Network building

Weapon innovation: networks and guiding principles

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The present path of weapon innovation, meant to increase national security, may actually undermine it. Present arms control negotiations, such as the CFE (Conventional Armed Forces in Europe), focus on reductions of troops and existing conventional weapons. In a situation of reduced levels of armament, qualitative changes arising from weapon innovations may pose an even greater threat to stability and thus to (inter)national security. Up till now these have not been part of arms control negotiations.

This article explores how to make arms control considerations part and parcel of the military technological innovation process. It introduces the specifically well-defined concept of ‘guiding principle’ as an instrument for decentralized control of innovation in military technology and applies theoretical constructs (notably a network analysis) from the sociology of technology to analyze the developmental process of the European Fighter Aircraft and its radar.

After World War II, Vannevar Bush wrote in his advice to the President, entitled Science: The Endless Frontier,

“There must be more — and more adequate — military research in peacetime. It is essential that the civilian scientists continue in peacetime some portion of those contributions to national security which they have made so effectively during the war.”

His advice has been realized to an extent that Bush is unlikely to have foreseen but, contrary to the rationale behind his proposal, in the view of many this effort has not always led to an increase of national security. For instance, Herbert York, former Director of Defense Research and Engineering and former US ambassador to arms control negotiations on a comprehensive nuclear test ban, has forcefully argued that the steady increase in US military power (expressed in terms of the quantitative and qualitative growth of weapon systems) has actually resulted in a rapid decrease of national security. He has denoted this paradox as the ‘ultimate absurdity’.

The present path of weapon innovation, meant to increase national security, may actually undermine it in two ways. First, new developments in weapons technology may undermine existing arms control treaties (as, for instance, cruise missiles undermined the SALT-I treaty). Secondly, particular types of weapons, because of certain operational characteristics, may have a destabilizing effect: they may, for instance, pose a threat to crisis stability.

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Although the far reaching implications of military technological innovations are widely recognized, until now they have not been part of arms control negotiations. One reason for this is the perceived lack of instruments for steering the process of weapon innovation. One of the problems encountered is that many analysts and politicians consider research and development (R&D) as an autonomous process, with an intrinsic momentum, that is outside the scope of control, or they think that anyhow the whole technological innovation process is so much dispersed that for that reason it cannot be steered.

**Dynamics of the arms race**

In the literature, the problem described above is usually referred to as the problem of the 'dynamics of the arms race'. Until recently two main approaches could be distinguished. One, the 'action-reaction' school, focuses on inter-state interactions, the other, the 'bureaucratic-politics' school, emphasizes intra-state processes. The two approaches, however, are not mutually exclusive.

In the inter-state approach the emphasis is on the competition in weaponry between the two power blocs NATO (North Atlantic Treaty Organization) and WTO (Warsaw Treaty Organization), which are both described as captives in a prisoner's dilemma. In other words, the military and politicians of each bloc feel pressed to promote weapons innovations in order to counter the weapon innovations of the other party and vice versa. The process is even more forceful than a simple action-reaction mechanism, in the sense that a party often 'reacts' not only to what the other party has done or is planning to do, but to what he thinks the other party might possibly do.

This points to the second approach in which the intra-state processes are perceived as the main driving force in the weapon innovation process. After World War II research and development of new weapons was institutionalized on a scale never seen before. This has brought many analysts, partly also by their own experience (York, Zuckerman), to the conclusion that technological development itself (often interpreted as 'technological momentum') constitutes the driving force. This is in accordance with Canby's observation on 'emerging technologies' that "[T]heir momentum is set by industry rather than by the military. Change has become so rapid that the military has become a follower rather than an initiator."4

What is lacking in the various approaches within both schools is a link between the described social and organizational processes and the concrete shape, or nature, of the weapon systems developed. Some recent historical and/or sociological case studies on military technology do not help us much either, because they do not address the question of what one may learn from these cases about steering military technological developments.7

Of interest is the recent work of Evangelista because it can be viewed both as a reaction to, and an integration of, the approaches of the two 'schools' mentioned above. Evangelista has developed a five-phase model for describing the innovation process of 'break-through' military technologies.8 The major advantage of this model is that it has an open eye both to processes internal to the technological community and to the interactions of this community with a wider community of military and politicians.

However, Evangelista has not addressed the question of how his model can be used in connection with the problem of control of weapon innovation. One of its shortcomings might then appear to be that in his model, technological development is still too much conceived as a linear process. This problem, however, might be overcome by using a network approach as will be discussed later.

**Our approach — guiding principles**

We will approach the problem of control of the weapon innovation process in two steps. The first is to present and elaborate a framework of analysis that (a) pays respect to the heterogeneity of the process and (b) offers cues for controlling it. The second step is to suggest and work out possibilities for actual control. The two steps are of course closely connected and tentative ideas about the second are necessary before the first can be worked out.

Concerning the second step, at first sight the control of military technology within the framework of arms control might seem relatively easy. Government and governmental bodies have a near monopoly in the buyer's market of weapons and one might suggest that they could just order those weapons that fit their
arms-control requirements.

But there is a paradox. These governments, in their turn, depend on the weapons laboratories and military industries for the supply of new technological options from which they might choose. Furthermore, the choice is not a 'free' one. Heavy investments may have been made; the future of industries and jobs may be at stake; and so on.

It appears that in the processes of military R&D, testing, evaluation and procurement a very heterogeneous set of actors and factors play a role. So, for the question of the control of military technological developments it will not suffice just to focus on what one central actor like the government should or should not do. In particular it will not suffice to restrict the attention to only the last stage, notably that of procurement, in the innovation process. To tackle this problem we will investigate the possibilities of what we call decentralized forms of control or regulation, that acknowledge this heterogeneity.

In a recent publication, the concept of 'guiding principle' has been developed to facilitate further elaboration of the idea of a decentralized steering and regulation of military R&D within the framework of arms control.9 'Guiding principle' is on the one hand an analytic concept used to describe and analyze processes of military technological development, while on the other hand it is intended to be an element in the design of intervention strategies for control of these developments.

The central premise behind the concept can be expressed as follows: various actors in the processes in which military technology is developed and implemented, act on the basis of 'guiding principles'. These guiding principles function as a strategy for problem solving, including criteria of evaluation, that guide military research, development and procurement. We do not seek guiding principles at the level of the individual (or smaller group of individuals). We are primarily interested — and this is our first specification of the concept — in those guiding principles that are possibly shared by many of them. In our approach between these actors. (In our conceptual vocabulary this means that they are actors in 'underlying networks'; see below.) We are, for instance, seeking guiding principles shared by politicians and military, or by R&D engineers and politicians, or other combinations of (two or more) different sets of actors. So 'guiding principles' is an inter-organizational concept.

A second specification of this concept is that it should function specifically as an 'interface' between military doctrines or strategies and weapon innovation. We have articulated the 'guiding principle' as an inter-organizational concept that plays a role in the interaction between military technological developments and military doctrines and strategies, in order to make it a potentially useful instrument for arms control measures. Guiding principles should, for instance, function in such a way that destabilizing developments are filtered out early in the innovation process.

We will return to this issue at the end of the article. But before we can investigate how this might be achieved, we need to analyze how guiding principles can be traced in concrete cases of development of military technology, how they have become integrated in problem solving and evaluation processes, and how they function.

Our framework — networks

In this article, the second step — designing schemes for arms control that also affect the weapon innovation process — will not be fully elaborated. But the brief description presented above will be used to work out the first step — that of developing a framework of analysis for processes of weapons innovation, that will, in later investigations, be used for working out the second step and putting (empirical) flesh to the bones of the idea of guiding principles.

Given the brief outline of the second step and our criticism of existing frameworks of analysis, our framework should acknowledge the heterogeneity of the weapon innovation process in the sense that both the technological and the social aspects are subject to continuous change. Furthermore we should be able to trace which factors guide various actors — in particular in their interactions with other actors — to be able, at a later stage, to trace guiding principles that are possibly shared by many of them. In our approach we also want to acknowledge that the interactions create both opportunities for actors to have their way and restrictions on what can be achieved.

