight. Most knew, as the large crowd beyond the perimeter wire did not, of the potentially lethal nature of the engine problem, and they knew that although its cause had been diagnosed, it had not yet been cured. In fact the flight was highly successful, the aircraft handled well, and there was no hint of the destructive resonance that had plagued the engines. Deep in the election battle the Prime Minister, Sir Alec Douglas Home, described it as "a splendid achievement" (Beamont 1968, 151). The aircraft was then grounded for several months in order to modify the engines and tackle minor problems with the undercarriage.

The General Election took place on October 15. The result was close, and it was not until the following day that it became clear that the Labour Party had been returned to power with a tiny majority of five. The new administration started work in an atmosphere of crisis as a result of a large balance of payments deficit, and it decided to cap defence expenditure at £2,000 million. It also ordered a detailed scrutiny of the various military aircraft projects and started a review of the proper future shape and size of the aircraft industry (Campbell 1983, 79). In February the new Prime Minister, Harold Wilson, made it clear that the future of the TSR.2 would depend on four factors: first, a technical assessment of the aircraft and its alternatives; second, the fact that although the overseas purchase of an alternative aircraft would save £250 million, this would also involve considerable dollar expenditure; third, the future shape of the aircraft industry, and the possible unemployment that would result from carcelling the program; and fourth, the nature of the terms that could be negotiated with the BAC.[8]

At the beginning of April spokespersons for the principal actors in the newly reconstructed global network—the Cabinet Ministers responsible for departments of government—met to take a decision. They considered three possible courses of action: to continue with the TSR.2; to cancel it and put nothing in its place; and to cancel it and replace it with the similar F111 (Crossman 1975, 191; Wilson 1971, 90). The Treasury remained hostile to the TSR.2 and accordingly sought cancellation. Although it was concerned that a large purchase of an alternative American aircraft such as the F111 would impose severe dollar costs, it was prepared to accept that an *option* for the purchase of this aircraft should be taken out on the understanding that this did not imply a firm commitment. The Ministry of Defence was also in favor of cancellation on cost grounds, and it was joined by those, such as the Navy, that favored the claims of other services and projects (Hastings 1966, 68, 70). The Minister of Defence was in favor of an F111 purchase, but there was same uncertainty whether Britain really needed this type of aircraft in view of the country's diminishing world role (Williams, Gregory, and Simpson 1969, 31). He was thus happy to take out an option on the American aircraft rather than placing a firm order.

The position of the Minister of Defence probably in part reflected a shift in the view of the Air Staff. The combination of delay and cost overrun, together with the much tougher policy of economies introduced by the new Minister of Defence, had convinced the Air Staff that it was most unlikely that there would be a full run of 150 TSR.2s, and this had led to doubt about whether it would be possible to risk such a small number of expensive aircraft in conventional warfare. For some officers this pointed to the desirability of acquiring larger numbers of cheaper aircraft that might be more flexibly deployed. In addition, though the technical problems of the TSR.2 appeared to be soluble, its delivery date was still at least three years away. Because the F111 was designed to essentially the same specification and was already in production, the RAF found this quite an attractive alternative (Reed and Williams 1971, 181).

The Ministry of Aviation was concerned that a decision to scrap the TSR.2 would seriously reduce the future capacity of the British aircraft industry to mount advanced military projects, and tended to favor cancellation, combined with the purchase of a lower-performance British substitute. However, most ministers, including the Minister of Aviation, believed that the industry was much too large for a medium-sized nation. The real problem was that there was not yet in place a policy about its future shape and size. Even so, the TSR.2 was costing about £1 million a week, and further delay in cancellation did not, on balance, seem justified.

In general, the government was concerned that cancellation would lead to unemployment. With a tiny Labour majority in Parliament, ministers were anxious not to court unneccessary unpopularity. Against this, however, ministers felt that the resultant unemployment would mostly be temporary: that many of those working on the TSR.2 would quickly be absorbed by other projects or firms.

Nevertheless, the decision was by no means clear-cut: there was no overall Cabinet majority for any of the three options (Wilson 1971, 90). A number of ministers—mainly, it seems, those who were not directly involved—wanted to postpone cancellation until a long-term defence policy was in place (Crossman 1975, 190). Overall, however, those who wanted to maintain the project were outnumbered by those in favor of cancellation with, or without, the F111 option, and the vagueness of the latter commitment ultimately made it possible for these two groups to sink their differences.

The cancellation was announced by the Chancellor of the Exchequer, James Callaghan, in his Budget Day speech on April 6, 1965. The result was political uproar as the Conservatives sought to voice their anger and frustration at what they regarded as a foolish and shortsighted decision. A censure motion was debated on April 13. Amid charge and countercharge, Minister of Aviation Roy Jenkins concluded the debate for the government by agreeing that the TSR.2 was a fine technical achievement:

> But, to be a success, aircraft projects must be more than this. They must have controllable costs; they must fulfill the country's needs at a price that the country can afford; they must be broadly price competitive with comparable aircraft produced in other countries, and they must have the prospect of an overseas market commensurate with the resources tied up in their development. On all these four grounds I regret to say that the TSR.2 was not a prize project but a prize albatross. (*Hansard*, April 13, 1965, c.1283)

The result of the censure debate was a resounding victory for the Government: it secured a majority of twenty-six, and any residual Opposition hopes that the the project might, somehow, be saved were dashed when members of the small Liberal Party voted with the Government.

Conclusion

In this chapter we have shown that the success and shape of a project, the TSR.2, depended crucially on the creation of two networks and on the exchange of intermediaries between these networks. From the global network came a range of resources—finance, political support, technical specifications and, in some cases at least, a hostile neutrality. These resources were made available to the project and generated what we have called a negotiation space. This was a space and a time within which a local network might be built that would in turn generate a range of intermediaries—but most obviously a working aircraft—that might be passed back to the actors in the global network in return for their support. We have also noted, however, that there were continual seepages between the global and the local networks in the case of the TSR.2 project. Actors in the global network were able to interfere with the structure and shape of the local network, while those in the local network were able to go behind the back of the project management, and consult directly with actors in the global network. The result was that project management was unable to impose itself as an obligatory point of passage between the two networks, and the troubles that we have detailed followed.[9]

The history we have described offers further evidence for several important findings of the new sociology of technology. First, it illustrates the interpretive flexibility of objects—the way in which they mean different things to different social groups. Second, as is obvious, it represents a further example of the social shaping of technology—namely the way in which objects are shaped by their organizational circumstances (Pinch and Bijker 1987; MacKenzie and Wajcman 1985; Callon 1986; Law 1987; MacKenzie 1987; MacKenzie and Spinardi 1988; Akrich, this volume; Bijker, this volume; Latour, this volume). Thus we have sketched out the way in which the TSR.2 aircraft changed in shape both literally and metaphorically during the course of its development, and the relationship between these changes and the compromises that grew up for a time between the relevant human and nonhuman actors—compromises that achieved, as we have seen, no final solidity but that were, in turn, reworked as a function of new circumstances in the local and global networks.

Thus back in 1957 what we might call *aircraft number one* did not have a physical shape at all in the minds of the Air Staff or the Ministry of Supply (see table 1.2). It was rather the performance specification—a role to be played—and some of the circumstances in which it should be built. And this role reflected their view of what would pass muster with other relevant actors. Thus, the RAF wanted a flying combat aircraft, but the Ministry of Defence had a view of the future that left room for neither a strategic bomber nor a fighter.

Table 1.2
Three aircraft

	Aircraft shape	Interested actors (+ definition of aircraft)	Hostile actors (+ definition of aircraft)	Neutral actors
1	• long range • supersonic • low altitude • STOL • all weather • large	RAF: • combat aircraft • in and out of Europe • dispersable • precision bombing/reconnaissance Defence: not strategic bomber	Navy: • Buccaneer Treasury: • cheap, versatile Buccaneer?	
2	• wing shape, delta, thin • two powerful engines • blown flaps • engines in fuselage • twin engines • integral fuel tanks	RAF: • large, twin-engine, sophisticated • TSR aircraft • STOL • long range Defence: • TSR aircraft BAC: • STOL difficult • VTOL impossible	Navy: • (blocked) Treasury: • (blocked)	Labour party • in ignorance
3	• option on F111 • TSR.2 cancelled	BAC: • buy 140 Conservative party: • TSR.2 essential Unions: • maintain work	RAF: • buy cheaper, more certain aircraft Defence: • buy cheaper aircraft Treasury: • cap expenditure • limit overseas spending Navy: • adopt Buccaneer Aviation: • buy chepaer U.K. aircraft Labour party: • cancel	