We will try to account for this heterogeneous set of demands by using the notion of a network. In our approach the nodes in a network are considered to be either individual human actors or (representatives of) groups of human actors.10 A network is further characterized by the interactions between the actors, which can be of a very heterogeneous nature. But at a certain level of abstraction, patterns can often be discerned that remain unaltered over longer periods of time, which makes it possible to recognize networks with a certain degree of stability.

Thus, stable patterns of interaction may develop between governments and military establishments; between industries and members of parliament; and

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so on. Although the actual subject and content of the interaction may be subject to continuous change (for instance, the specific weapons that are produced and implemented) these patterns can be stable over long periods of time and, moreover, tend to preserve themselves by 'adaptation' of the content of interaction (for instance the development of new weapons).

In this article we start to apply this approach to a 'large-scale' military technological project, the European Fighter Aircraft (EFA), that is currently under development in a collaborative program between four West European nations. The large scale of this project enables us to focus on networks at a 'high level of aggregation', such as those in which military strategy is formulated and implemented (and especially those in which various military actors play an important role); networks in which weapon systems are conceived, developed and produced (especially industry); and those with a broader political agenda (governments, parliaments).

These networks may overlap to a certain extent but the main point is that different dynamics can be distinguished that are characterized by different stabilized patterns of interaction and that each of these patterns (networks) shows a tendency to preserve itself.

When we look at the development of large weapon systems with this framework in mind, we see that sometimes relevant developments take place within one or more of these networks while at other times major developments are located 'between' these networks. In due course these 'inter-network' interactions may lead to new stable patterns of interaction, and thus to a new network in connection with the weapon system under development.

In this article the analysis will focus on a limited number of episodes in the development of EFA, where a number of the 'underlying networks' become linked to one another or in which an existing network comes under heavy stress. This focusing on what we will call critical episodes, is because in the interaction leading to such new networks and in 'stress situations', the content of the technology is under discussion and is, to a large extent, given shape in the same process that determines the social relationships in the new network. It is this same process that decides whether an existing network in a stress situation survives or shatters.

In this shaping process certain features of the internal dynamics of the underlying networks play an important role and may set certain boundaries within which the new network and the artefact can be given shape. Once these 'negotiations' have led to the creation of a new network, there is far less room for fundamentally shaping or re-shaping the technology in the project. This situation may change again when the network comes under stress.

The analytical framework given above, will be used for the conceptual and empirical analysis of the European Fighter Aircraft project.

EFA and EFA's radar

We will now focus on two critical episodes in the development of the European Fighter Aircraft (EFA). A brief description will be given of its general history to provide a broader technological and social context. The first episode focuses on the period from the first more or less specified description of the operational and technological characteristics of the fighter to the point when, by mid-1985, four nations signed an agreement for actually developing it.

In analytical terms this episode is used to emphasize how characteristics of underlying networks can help to understand how, what may be called the new 'network in the making' is constituted socially. Special emphasis will be put on how the underlying networks set limits to what is possible in connection with this new network. It will be illustrated how certain characteristics of one of the underlying networks made it impossible for one of the originally participating countries to become an actor in the new EFA network.

The second critical episode in connection with EFA focuses on the decision-making process in connection with the radar for the fighter. There were two serious candidates, that were promoted by different configurations of underlying networks. After three years of heavy competition and discussions, in May 1990 a decision was made.

In the first critical episode, there was hardly anything that could be called an EFA network and at one point the knot was cut by some of the potentially participating actors, making one country drop out. In the second case, the EFA network had matured and grown to a considerable 'size' and many of the participating actors time and again stressed the importance of finding a compromise over the radar. Cutting the knot, many feared, might threaten the existence of the network as a whole.

Thus, the first case illustrates how a 'weak' network in the making is given shape by certain characteristics of underlying networks. In the second case the network in the making has become strong enough to (co-)determine its own further development.

Setting the stage for EFA

Plans for European cooperation in building a new fighter aircraft have been in the air since the late 1970s. These plans can be seen to fit a more general pattern that has developed over the last two decades, during which in a number of West European countries, there has grown strong desire to become less dependent on the USA in weapons development and production.

A number of factors played a role in creating this incentive. One is that, especially from the late 1970s onward, notions developed that American security interests differed in a number of respects from those of Europe. This was also connected to European
desires to become less dependent on the USA in arms production, or at least to open a 'two-way street' in arms transfer between the United States and Europe.13

Furthermore, economic competition between the USA and western Europe grew hand-in-hand with European striving to develop a competitive technological innovative power independent of the United States. Aerospace technology is considered a key technology in this respect.

Finally, and not least important, in western Europe opposition grew to the American export restrictions on key technologies. Since many advanced devices produced in western Europe contained American technology a lot of them were subject to prior American consent for intended exports. This issue also clearly played a role in connection with the EFA-radar as will be discussed later.

West European countries, seeking to become independent of the USA in 'key technologies', subsequently had to face very high R&D costs in a relatively small domestic market. This, then, created an incentive for cooperation between West European countries14 of which EFA is one example.

Actually, the European Fighter Aircraft project had a precursor in the British-led Experimental Aircraft Programme (EAP). The EAP followed from an initiative in 1979 by British Aerospace, together with the UK electronic companies Ferranti, GEC Avionics and Smiths Industries to start developments on a new advanced technology aircraft. The initiative resulted from a main concern with these industries: how to fill the factories when current production programmes of the Jaguar, Tornado and Harrier expire, while the British government has no firm plans for a next generation aircraft.15

After heavy lobbying the UK government supported the initiative, which was announced at the Farnborough International Airshow in 1982, as the joint industry/government funded Experimental Aircraft Programme.

The French reacted within weeks, announcing that they also had a national demonstrator program — ACX (Avion de Combat Experimentale), later called 'Rafale' — which was to be developed by the French aerospace company Dassault. Prototypes of both aircraft were to fly at the 1986 Farnborough International Airshow.

The West German government, in favour of a common European enterprise for a new fighter aircraft, regretted this dual track. As it did not want to choose between these projects, it exercised pressure on the German aerospace firm MBB to withdraw its participation in the EAP.

After this, serious negotiations started among five nations (FRG, UK, France, Italy and Spain) on the joint development of a European Fighter Aircraft. The importance of this for our network analysis is to show that, at the start of the EFA negotiations, some underlying networks, coupled to two different projects, were already existent.

Military requirements

In connection with the fighter under discussion, by 16 December 1983 discussions between air force staffs of different countries had matured to the extent that the Chiefs of Staff of the FRG, France, Italy, Spain and the UK reached agreement on a preliminary statement of operational characteristics of what became known as the European Fighter Aircraft (EFA).

The outline agreement, called the Outline European Staff Target (OEST), emphasized air-to-air combat capability as EFA’s primary requirement while air-to-surface combat would be secondary. The OEST specified that the aircraft should be a single-seat, twin-engine aircraft with high agility and short takeoff and landing capabilities. Furthermore, the type of armament was indicated and it was pointed out that the aircraft should have a ‘basic mass empty’ (BME) of 8.5 tons.

It was expected that the five partners would have a total requirement for about 800 aircraft while independent studies indicated that at least another 300 could be sold, primarily in the Middle East.16 The Chiefs of Air Staff continued joint air force studies and by 11 October 1984 had arrived at a more definitive agreement — the ‘European Staff Target’ (EST).17

Up to this point only the military requirements that were specified by the air force staffs had influenced the type of technology to be used. Soon, however, the picture would become more complicated and a number of other factors would also play an important role, such as costs of development, operational costs, possibilities for export, national policies in connection with industrial development and employment, striving to become independent of the USA, and commonality with existing programs.

On 9 July 1984 the defense ministers of the five nations met in Madrid and stressed the importance of the joint development. They signed an agreement for a formal feasibility study on EFA and made commitments to finance a study of the technology and to work-share on the airframe, engine and avionics systems.

The national armaments directors were to present a final recommendation on the project to the defense ministers in Rome the following March. The ministers would then decide whether to go ahead with the project definition phase. The countries had compromised over an aircraft of about 9.5 tons, optimized for air superiority but with built-in ground attack capability.