A tactical bomber and reconnaissance aircraft was the only remaining possibility—an aircraft that would play out specific, nonstrategic roles in Europe and British dependencies overseas. By contrast, the Treasury was quite uninterested in the defence of the Western Alliance. Much more important was the defence of the public purse in the face of ever more costly military technologies. Accordingly, it wanted no aircraft, or (second best) an existing aircraft, or if this was not possible (third, fallback, option), then no more than *one* type of new aircraft. The RAF judged it could force the Treasury to its fallback position, so it responded by specifying a single versatile aircraft. The Navy had strong views about defence needs, but it saw these in its own, quite different, carrier-based way. Accordingly, it wanted the RAF to procure a version of its small, subsonic Buccaneer. In a more negative sense, this was a strong incentive for the RAF to argue the need for a large, supersonic aircraft that was qualitatively different from its naval rival. And the Ministry of Supply wanted an aircraft that would he built by a consortium of firms rather than one alone.

Though it was touch and go, the Air Staff judged things rightly and the global network required by this shadow aircraft number one was stabilized. The result was *aircraft number two*—this time one that had, albeit on paper, a physical shape. This shape was partly a function of the global network of institutional actors mentioned above. But many other actors, considerations, and negotiations helped to structure the design. Thus the shape of the wings represented a compromise between the demanding specification required by the RAF on the one hand, and design skills, knowledge of aerodynamics and materials strengths, and the practice of wind-tunnel testing on the other. How on earth was short takeoff and landing to be reconciled with high-altitude Mach 2.5 flight and low-altitude, low-gust response? The wing was the physical answer to this question. It represented a compromise between these different considerations. But it also represented a compromise between the English Electric and Vickers design teams—in which English Electric had the upper hand. Similar reasoning—again in favor of English Electric—led to a decision about the location of the engines. These, it was decided, would lie within the fuselage to clear wing surfaces and avoid undue differential propulsive force in case of single engine failure—and this despite the potential fire hazard that so concerned the Vickers team. And it is possible to travel through the aircraft explaining the shape of each system as a physical compromise between the specification, the design teams, and a range of inputs from aerodynamics to the views of experts at the Royal Aircraft Establishment.

It can be argued that aircraft number two grew out of aircraft number one. Certainly many of the constraints and resources that went to shape number one helped to shape number two. But the process is not one of unilinear development. Aircraft number two was not simply the "unpacking" of a set of implications that were built into aircraft number one. Aircraft number one posed a set of problems to which there were many possible solutions. Aircraft number two represented a particular set of solutions to those problems—compromises negotiated by further numerous actors. Or, in some cases at least, it represented refusal to accept the problems posed by GOR 339, as is most obvious in the case of the short takeoff and landing requirement where the available rules of aerofoil behavior overruled the wishes of the Air Staff. In this instance, then, we see (if anything) the obverse of the social shaping of technology: it was the technical around which the social was being bent.

But if aircraft number two represents a translation rather than a simple development of aircraft number one, a translation shaped by a set of compromises between a somewhat different set of actors, then the metamorphosis of the project is yet more obvious for *aircraft number three*. This, which is more usually known as the F111, gradually took shape after the General Election. Thus we have traced the changes that took place among many of the most important actors after October 1964. The Treasury imposed rigorous economies and expressed extreme concern about the ever-increasing costs of the TSR.2 project, its short run, and its lack of export prospects. The Ministry of Aviation sought to shape a smaller and better-adapted aircraft industry. The Ministry of Defence was involved not only in cost cutting but also in a Defence Review that might lead to the abandonment of many British overseas responsibilities and with it, part of the rationale for the TSR.2. The Air Staff were increasingly concerned that they would not obtain the full 140 TSR.2s. For their different reasons *all* of these were prepared, with greater or lesser enthusiasm, to abandon the TSR.2 and take out an option on the F111. Accordingly, the project for a tactical strike and reconnaissance aircraft had been reshaped yet again by the relations between the actors involved, and with that reshaping the object that lay at its focal point had undergone metamorphosis yet again. This reshaping is summarized in table 1.2.

So much for the shaping and reshaping of TSR.2.[10] But how should we describe such a "translation trajectory?"[11] This, then, is our third concern. If technologies are interpretively flexible, if they are shaped by their contexts but they also shape the latter, then can we say nothing general about the contingent and iterative processes that generate them? Our answer, as we hinted in the introduction, is to deploy a network vocabulary and, specifically, to make use of the concepts of *global network*, *local network*, and *obligatory point of passage*. Our proposal is that the shape and fate of technological projects is a function of three interrelated factors.

The *first* is the capacity of the project to build and maintain a global network that will for a time provide resources of various kinds in the expectation of an ultimate return. Note that the successful construction of a global network has a specific and important consequence: it offers a degree of privacy for project builders to make their mistakes in private, and without interference—it offers a negotiation space (see Callon and Law 1989). In the ideal case the project builder thus obtains a degree of autonomy in its attempts to generate a return. It also—again in the ideal case—achieves both complete control over and responsibility for those attempts.

The *second* is the ability of the project to build a local network using the resources provided by the global network to ultimately offer a material, economic, cultural, or symbolic return to actors lodged in the global network. Put less formally, it is the ability to experiment, to try things out, and to put them together successfully. It is also the ability to control whatever has been produced and feed it back into and so satisfy the understandings that have been entered into with other actors in the global network.

The *third* factor, which is entailed in the first two, is the capacity of the project to impose itself as an obligatory point of passage between the two networks. Unless it is able to do so, it has 1. no control over the use of global resources that may, as a result, be misused or withdrawn, and 2. it is unable to claim responsibility in the global network for any successes that are actually achieved in the local network. It is, in short, in no position to profit from the local network.

Note, now, that the objects and actors in *both* global and local networks are heterogeneous. Thus in the case of the TSR.2 we mentioned a range of important institutional actors in the form of Whitehall ministries. But we also touched upon geopolitical factors (the presumed interests of a range of nation states) and technological changes (the advance of missile and anti-aircraft technologies). And we might equally well have considered the role of such naturally occurring features as prevailing winds (they were vital in the calculation of ferry ranges), and terrain cross-sections (which went into the calculation of the risks involved in low-level flying), or, for that matter, such human geographical but global considerations as the availablility and distribution of airstrips of different lengths.

But if global networks are heterogeneous, then so too are local networks. The TSR.2 project mobilized institutional actors in the form of contractors, subcontractors, and specialist agencies such as the Institute for Aviation Medicine. It mobilized tens of thousands of draftsmen, designers, market personnel, and fitters. It involved the use of a great body of high-status knowledge in the form of scientific and technical expertise and a large amount of equally important shop-floor knowledge and skills. And it involved numberless machine tools, jigs, motor vehicles, chaser aircraft, and test rigs, not to mention an awesome quantity of paperwork in the form of drawings, instructions, management charts, brochures, sales pamphlets, maps, and publicity handouts.

If the elements that make up global and local networks are heterogeneous, then the extent upon which they can be depended is also problematic: the degree to which they may be mobilized is variable, reversible, and in the last instance can only be determined empirically. In other words, the extent to which it is possible for a project to control its two networks and the way in which they relate is problematic, and it is the degree and form of mobilization of the two networks and the way in which they are connected that determines both the trajectory and success of a project (figure 1.1).

Concentrating on the two networks, it is possible to plot any project in a two-dimensional graph, where the *x* axis measures the degree of mobilization of local actors (control over local network) and the *y* axis measures the extent to which external actors are linked (control over global network). Furthermore, it is possible to describe the translation trajectory of any project (figure 1.2).

Thus, in the case of the TSR.2, the project started in the center of the diagram and climbed up the vertical axis as it sought to distinguish its product from the Buccaneer (A). Then, as the management structures were elaborated, it sought to move along the *x* axis to the right (B), and this tendency was strengthened as a design was agreed between the two former design teams, which in turn facilitated the formation of a single, unified design team (C). However, this position was not maintained. Little by little, as the subcontractors failed to fall into line, and in some cases interacted directly with the RAF, the degree to which the project management monopolized the internal network declined (D). This process reached a nadir when the low-