The UK wanted to put the EFA into service in 1993 but eventually accepted the French preference for 1995. The FRG, France and the UK each committed about $65 million to pay for feasibility studies to be conducted by their respective industries. The feasibility study work was distributed as follows: 25% each to the FRG, France and the UK, 15% to Italy and 10% to Spain.18

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Industrial requirements

The next step in the EFA program was to get the aerospace industries of the five collaborating nations to agree on work and design sharing and on program funding. This was expected to happen by mid-1984. Participation of five nations was generally thought to make management difficult although three of the five countries had built up an experience in this respect: the FRG, Italy and the UK had cooperated in the development and production of the Tornado fighter.19

Until this point the countries seemed reasonably well agreed on what they wanted, but when industry came in, deeply rooted differences of opinion became apparent. First there was the problem that French industries demanded design leadership of both airframe and engine. German and British industries wanted equal shares.20 It appeared that the French stance was not simply a matter of greed, but reflected a deeper conflict of opinion over EFA’s meaning which would also have consequences for the appearance of the aircraft.

Over the past decades France has very explicitly pursued a policy of remaining independent of others for its national security, and in nuclear matters to be on an equal footing with countries like the UK and the USA. France is a member of the political structure of NATO but it stepped out of the military structure. It has developed its own nuclear forces, the ‘Force de Frappe’, that operates completely independently of the NATO command structure.

Another consequence of this desire for independence has been the establishment of a national armaments industry for all major categories of weapons, including advanced fighters. But for a medium-sized country, sustaining a high-tech defense industry solely for domestic purposes creates a heavy burden on the national budget, which makes the French industry, as well as the political leadership, very keen on export and on cooperative programs to spread costs over larger volumes of production.21

In network terms, this implies that, in France, there has been a long standing network in arms production with strong ties between the government and a number of branches of industry that are considered strategic. Strong then means that these relationships would not easily break up and that industry and government usually spoke with one voice. In connection with the technology, the main issues in the network were keeping up innovative power and burden sharing, the latter often being translated into seeking export possibilities but sometimes also into seeking cooperation in R&D.

In connection with the development of EFA a relevant characteristic of the French network was that, especially after the fiasco of the Mirage-4000, the future of Dassault-Breguet as a producer of advanced fighters was at stake. For the French government as well as for Dassault-Breguet, a very important consideration was the decline of (export) sales of military aircraft. The French came to the conclusion that a future fighter should be as light as possible to make it cheaper and, therefore, more easy to export. This decision was based on a generally shared belief that fighters get more costly the heavier they get. Thus, for the French a smaller aircraft would be a guarantee against high cost.22

In the UK, all these issues also played a role, but when we take a closer look at the networks that had developed there, some important differences in emphasis appear when compared to France. Much more then the French, British firms had developed relationships with foreign companies in arms development and production. Building the Tornado aircraft is one example.

In addition, the British military and government relied more on foreign (especially American) technology for their armaments than did the French. Although the UK was striving to become more independent from the USA, this implied much less an urge for national independence than an incentive for seeking European cooperation.

Heading for trouble

For the UK, the military requirements of the aircraft were of prime importance. The Royal Air Force (RAF) believed, because of Britain’s geographical position with respect to central Europe23 and its long-range overseas responsibilities, that a small aircraft would be inadequate. For long ranges a larger aircraft would be needed, while for the French, being closer to central Europe, this was not necessary. This conflict, that was rooted in different opinions on the tasks EFA should fulfill, meant the British wanted an aircraft that was 20% heavier than the French.24

These differences were discussed among the armaments directors of the participating countries shortly before the defense ministers convened in the Hague on 22 November 1984. At this meeting the ministers asked industry to present a design with two variants: one weighing 9.5 tons plus 250 kg; the other weighing 9.5 tons minus 250 kg. Dassault worked on the lighter version and came up with a design which was almost exactly derived from the Rafale demonstrator; Aeritalia, British Aerospace, Casa (Spain) and MBB (FRG) worked on the upper limit and produced a design that looked very much like the British EAP.26
Early in 1985 British Aerospace (BAe) announced that it was prepared to give France design leadership in return for French agreement for an international development organization in which all members would be equal partners. According to Admiral Raymond Lygo (Managing Director BAe), important considerations for such a cooperative project would be:

- It would be very serious if the political drive for the concept of European collaboration allowed one nation to have its way to the extent that the resulting aircraft would not meet either the British requirements or the competition for export sales.
- Both the UK and France had the capability of developing and producing a new fighter independently of the rest of Europe, but both would have to face competition in the export market from the Soviet Union and US industry (which was considered to be heavily subsidized through the NASA (National Aeronautic and Space Administration) and foreign military sales programs).
- The partners would first have to look at operational requirements and design a fighter aircraft that would deal with the perceived threat. They would then have to build an aircraft they could afford.
- The UK should only be a party to a program that placed national defense requirements above export considerations.

This position reflected a certain desire for compromise but also some strong differences with the French position. This was further emphasized when a seven-member British industrial consortium laid out a six-point program that it wanted the government to adopt as the UK position in negotiations with other EFA partners.

Similar concern was also expressed by a national aerospace engineering union and several MPs. The companies involved were: BAe, Rolls-Royce, Dowty, Lucas, Smiths Industries, Ferranti and GEC Avionics. The position proposed should “safeguard the UK national position and the continuing viability of the British aerospace industry”. The points of the program were:

- The resulting weapon system should meet the minimum operational target of the RAF.
- During the development phase, work should be shared with major partners on a basis of equality, although subsequent adjustments would have to be made in the production phase, where work shares would be based on the numbers of aircraft purchased by each nation.
- Work shares should apply separately to airframe, engine and component programs within the overall project.
- Equality of management authority and responsibility should be arranged among the five nations with no overt leadership.
- A central NATO agency should be established with authority to place contracts with companies in each of the partner nations.
- The program should be scheduled to get the aircraft into service as soon as possible — but not later than January 1995 — to ensure maximum penetration of world export markets.

Differing requirements

The six-point plan was presented in Parliament by Robert Atkins, in whose district BAe operated a factory at Warton. Atkins expressed concern about the French position by stating that there is a deep-seated belief in the UK industry “that the French are out-manoeuvring us”. According to Atkins the industrial consortium had a preference for a “national solution to the new fighter requirement for the RAF in view of the greater opportunity to utilize the industry’s resources and technology”. But the group had gone along with the multinational program because of the greater market base it would create and the longer potential production runs.

In February 1985, two designs were offered, neither of which completely fulfilled the European Staff Target, although the Dassault design was considered to be further removed than the proposal made by industries from the other countries. The proposals were discussed by the national armaments directors on 12 March in Paris but they failed to reach an agreement on design leadership, engine type and size.

After further meetings of the armaments directors, the defense ministers met in Rome on 16 May but they could not resolve the conflict either. They called for more studies on the air-frame and power plant configuration. The studies ordered included:

- Determinations of performance characteristics of an aircraft with BME weight of 9.5 metric tons and 9.75 metric tons.
- Studies of performance capabilities of an aircraft powered by an engine between 88 and 92 kN (kilometers, or 19,800-20,700 lb) thrust and a second aircraft in the 80-85 kN thrust range.
- Studies of possible interim engines.

Calling for an evaluation of the possibilities of different engine sizes was a further expression of the
different meaning EFA had for a number of relevant French and British actors. French industry and government had a preference for the French Snecma M-88 engine that was already under development. On the other side there was the Turbo Union consortium that had built an engine for the Tornado fighter, a cooperative program between the FRG, Italy and the UK. Turbo Union had a preference for a completely new engine.33

The French preference for the M-88 was, at least in part, inspired by seeking a guarantee against the aircraft becoming too heavy because this engine was designed for a 'low' 80 kN thrust. This would make the aircraft cheaper and therefore more easy to export.

On the British side, the anticipated long-range mission implied a preference for a powerful engine. Furthermore there was a desire to upgrade their Tornado fighters sometime in the mid-1990s with a new engine that would have a thrust of over 90 kN.34

When the defense ministers had signed the agreement for a feasibility study in mid-1984, they had decided that a new engine should be developed but, as has been illustrated above, a major hurdle remained — the disagreement about the thrust of the engine.

In reply to the defense ministers' call for more studies, industry presented 16 different, more refined designs in early June 1985. These plans were discussed by the ministers but again they failed to make a choice.

Once more they asked industry to make new proposals on a design of 9.5 tons plus 250 kg for potential additional mass. Three engines would have to be considered with 84, 88 and 91 kN thrust respectively. Plans would have to be presented by mid-July.35 These plans were subsequently discussed by the national armaments directors but it appeared that there were still large differences of opinion on:

- the type of political and industrial organization;
- who would have design leadership;
- where to locate headquarters. The UK did not want it to be in Paris while the French did not want it in London.38

Cutting the knot

By this time the FRG found that negotiations were taking too long and started pushing for a decision. The German defense minister Wörner stated that a decision should be made by 31 July 1985 at the latest. He made a number of compromise proposals to the armaments directors in connection with the technology to be used, type of organization and staffing. However, these proposals were unacceptable to the French.39

During a marathon meeting of the armaments directors in Turin on 1 August the Germans cut the knot by choosing the British side. At the meeting three of the five countries, notably the FRG, Italy and the UK signed a memorandum of understanding for the development of EFA. France and Spain could still join until 15 August.

Under this agreement, the FRG and the UK would take a 38% share, and Italy 24%. The former two would buy 250 aircraft each, Italy at least 100. The total number of 600 aircraft was expected to cost $20 billion.40 Shortly thereafter Spain decided to participate and shares became divided 33% for the FRG and UK, Italy 21% and Spain 13%.41 France continued on its own and pursued the development of the fighter Rafale.

Network dynamics

During the episode described above a very heterogeneous set of actors in one way or another tried to participate in the development of EFA, each with their own motivation and background. Together they were engaged in building up an EFA network that is characterized by the relationships between the participating actors and by the technological characteristics of the aircraft under development.

In the episode considered, both the social and technological composition of the network were subject to considerable change. It was unclear which technology would be used and who would participate. It might thus seem that everything might be possible but this appeared not to be the case. We can understand why not by seeing the various actors, not only as potential actors in a 'network in the making', but also as actors in established 'underlying' networks.

For all participants it was clear that the network in the making would entail a number of characteristics, such as:

- An aircraft would have to be constructed that would use very advanced (complicated) technology. This implied the participation of large numbers of (sub)contractors.
- In terms of finance the project would be very big.
- Participants in the project would be 'strong' actors with a large constituency, like governments, departments of defense (armaments directors), air force staffs and large industrial corporations.

Those characteristics made it very attractive for the various actors to be part of the EFA network. But they would not partake at all costs. In a first attempt to understand what happened we can look at the different 'relevant social groups' involved. For each of them EFA meant something different. For instance:

- For the air force staffs, EFA should fit into their military strategy and be capable of performing certain military missions.
- For the departments of defense, more general issues with respect to defense postures played a role,
For each of the relevant social groups EFA meant something different, but it was the underlying networks in which France and Britain were involved which caused the greatest differences to emerge also including policies with respect to (inter)national arms production.

- For industry, the main issues were to maintain a potential for technological development, to keep up with new technological knowledge and to be able to sell large numbers of manufactured products.
- Governments (and parliaments) often acted as mediators between other actors but for them a number of broader items such as budget constraints also played an important role.

Such a characterization to a certain extent elucidates the positions sketched above but it cannot explain the large differences between the French and the British. To clarify this we have to look, not only at the individual actors, but also at the relationships they had developed, in the past, with other actors: we have to look at the underlying networks in which they participated. Interesting differences then appear.

When we only look at France and the UK, by late 1983 the picture can be sketched as follows. There was a relevant French network in which one of the main problems was the survival of Dassault as a manufacturer of military aircraft. Furthermore there was a strong incentive to become as little dependent upon foreigners as possible.

In this network both French industry and the French government saw EFA primarily as an instrument for helping Dassault. Interestingly, the position of the French air force staff was very close to that of the other countries. The national chiefs of staff expressed that it was industry, and not the military, that had made the five-nation cooperation impossible.

For the British, EFA was primarily an aircraft that should fulfil a military mission. It was mentioned earlier that seven British industries had acknowledged the importance of meeting the RAF's operational requirements (which were closely related to EAP's characteristics). It then appeared that the British military requirements, although they were close to those of the French, were incompatible with the French industrial demands.

Radar — EFA's eyes and brains

Before going into the details of the disputes over the radar let us first sketch some general relevant further developments in connection with EFA. In May 1986 the airforce staffs of the remaining four nations accepted the then basic design parameters which called for an aircraft with a basic mass empty of 9.75 metric tons (approximately 21,450 lb), two engines of 20,500 lb thrust each and a wing area of 50 sq meters. This design met the requirements of all four air forces.

The development phase of the program would be conducted under the supervision of an International Project Office. To carry out the actual development work, industries of the four nations formed a consortium called Eurojet GmbH that was based in Munich. Another four nation consortium, Eurofighter GmbH, would manage the production of the EFA engines.

Concerning the technical outlai of EFA the original characteristics were set by the air force staff on the basis of the operational requirements for the fighter. The aircraft should be usable in close combat as well as in combat beyond visual range. For the armaments this meant that it would be equipped with the Advanced Medium Range Air-to-Air Missile (AMRAAM) as well as the Advanced Short Range Air-to-Air Missile (ASRAAM). Using these missiles had important consequences for the radar that would be needed.

Further operational requirements were that the aircraft should be usable under all weather conditions, by night and against a background of the increasing importance of electronic warfare. Although originally EFA was conceived as an air superiority fighter, it gained an additional attack responsibility as its mission was redefined by the partner nations.

But operational requirements were not the only important factors. There was a strong incentive, especially on the German part, to keep costs down. Furthermore the fighter should become operational as soon as possible, while it should be adaptable to changing circumstances in connection with further technological development, military doctrines and the capabilities of adversaries. As a result the German designers and government officials tended to rely heavily on proven technology.

Shared among the four countries was the reliance on a modular approach, to allow updating of the EFA, which was to begin almost immediately after it entered service. Separating the basic airframe from segments that might require more technology development would allow Germany to deploy the aircraft even if one or two of the new technology sections were delayed.

In the fall of 1987, work conducted had led to a freeze of EFA's design. The aircraft was designed for high sustained turn and acceleration rates and operational speeds from above Mach 2 at altitude to high subsonic speeds for endurance on the deck, according to Eurofighter.

The air force chiefs of staff of the EFA nations formally signed the EFA European staff requirement for development (ESRD) on 18 September. Shortly thereafter Eurofighter submitted its third updated
development program proposal to the international project office, called the NATO European Fighter Management Agency (NEFMA), which de facto is the representation of the four defense ministries of the participating countries. The proposal was subsequently passed on to member governments.49

While thus progress seemed to have been made on the side of formulating military requirements and technological design, the budgetary side remained problematic. The German minister of defense, Wörner, asked his counterparts for further program cost reductions of approximately DM 2 billion to ease the financial burden of EFA’s development.

In early February 1988, a series of meetings was held in Bonn in an attempt to clarify budget and procurement options.50 Wörner’s attempts to cut costs were successful in the sense that the budget estimates for EFA came down. The agreements reached with the EFA partners satisfied the German Bundestag members and, in early May, the defense and budget committees approved DM 5.8 billion ($3.5 bn) for the development of the European Fighter Aircraft.51

Shortly thereafter the FRG, Italy and the UK signed the Memorandum of Understanding. Spain was expected to follow some months later due to parliamentary procedures.52

Work could then proceed quickly to produce eight flying prototypes, including two dual-seat trainers, with a first flight date of 1991. The workshare was agreed to be: British Aerospace — fuselage and half of the right wing; MBB (FR G) — centre fuselage and vertical fin; Aeritalia — left wing and half of rear fuselage; CASA (Spain) — half rear fuselage and half of right wing.53

After the Spanish government had approved the country’s 13% share in EFA,54 the four governments signed the two main development awards, allowing a £5-6 bn FSD (full scale development) program under a tight maximum/fixed-price contract to proceed. The FSD agreement was signed on 23 November 1988 by NEFMA and the two industrial consortia, Eurofighter GmbH and Eurojet GmbH.55

The first prototype EFA was scheduled to begin flight test work in 1991 in West Germany, and deliveries of production aircraft were planned for 1996 under the terms of the contracts. The agreements were maximum-price contracts, but would be converted to fixed-price agreements as the developmental work was defined. This process required the two development consortia to assume a significant share of the development risk.56

Eurofighter expected to put out slightly under 300 requests for proposals (RFPs) governing EFA subas-
systems. Before releasing the RFPs, the four partner companies within Eurofighter would produce a technical definition of every subsystem and component that would go into EFA. These specifications would then be approved by Eurofighter. It would also be up to the partners to send out RFPs to firms within the four nations, which would have six weeks to respond.