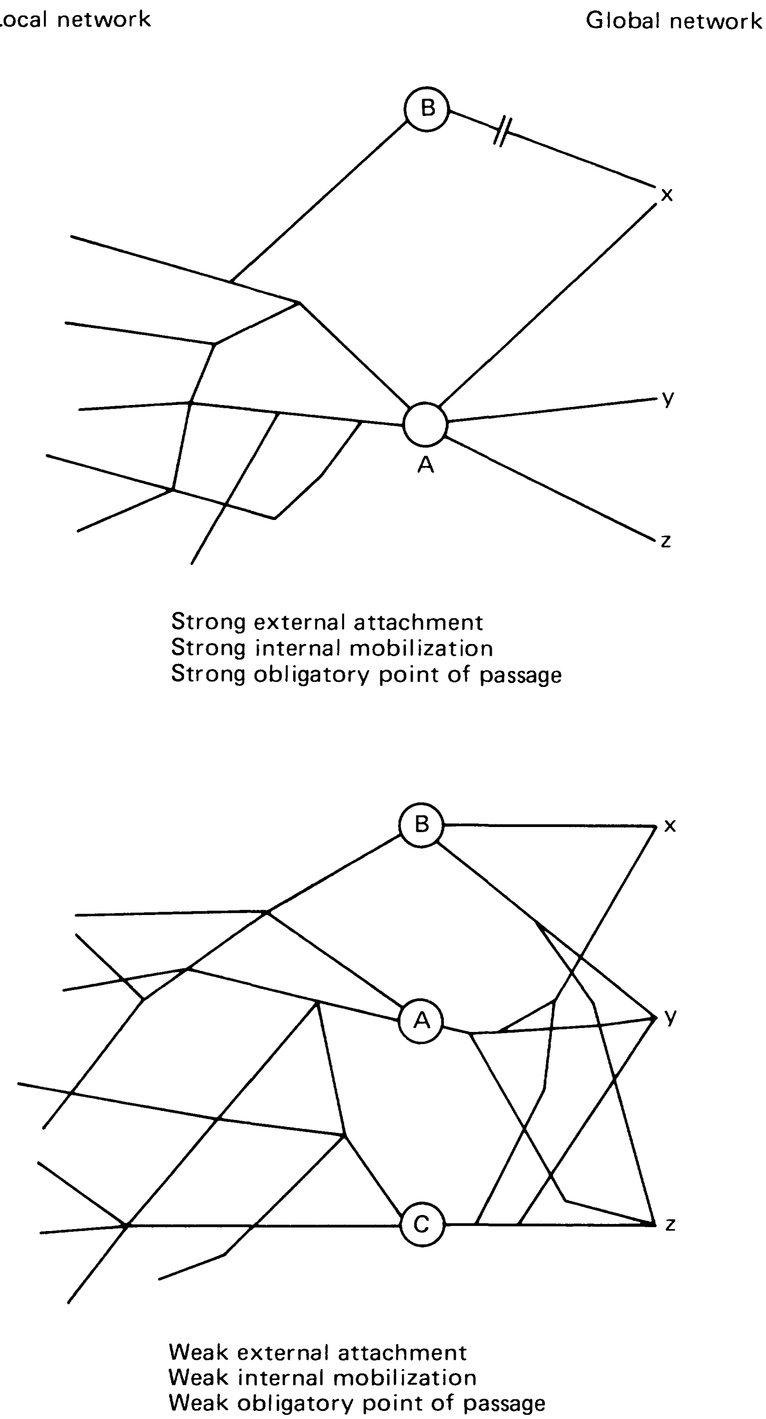

Figure 1.1
Strongly and weakly mobilized networks.