The bidder had to send five responses: one to each of the four companies with design responsibility, plus an additional copy to Eurofighter, the overall arbiter. The company with system design responsibility would then place the contract on Eurofighter’s behalf, following a commercial and technical appraisal of the subsystem, in which Eurofighter had the final say in the event of any disagreement. NEFMA — actually the four Ministries of Defense — would have an influence on certain items such as the radar and engine.57 Below it will be discussed in detail how this set-up worked out in the development of the EFA radar.

**Battle over the radar**

Radar fulfills a critical role in most fighter missions, in particular as to search, detection, identification, and tracking of enemy aircraft. Subsequently it has to guide missiles to these targets or to provide initial data for launching weapons that have their own homing devices.

Radar is required to have ever-increasing capabilities in tracking more and more objects, simultaneously providing guidance to a number of launched weapons. Increasing demands are put on the detection range capability. In addition, it has to warn the pilot of attacks by enemy missiles and to provide electronic counter measures.

Thus, except for close air combat, where performance, such as agility, of the aircraft is a crucial factor, the capability for missions is limited by the radar and by the weapons carried by the fighter, for which it mainly acts as a launching platform.

Requirements of the radar will further depend on the military missions envisaged by the air forces. Interception, air superiority, close air support and air-to-surface missions, put emphasis on distinct radar capacities. Technological innovations pertain both to the hardware and software, for instance beam steering and signal processing.

The contest over the radar reflects, at the level of radar manufacturers and governments, to a great extent the network building processes concerning the aircraft as a whole. The main difference is that actors in the radar case were to act mainly within the framework of the overall EFA network. We will describe the actors (mainly focusing on the UK and the FRG), and discuss their actions and the themes

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**Radar fulfills a critical role in fighter missions in searching for, detection, identification and tracking of, enemy aircraft, and guiding missiles to these targets**
that played a role in establishing a multinational radar technology network.

Two consortia

At the country level, the actors that were building a network for the EFA radar were the same as for EFA as a whole. At the company level, different actors played a part who were, however, closely linked to their respective governments.

Thus in 1984, a year before the break between France and the other four European countries, the French electronic giant Thomson-CSF talked with Ferranti (UK) and AEG-Telefunken (FRG) about collaborating on radar and avionics systems for the fighter and, in early 1985, in spite of the threatening split of the five country EFA cooperation, Thomson still looked for possible cooperation with these companies and with the Italian FIAR and Spanish EESA companies.59, 60

After the break with France, Thomson-CSF dropped out, and two consortia emerged for the competition on the attractive radar project, with an estimated market value of about $1.5 billion.61

The British company Ferranti, leader of a consortium including the Italian FIAR and Spanish INSEL, offered a radar, called ECR 90 (European Collaborative Radar for the 1990s) based on the development of the Blue Vixen multimode radar. The Blue Vixen is an example of one typical development process in military technology, in which a technology trajectory is initiated by a company from its own funds and subsequently transformed into a governmental funded program.

The Blue Vixen radar evolved from the company funded 'Blue Falcon' program, aimed at developing technologies applicable to the next generation coherent multimode radar system.62 In 1983, the British Ministry of Defense took over funding the development and production of what since then was called The Blue Vixen radar, as part of the Mid-Life Update Program of the British strike/attack aircraft Sea Harrier. The ECR-90, more advanced than, but derived from, the Blue Vixen, would thus fit in the radar technology used elsewhere in the British armed forces.

The ECR-90 will be particularly software intensive and so can be tailored to the needs of different users. Through its flexibility the radar is expected to have a 30 years life service. Work within the ECR-90 consortium would be divided according to the number of aircraft ordered by the EFA member nations. Important to the participating countries is that each of the consortium members is to assemble and test complete radar systems and will have access to all technology developed.63

The second radar candidate, called MSD-2000 or 'Emerald', is a derivative of the Hughes AN/APG-65 radar and offered by the US/German consortium of Hughes and AEG. This is a fire control radar developed by Hughes for the US-Navy F/A-18 Hornet fighter. It has a proven performance for a complete set of air-to-air and air-to-surface modes and has a growth potential which would meet EFA radar requirements.64

Hughes AN/APG-65 radar is also to be used in the update program of the F-4 fighter, which would allow Germany to use spares bought for the F-4s and also to use the radars themselves when the F-4s are eventually retired.65 The German partner in the consortium, AEG, was originally part of the competing Ferranti-led team. However, if the ECR-90 were selected, AEG would be allowed to return as an associate in the consortium, and obtain the German share of 33% in the radar development.66

Radar networks

We will now discuss the actions taken by the radar companies in their efforts to have their radars selected for further development, as well as the themes that dominated in the interactions.

In the contest both consortia and the individual companies tried to strengthen their position. To this end, the consortia partly followed a network strategy by extending their network by linking up with other companies. Thus, they tried either to increase their capacities for developing even more capable radar systems by adding new know-how, or to strengthen their position within particular EFA countries. They also emphasized those attributes that were apparently important for the decision-makers and in which their own radar seemed to have better credits than the competitor's, such as export, capability, flexibility, reliability.

The most decisive voices were the governments of the four countries. The UK, together with Italy, had the most demanding requirement for the radar. In the competition between domestic electronic firms for participation in the EFA radar the UK had chosen Ferranti (in preference to its main competitor the British electronics company GEC) and now it kept pushing Ferranti in the international competition.67

On the other side, the German government strongly supported the MSD-2000 (Emerald) radar. The main objection that the FRG had against the Ferranti radar was the risk in technological development and consequently in costs. Limiting risks and costs in radar development was said to be predominant for the FRG.

Another reason for Germany's preference for the MSD-2000 was seeking commonality with its F-4Fs that will be upgraded with Hughes AN/APG-65 radar, and will be equipped with the same weapons as scheduled for EFA.68 To German pilots the EFA radar would appear virtually identical to the APG-65 radar in their F-4Fs. Moreover spare parts could then be used for EFA, which would reduce operational costs.69

So, in 1986, the participating nations held very
In 1986 the participating nations held very different positions; at that stage their disagreement was mainly in terms of differences in the required capabilities of the radar.

Different positions; at that stage their disagreement was formulated mainly in terms of differences in the (required) capabilities of the radar. They even considered a split buy. West Germany and Spain the MSD-2000; Italy and the UK the ECR-90.

In July 1986, about a month before the repeatedly delayed Request for Proposals for the radar from the Eurofighter consortium was expected, the Hughes/AEG consortium strengthened its position by linking up with the UK company GEC Avionics (later GEC-Marconi). The addition of the GEC signal processor would allow two versions of the Hughes radar to be offered — one with only relatively minor modifications for the FRG and Spain and a more sophisticated one equipped with the GEC processor for the UK and Italy. The new signal processor would be highly flexible, allowing major updates with only software changes.

Its development had been started by GEC three years previously and had been company funded up to that time. Like the ECR-90 consortium, GEC emphasized the importance of flexibility and growth potential in EFA’s radar, arguing that the military threat might have substantially changed by the time the radar went into service in the mid-1990s.

Bidding opens

The ‘official’ battle for the radar started in December 1986 with the Requests for Proposals issued by Eurofighter to 15 radar manufacturers in the four countries and the USA. The winner was to be selected by Eurofighter GmbH in the spring, so that development could start in the summer of 1987. Eurofighter GmbH, by its nature, would have to decide primarily on technical and economic criteria.

Apparently due to changes in the radar specification by Eurofighter GmbH and in order to allow the late entrance of US competitors such as Westinghouse, the deadline for returning the bids was extended several times. No decision was made, however, by Eurofighter GmbH; apparently ‘political’ aspects (including the ‘Europeanization’ of the technology (see below)) were tied up with the decision, that fell outside the competence of Eurofighter GmbH. The discord between the member states was reason for Hughes/AEG to submit two proposals, offering one radar that would be fully compliant with the EFA specification, and another, shorter-term version that would not be fully compliant but would cost significantly less.