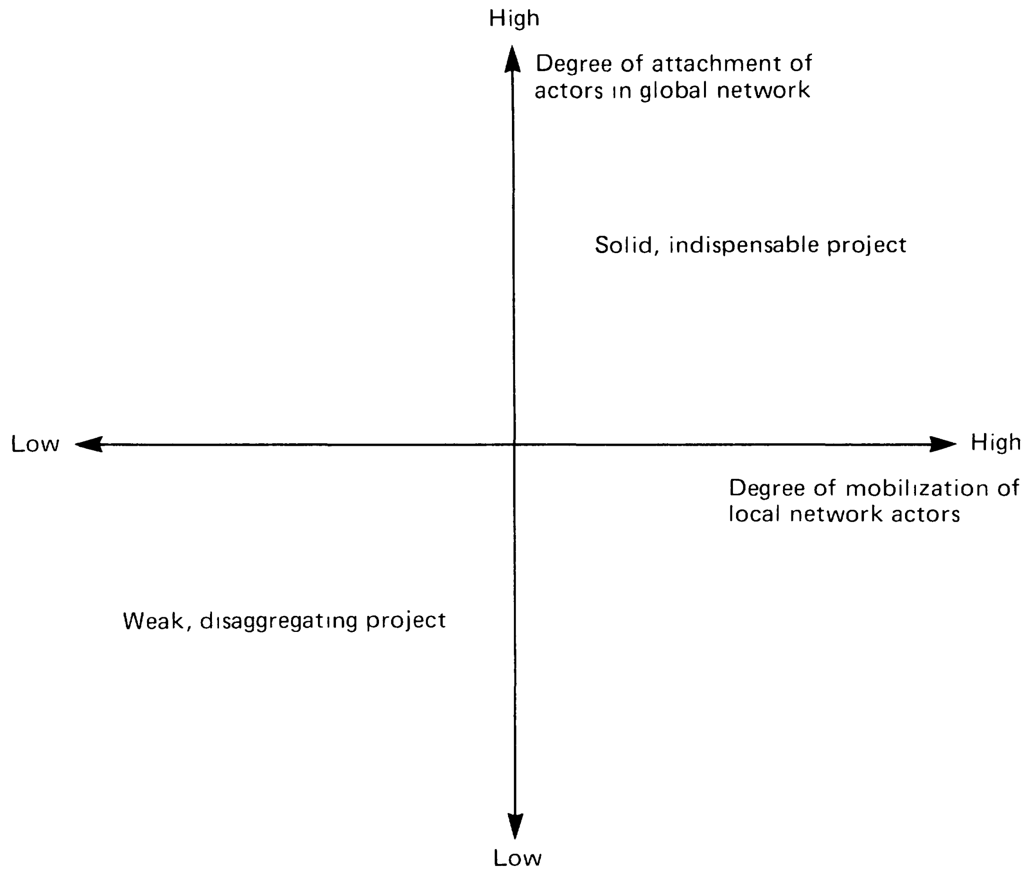

Figure 1.2
Mobilization of local and global networks.

pressure shaft of the engine disintegrated and the latter blew up (E), and the Australians opted to purchase the F111 (F). However, after much remedial work the successful maiden flight took place and a degree of control over the local network was reasserted (G). Accordingly, the project moved back into quadrant 1, but with changing political circumstances and the availability of the F111, it reentered this quadrant lower down the *y* axis. Finally, with the election of a Labour government, the F111 came to be seen as a realistic alternative, and the project slipped down into quadrant 4 (H), and with cancellation it concluded by losing complete control of the local network, so ending up at the lowest point in quadrant 3 (I) (see figure 1.3). The major turning points in the trajectory of the project across this diagram can be depicted as a table of choices and consequences (see table 1.3).

We conclude, then, with the thought that the trajectories of technological projects are contingent and iterative. Sometimes, to be sure, a project or a technology may move forward in a manner that