In late 1987, Eurofighter GmbH, to get out of the deadlock, asked for refined bids for the EFA radar in order to obtain a system less expensive than those originally proposed. To this end some of the initial requirements, mainly of a technical and commercial nature and less of performance, were relaxed. Like the AEG/Hughes consortium, Ferranti now offered a less expensive radar, which was a variant of the Blue Vixen radar.

However, this procedure brought no solution to the highly political choice either. Moreover, the Eurofighter consortium itself became split along national lines. The British BAe supported the ECR-90 submission on the grounds that it believed it to be technically superior, whereas the German MBb was backing the MSD-2000, because it offered a less risky approach to full-scale development. So, in the summer of 1988, Eurofighter GmbH handed NEFMA a split recommendation to decide upon.

Within the framework of EFA it had been agreed that each of the four countries would have their share in the development and production of the radar. Within the ECR-90 consortium there was consensus that work was to be divided according to the number of aircraft ordered by member nations.

In the contest, a close connection existed between the governments and the electronic companies that had been chosen by them to participate in the international competition for the EFA radar. In our vocabulary they constituted underlying networks — the Spanish government and the industrial consortium INISEL; the UK government and Ferranti; the West-German government, the company AEG and the US company Hughes — that had to be linked to each other. The composition of the two consortia is depicted in Figure 1. (Siemens joined the ECR-90 consortium but would not be fully compliant with the EFA specification.)

Figure 1. The two consortia competing for radar in 1989

Note: The arrows show how, after a decision, companies will join the competing consortium.
A curious relationship existed, however, between the individual companies and these consortia, because, if the ECR-90 were chosen, AEG (FRG) would also participate in the development and production of this radar, whereas if the MSD-2000 were selected, FIAR (Italy) and INISEL (Spain) were to join the AEG/Hughes consortium.\footnote{77}

Thus, if the cooperation on EFA did not break up, the outcome of the network building activities around the EFA radar would be either a network of Ferranti, FIAR, INISEL and AEG to develop the ECR-90, or one including AEG, Hughes, GEC, FIAR, INISEL for the MSD-2000. The only real losers would be either Ferranti or GEC, both from the UK, and the US company Hughes.\footnote{78}

**Tough negotiations — 1989**

In late 1988, negotiations on the radar became tougher. The dominant issues were: risks in development and production costs, and export restrictions by the USA. Not at issue (any more) were the performance characteristics for various military missions. Thus at this stage the military had shifted into the background.

Tensions between the UK and the FRG increased and the West German government even used the threat of a split choice. At NEFMA meetings (basically representing the ministers of defense) in December 1988 and early 1989 West Germany took an uncompromising position and warned that it would proceed with the MSD-2000.\footnote{79} That really threatened the EFA consortium as a whole, since selection of only one radar had been part of the basic Memorandum of Understanding (MOU). The budget would be significantly overrun if two radars had to be developed and integrated separately into the EFA airframe.\footnote{80}

Subsequently the German Defense Ministry and the Luftwaffe (with backing from the West German industrial partner for constructing the EFA airframe, MBB), warned its EFA partners that it would install the enhanced AN/APG-65, that was already under development for the F-4 upgrading.

In this clash the United Kingdom stood firm on the fourth time — to make a recommendation on the radar by 28 April 1989, after re-evaluating the two bids. So Eurofighter asked the two consortia for 'best and final' offers.

At this stage differences in capabilities between the two radars played hardly any role. As technical performance was no longer an issue, it was likely that selection would have to be made at senior government level.

In West Germany the Ministry of Defense was under heavy pressure from the Bundestag to limit the costs of EFA and its radar.\footnote{81} In an extensive examination of EFA in Parliament, Defense Minister Stoltenberg assured the Defense and Finance Committees that firm price guarantees would be sought before any decisions were made on major subsystems. In the meantime EFA officials were anxious to settle the radar dispute quickly to prevent a possible FRG pull-out of the production phase if the Social Democrats gained office in the 1990 elections.\footnote{82}

To prevent a complete failure of the common radar project the UK Ministry of Defense (MoD) tried to meet the objections of the FRG regarding costs and risks by offering to underwrite the risk on ECR 90. Bonn officials commented however that this only related to development costs and that any consequential costs were not accounted for. Such costs could arise from prolonged testing of a delayed system.\footnote{83}

Moreover the MoD failed to secure guarantees from the UK Treasury for an insurance scheme to underwrite West Germany's portion of the risk. To defuse the crisis, it was agreed at high level consultations between the UK and FRG Secretaries of State for Defense that the EFA radar would adhere to current budget and time schedules and would not result in an 'uncommon' radar solution as had been threatened by West Germany.

In the meantime the company actors tried to strengthen their position. Thus Ferranti concluded an agreement with Siemens, giving ECR-90 an 'active' West German partner.\footnote{84} In addition, both Ferranti and AEG were working on reducing the cost of their radar bids, in accordance with Eurofighter's latest instructions, to present 'best and final' offers by early April 1989. The price cuts had to be implemented without compromising the performance of the radar, according to EFA instructions.\footnote{85}
UK-FRG conflict

The 'negotiations' about the financial and technological risk issue, so strongly pushed by the FRG, were marked by several moves, by both countries. First from the British to secure a choice in favour of Ferranti, then from West Germany to persuade the British to elect the MSD-2000.

The first British bid, mentioned above, was unacceptable to West Germany and was followed by a second. This offer was made after the FRG suggested that it was willing to accept the Ferranti-led ECR-90, but only if the radar was underwritten by international guarantees indemnifying any development cost overruns.

In a confidential memo to West German defense officials, the UK Chief of Defense Procurement suggested that Bonn direct MBB to transfer DM 150-300 million of EFA work of its choice to BAE. This would allow the FRG to retain cash reserves to offset Bonn's perception of the risk associated with the ECR-90 (a possible overrun of the development budget by up to DM 300 million). West Germany however reacted sceptically to the UK proposal, saying that a transfer of work would not only take jobs away from MBB, but would also remove valuable technological know-how that the FRG hoped to gain from the EFA program.

In July 1989, further high level meetings took place, this time between the UK Secretary of State for Defense, George Younger and his West German counterpart Gerhard Stoltenberg, illustrating the seriousness of the radar dispute. 86

In the summer of 1989, NEFMA and government officials met again, which resulted in Eurofighter GmbH asking the two teams bidding for the radar contract to submit yet another round of 'best and final offers' (BAFOs). This was said to be driven by the need to draft a new price structure for the optimised MSD-2000 and at the same time give Ferranti an opportunity to revise its costs for ECR-90.

In the meantime the UK Ministry of Defense was working on an optimization study of the MSD-2000 to see if it could be brought in line with the Royal Air Force's demanding radar requirement. 87 AEG had prepared a study into the MSD-2000 Plus to determine whether the improved radar now met the RAF requirements.

At that time West Germany came up with a 'counter offensive' to British risk guarantees, offering to pay almost all the cost of optimising the AEG-led MSD-2000 radar to satisfy UK requirements for EFA and guaranteed to underwrite the development risk. This initiative was virtually a mirror-image of a UK proposal, earlier in 1989, to underwrite the development risk of the Ferranti-led ECR-90. The FRG offered to pay DM 44 m of the DM 49 m needed for the improvements, and to finance any cost overruns on the development program.

At last, in May 1990, the final decision was made: the ECR-90 was elected as EFA's radar. 88 Could this have been predicted from an analysis of the network dynamics? Not with certainty; but the result was not unlikely in view of recent developments in network structures. First, ECR-90 had acquired an active proponent (Siemens) in West Germany. Second, after Ferranti's financial problems (see note 78), the British Government had encouraged the take-over of Ferranti by its competitor GEC, in order to reassure the EFA partners that the ECR-90 radar would continue (and to preserve Ferranti's technological know-how on radar). 89

GEC's strong financial position also implied that West Germany would estimate the financial risk lower, and the British Ministry of Finance would be less hesitant to guarantee limited financial risks for West Germany. 90 In addition, GEC would now become a strong advocate of the ECR-90. The selection of the ECR-90 might possibly even have been a prerequisite for GEC to yield to the UK Government's request for the take-over.

Moreover the governments had a propensity to reach agreement because of their commitment to the EFA network. Indeed, the decision on the radar was also important for the EFA project as a whole: a 'time bomb' was removed. More than that, the EFA network was even reinforced by the new commitment to the radar choice.

We conclude the radar contest by discussing one additional issue — US export controls — that played a major role in the battle over the radar.

Export controls

One theme that was heavily exploited in the competition on the EFA-radar was that of export controls by the USA in case US technology were used. Europeans are particular sensitive to this issue because of the very tight export policy exercised by the Pentagon. Moreover at the end of the 1970s there had been some traumatic conflicts over the export of civilian machines that incorporated some US technology, by West European countries to the Soviet Union and other East European countries. Thus the EFA consortium had reservations about selecting the Hughes-derived radar. 91

Ferranti had always emphasized that its consortium would use only European technology, in contrast to the Hughes/AEG consortium, so that there would be no export restrictions for EFA and its radar. 92 93

At the end of the 1970s there had been some traumatic conflicts over the export of civilian machines that incorporated some US technology, by West European countries to East European countries
Although Hughes tried to reassure the Europeans, it had difficulty in convincing them. For instance, the draft Memorandum of Understanding (MOU) from the Pentagon in April 1988, only proposed a “time phased release” of critical technology within the Hughes AN/APG-65 radar (needed for its derivative, the MSD-2000) that might be compatible with the EFA development schedules.

It was also stated that “non-cooperative target recognition” and “electronic counter measures” would not be included in the transfer. The memo indicated that the USA did not expect to address export requests from the Europeans until the year 2003, or until EFA nations had significantly completed their own procurement programs. Nevertheless, the US government actively promoted US technology for the EFA. Thus in July 1988, US DOD (Department of Defense) Undersecretary for Planning and Resources, Dennis Kloske, had a meeting with senior officials from Eurofighter and NEFMA in a new move to promote a US radar (and engine) for EFA.

In August 1988, a second draft MOU circulated in Europe, that approved the transfer of all necessary AN/APG-65 hardware and software technology. Though some details were still under discussion the proposal seemed basically acceptable to EFA nations. Nevertheless the sentiment to keep EFA and its systems European remained strong.94,95

In an attempt to finally persuade West Germany to adopt a US radar for the EFA, the United States invited West Germany to join an international upgrade of the AN/APG-65 fire-control radar.96

Export control was also an issue in Spain because the Air Force had had a bad experience with access to software in its APG-65 radars, due to US export controls. Consequently, within the Spanish Air Force a preference seemed to emerge for the ECR-90 radar.97 In view of the concern of Spanish pilots about access to software, Hughes offered Spain an agreement on software should any problems be encountered if its radar were selected.

The Spanish company INISEL was rather indifferent to the choice to be made. It believed that both the ECR-90 and the MSD-2000 offers were satisfactory for Spanish industry since both exceeded military requirements and offered similar technological and economic returns to domestic companies.

In view of the commotion over export controls, it is striking that West Germany never showed any reluctance to the Hughes radar because of US export restrictions. The reason might be that except for the British-German-Italian Tornado aircraft, West Germany has never been a big exporter of military aircraft.

Influences on network-building

How do technology and network-building influence each other? How do the nature and content of the interactions between the actors influence technological developments? And what kind of differences in technology influence the network-building process?

MoD-industry funding

One important feature of the radar development in the EFA case is that the offers of both consortia followed technological paths already in progress — the Blue Vixen by Ferranti and the APG-65 by Hughes. In other words no ‘revolutionary’ concepts were being offered by the consortia.

This is understandable from the way the four countries, by means of specific financial conditions regulated the radar development. Rather than funding the research and development on a ‘cost-plus’ basis, the joint EFA-organizations (NEFMA and Eurofighter) asked for competing proposals for which the price had to be fixed. This caused the companies to take less risky technological trajectories. Thus, technologically more innovative, but also more risky, designs, for instance of an ‘active ray radar’, were not chosen by either of the two consortia.

On the other hand, the two technological trajectories had both been initiated by the companies themselves as company-funded projects. In the case of the Blue Vixen radar, the base for the ECR-90, the UK Ministry of Defense had stepped in by funding further development for the Sea Harrier update program.

The competing UK company, GEC, saw an opportunity in the EFA radar for further development of its company-funded processor, by joining the Hughes/AEG project. Thus the nature of the government-industry bond may have a significant influence on the character of the innovation process of military technology.

Interactions on technology

One of the interesting aspects of the interactions between organizations concerning technology is that technological characteristics may be, and have to be, described in very heterogeneous terms and at various levels. Thus, terms used to promote one’s own, or to denounce the competitor’s, technology, were flexibility, technically superior, modular approach, risky vs proven technology, commonality, US control.

For a sensible interaction, translations have to be made between the various levels, according to the language used by the specific actors. An engineer’s characterization of GEC’s processor technology by: “it uses two-micron CMOS gate array components” or “it has a throughput of 350 million operations per second”, has to be translated into the military terms of the ‘track while scan’ capabilities of the radar. Thus the translation between the various possible levels of characterization of the technology either creates or restricts the room for mapping the wishes of the interacting organizations.

As to the formulation of military requirements, air
forces were important, but not the only, actors. The requirements also had to be negotiated with the ministries of defense, and had to be based on estimates of what was technically feasible. Technical feasibility, however, depends on the expertise of the companies involved in the development of the technology.

Defining requirements can, therefore, also be used in a strategy to put particular companies in a favourable position, thus directing the composition of the network. West Germany for instance, wanted the operating requirements to set standards similar to those of the Hughes AN/APG-65 type radar, which implied that development costs would make it difficult for other candidates to compete. Although an official EFA stance was formulated, it was evident that the member countries — the UK/Italy vs FRG/Spain — made different demands, the latter being less 'demanding'.

The strategy followed by the competing companies was to link up with companies in the other EFA countries, not only to strengthen their social network position but also to increase their technological capabilities. Thus the entry of GEC into the Hughes/AEG network not only strengthened the social network of the MSD-2000, but also its technology: the GEC signal processor, for which some new VLSI (very large-scale integration) chips were designed, would substantially enhance throughput capacity of the AN/APG-65 radar, though overall performance would probably still fall below the capabilities of the all-new ECR-90 (according to officials from both Ferranti and GEC). The result of all these actions was that, finally, the differences between the two radars became subordinated to cost requirements and to (industrial) politics.

Building military networks

Military technological developments can be analyzed in various ways by putting emphasis on different aspects of the development process. In the introduction we referred, by way of example, to the 'action-reaction' and to the 'bureaucratic politics' schools. For several reasons we think that a network approach is more fruitful, both for understanding the dynamics of the process and for designing intervention strategies.

Such an approach pays tribute to the fact that, although in principle a great variety of developments is always possible, in concrete situations not every development is equally likely to occur: the network approach shows that there may be severe constraints. On the other hand it recognizes that there is room for actors to influence developments: the networks also offer opportunities to the actors. At the same time a network approach is able to deal with the very heterogeneous set of actors, factors and events that apparently play a role.

The task then is to analyze the nature of these constraints and opportunities, and to see how they relate to technological developments. In other words, we have to focus on the interactions between the actors in the network, on the nature of actor activities in relation to the network structure, and on the coupling and decoupling processes between networks and underlying networks.

Below we will discuss the main features which we think are of importance for understanding the process of network building, network dynamics and the related course of technological development. These are partly still of a hypothetical character due to the stage of our empirical research. The same is true for the role of 'guiding principles' in network interactions and their relation to military requirements and weapon innovation, which will be discussed — mainly conceptually — later. We discern the following main features:

- Not all actors are equivalent in their network activities: one should distinguish between dedicated network builders and other, more reactive network actors.
- 'Reactive' network actors operate largely within the framework constructed by the dedicated network builders.
- The dedicated network builders are tied to the other network actors by bonds that to a great extent determine the room for building a network. Thus both play a role; but a different one.
- Whereas military technology is supposed to be subordinate to military requirements, network composition and network dynamics rather than initial requirements determine the resulting course of technological development.
- When a network matures it becomes more resilient: it will adapt to possible internal tensions, between the actors rather than fall apart. These adaptations may include the course of technological developments.