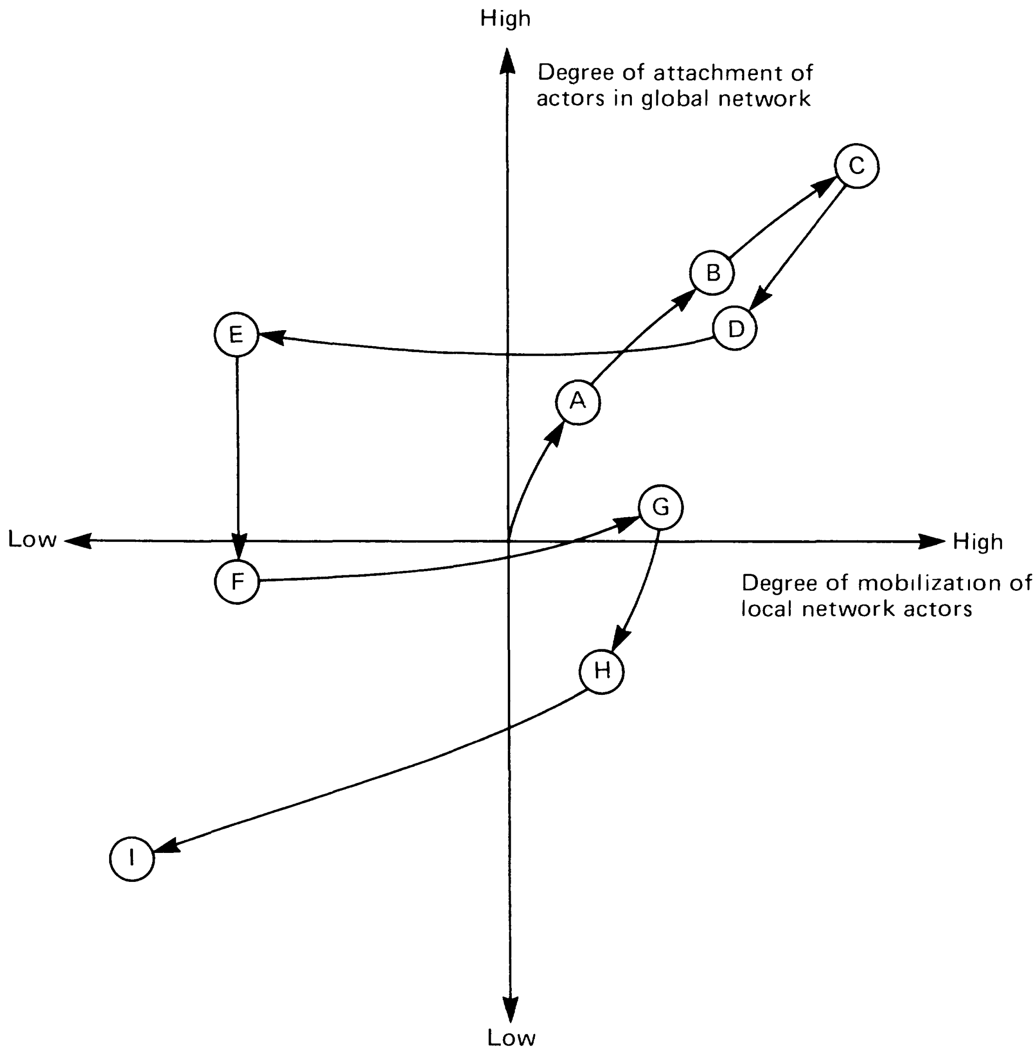

Figure 1.3
The trajectory of TSR.2.

accords to the stereotypical representation of the process of research and development. There is, however, no *necessity* about such progress. If all is smooth, this is because contingency has operated in that way. The kind of erratic progress we have described is far more likely—though such contingencies are often concealed in the Whiggish histories that celebrate the necessity of the successful after the event (see Bowker, this volume).

But our object is to move beyond the claim that outcomes are the product of contingency. Though this is right, it is also unhelpful unless we are content to accumulate specific case studies. Our aim is rather to seek patterns in the case studies. We believe that the case of the TSR.2—like a number of others in this volume—suggests that a crucial strategic move in building many, perhaps all, obdurate sociotechnologies is to create a distinction between inside and out-

Table 1.3
Choices and consequences

	Events/decisions	Local consequences	Global consequences
A	To build a new aircraft	Articulate design	Navy and Treasury blocked
B	Appointment of prime contractor	Articulate weapons	Minimize outside intervention
C	Decision about design	Develop production facilities	Secure funding
D	Support prime contractor's choices	Undermine prime contractor	Permit direct RAF intervention
E	Destruction of engines	Delay, mobilization of new teams and facilities	Expense and increased skepticism
F	Australian purchasing decision	Increasing skepticism by subcontractors	Increased politicization of project
G	Maiden flight	Technical confidence in aircraft and contractor	Strengthens supporters of project
H	Labour party wins election	Increases doubts among subcontractors	Strengthens opponents of project
I	Cancellation	Dissolution of project	Option to purchase F111

side, between backstage and front stage. The methods and materials for building such backstage negotiation spaces and relating them to the front stage are varied, and as the case of the TSR.2 shows, they are certainly not a function of strategy alone. We make use of a network metaphor because we need a neutral way of talking about the barriers that shape, for a time, the seamless web of sociotechnology.

Notes

John Law gratefully acknowledges the award by the Nuffield Foundation of a Social Science Research Fellowship, which made possible the empirical research on which this paper is based.

1. Here we adopt the methodological adage of Latour (1987) and "follow the actors."

2. In an earlier paper (Callon and Law 1989) in which we developed this argument in greater detail, we referred to these neighbors as "preforming networks."

3. Fuller details of this process of design are reported in Law 1987.

4. Little is known about the actual process by which decisions were reached. The best information available to us amounts to little more than hints. It does appear,

however, that the Treasury and the Ministry of Defence were fought off again in February 1958 (Wood 1975, 158). The Treasury was still concerned about the cost of the whole project, and the Ministry of Defence, noting the smaller of the two submissions from Vickers, toyed with the idea of specifying an aircraft that would fulfill some GOR 339 requirements and also be capable of carrier-borne operations (Wood 1975, 156). However, the RAF's need for a large aircraft of the TSR type was pressed both formally and informally, and GOR 339 emerged unscathed.

5. This specified that the TSR.2, as it was coming to be known, should be capable of high-altitude supersonic flight and a 1,000-nautical-mile radius of operations in a mixed sub- and supersonic sortie. It should also be capable of low-altitude treetop-level flight, have a terrain-following radar, display a low gust response, and have a short takeoff capacity, which in turn entailed a high thrust-to-weight ratio. It should have precision, self-contained navigational aids, be capable of delivering both nuclear and high-explosive bombs, have advanced photographic and linescan capabilities, and be reliable in order to minimize losses and permit operation from poorly equipped forward bases. Finally, it should have a ferry range of 3,000 nautical miles and be capable of inflight refueling.

6. In its definitive form the proposed aircraft had 1. a cruising speed Mach 0.9–1.1 at sea level and Mach 2.05 at high altitude; 2. a sortie radius of 1,000 nautical miles, 3. a takeoff capability of 3,000–4,500 feet on rough surfaces; 4. a climbing rate of 50,000 feet per minute at sea level; 5. a takeoff weight of 95,000 pounds for a 1,000-nautical-mile mission; 6. a high-wing delta configuration with large blown flaps but no control surfaces; 7. a large tailplane with all-moving vertical and horizontal surfaces; 8. two internally mounted Olympus 22R engines; 9. an internal weapons bay; and 10. an internal fuel capacity of 5,588 gallons.

7. The development of the engine and the detective work involved in diagnosing the cause of its failure is discussed in detail in Law 1992.

8. In January the government considered an offer from the BAC to manufacture 110 aircraft at a price of £575 million, with the firm picking up the first £9 million of any cost overrun (*Flight International* 87, 2928, April 22, 1965, p. 622). It did not accept this offer primarily because it was not prepared to carry all additional losses.

9. The limits to organizational power are usefully discussed in Clegg 1989.

10. Although it is outside this story, the aircraft went through a further reshaping in 1967 when the F111 was canceled. At that point aircraft number 4—a further version of the Buccaneer—entered the scene.

11. The notion of "translation trajectory" is, of course, ironic. Translations are the product of continual negotiation. They are precisely not the result of momentum imparted at their point of origin. We use the term to indicate the way in which our concerns overlap those of trajectory theorists—see, for instance, Sahal 1981, Dosi 1982, and Nelson and Winter 1982—but offer an analysis of technical change that is quite different in kind.

2

What's in a Patent?

Geof Bowker

In this essay, I am concerned with the kinds of accounts given of technical objects in patents, scientific literature, and company archives and in the relationships among the differing presentations of patents in these various sources. Numerous authors have pointed to the importance of patents in industrial science. In a notable turn of phrase, David Noble asserted that "Patents petrified the process of science, and the frozen fragments of genius became weapons in the armories of science-based industry."[1] Thomas Hughes (1983) has highlighted the fact that the research laboratory at General Electric was set up on the advice of the patent lawyer;[2] Reich (1985) has shown that in the Bell Company, industrial research was encouraged only when the strategy failed of buying up patents, then defending them in court.[3] Dennis and Bowker have identified the to-and-fro between patent lawyer and industrial laboratory as a key feature of industrial science.[4] In a ground-breaking essay, Cambrosio, Keating, and Mackenzie (1988, forthcoming) discussed the parallel between sociological and legal discourse about inventions and concluded that lawyers attacking patents draw on the same repertoire of analytical tools as the externalist sociologist.[5] I intend to develop this new perspective by looking at the ways in which patents are defended both in the courtroom and in the field. I will draw on the example of one company, Schlumberger, to discuss the relationship between the official version of history written into the patent and the actual use made of the patent.

In looking at patents as texts, I will concentrate on two features common to them all: they give internalist and Whig accounts of the development of the process or apparatus that they describe, and as legal instruments they attempt to impose that interpretation on the material world.[6] Now that within the history of science the ramparts of internalism and Whiggism have transmuted from stone to straw, *we* know that any account couched in these terms is necessarily false.