The network in which the development of military technology is embedded is distinct from most networks related to the development of civilian technology, due to its connection with national security and defense. Directly or indirectly this network nearly always includes — at the actor level on which we focus — the various countries' defense industries, governments and governmental agencies, military services, and parliaments. The distinction between these actor categories is based on:
• differences in their position in a country’s societal structure,
• differences in their main types of activities, and
• differences regarding the associated perspectives on military technology.

Of course within each of these categories a broad spectrum of actors still exists. However, for our purpose of tracing general characteristics of military technological developments in actor and network terms, the differences between these categories are of more importance than are the intra-category differences.

The nature and intensity of the relationships between the various actor categories may be different for different countries. The existence of particular underlying intra-country networks has a far-reaching impact on the shape of international cooperative networks for developing military technology, as will be discussed below.

Building a new network

In the EFA case, the need for a new advanced fighter aircraft in itself was not disputed, by any of the actors; not by the government, nor by the industries, nor by the air forces (which, on the contrary, lent strong support). Thus the question as to whether a new fighter aircraft was actually needed — were there no alternatives for air defense? — was not at issue and played no role in the interactions between the various actors. None of the actors had to develop any activities to get support for the idea of a new fighter in itself. At present, due to the dramatic changes in Eastern Europe, this situation is changing. We will return to this theme of ‘tacit background’ in the network, later.

The initiative for international cooperation on a new fighter came from the governments, not the industries, of five European countries. And it was the governments that were primarily active in building the network. Indeed it might be said that the governments were the only actors that were in a position to take such an initiative. The main reason for this is the particular position of military technology and weapon systems in our societies.

In its turn, however, the government is heavily dependent on the defense industry, because the technological options for realizing military requirements, depend on what industry is able to offer (although not only the domestic industry). This mutual dependence of government and defense industry implies a unique relationship between these two actors in the weapon innovation process.

Contrary to what is common in civilian technology, development of a new weapon system occurs in close cooperation with, and is, in most cases, actually funded by, the government. These relationships can be characterized as underlying (national) networks, which at times played a decisive role in the network-building process for EFA. The position of the governmental actors in these networks implies that the governments had to play a key role in the initiative for international cooperation, that is, they acted as dedicated network builders.

In fact, the governments explicitly supported international cooperation because of some major problems they faced, making them the driving force in creating a cooperative network. Most outstanding of these problems were the excessively rising costs of the ever more technologically advanced aircrafts. This led to a shared interest in intra-European ‘burden sharing’ and a desire for more independence from the United States in weapon procurement matters for economic reasons. EFA, in this respect, is only one example of a much broader attempt to seek European cooperation in the field of weapons development and acquisition.

Although in a favorable position to initiate international network-building, governments cannot simply ‘instruct’ their defense industries to cooperate. In spite of a number of successful multinational projects, the past had shown that international cooperation between national defense industries is not easy to achieve. The route that the governments followed was to create a shared framework which could bind together the five countries and within which cooperation might occur.

The formulation of military requirements, laid down in the Outline European Staff Target of 1983, fulfilled this role. This was not done by the governments directly, but through their air force staffs, which, being the end users, had a say in what they required. At that stage the EFA technology was defined at the level of operational characteristics, a level which still left room for a variety of technological realizations at a more specific level.

Thus the formulation of military requirements played an important part in the initial efforts at cooperation. Subsequently the defense industries had to link to the fledgling network of the five countries' governments (defense ministers) and military (air forces). The industries had to agree on management issues, on technological options on which they could cooperate, and on work and design sharing.

Underlying networks

At this point it became clear that not just individual industries but underlying (industry-government) networks had to be linked to the new EFA network. This process revealed the strength of these underlying networks consisting mainly of a country’s government and national defense industries.

In the first place each government supported its defense industry — although not a priori a particular one — by requiring that part of the EFA development and production should be carried out by these industries. Thus it would be difficult for outside industries to compete for EFA orders.
Secondly, although the initiative for cooperation had come from the governments, in cases of tension between the network in the making and the underlying government-industry networks, the latter appeared to be the strongest, certainly at the initial stage of the new network. Thus the network in the making had to adapt to certain characteristics of these constituting underlying networks, rather than the other way around.

This was most manifest when France stepped out and decided to pursue the development of a new fighter, the Rafale, on its own. The strength of the French government-industry bond can best be formulated in terms of an undisputed characteristic of the French underlying national network — the institutionalized perception in France of the importance of its defense industry.

The French government is heavily dependent on its own defense industry to secure its independence in defense affairs, while the industry itself is very dependent on the government as well as on export orders. Thus French national security policy and sustaining an indigenous defense industry in connection with a very active armaments export policy are closely interconnected.104

So when the French government-industry network saw little prospect of a leading role for the French industry and for an export market because of the demands of the other countries on the aircraft, they dropped out of the network. The events also show that, on the one hand, the French government, as a dedicated network builder, had, through the underlying network with its domestic defense industry Dassault, opportunities to stimulate the development of an international network, while, on the other hand, it was severely constrained in its options to do so.

In France the government-industry bond is much stronger than the link between industry and the military services.105 There is also very little legislative oversight by parliament.106 That explains why the French Air Force could not block France's choice in favour of Dassault's Rafale fighter in spite of the fact that it (and also the Navy) had a preference for the direct purchase of US F/A-18 Hornet aircraft, that would probably be half the price.107

Was the export issue then of no importance to the other countries? It certainly was, but to a lesser extent than to the French government. The UK has an active armaments export policy, but at the same time, it is used to being dependent, to a certain extent, on other countries for its weapons procurement, notably the USA. Thus it is less hesitant than France to lower the pressure on its defense budget through international cooperation, rather than through exports (although the British defense industry still prefers national projects (see also below)).

This is even more true for West Germany which has not been a big military aircraft exporter (apart from joint exports with Great Britain and Italy of the Tornado fighter). For West Germany a main interest in the last decades has been to build up a strong aerospace industry, but not, as in the case of France, by strictly adhering to national independence.108 The FRG seeks to achieve its goal primarily through international cooperation.

**Dedication to network-building**

The distinction between dedicated network builders and the other network actors becomes clear in the radar case. The French electronics firm Thomson-CSF, as a 'reactive' network actor is heavily dependent on the actions of both the French and other network-building governments. Initially Thomson-CSF was very active in trying to establish a joint radar project with companies from the other four countries.

However, when France dropped out of the EFA project it implied a very serious constraint for Thomson-CSF. It was virtually excluded from the EFA network, and subsequently concentrated on the radar for the French Rafale fighter. It is clear that it is not sufficient to look at individual actors: judged on technological capability the electronic giant Thomson-CSF might certainly have participated in the EFA radar. However, being tied to the French underlying network, it dropped out of the emerging radar network at the same moment that France stepped out of the EFA project. Here network structures were decisive, not individual actors.109

The distinction between dedicated network builders and more 'reactive' network actors is also exemplified by the different positions of the UK industry and UK government. The UK industry preferred a 'national solution' based solely on the RAF requirement for the fighter and the almost exclusive involvement of the British defense industry.110 However, it had to work within the framework of the multinational network that the government was building, in which the industry's influence was much less straightforward than in the French situation.

The UK defense acquisition system is somewhat less closed than that of France, in the sense that within the UK subnetwork the British parliament (at least the party in government) is also an important actor. In its attempts to build an international network the British government in its turn was bound to secure a substantial share of developmental work for its defense industry, not yielding to the French demands for leadership.

Once the EFA network started to take shape through the establishment of the NEFMA coordinating organization and the industrial consortia Eurofighter GmbH and Eurojet GmbH, it built up resilience against falling apart. Nevertheless its existence was still threatened by the contest over the radar: lack of consensus might eventually wreck the whole EFA enterprise.

Again, it was the governments — the dedicated network builders — that were actively trying to preserve the network. The 1989 radar crisis between the United Kingdom and West Germany, for in-
Once the EFA network started to take shape through the establishment of the NEFMA coordinating organization and the industrial consortia, it built up resilience against falling apart.

stance, was repeatedly smoothed over at the high level of the secretaries of defense. International commitments (such as the MOU to develop only one radar) were used by the dedicated network builders to counter both domestic and foreign pressure.

This illustrates how preservation of the newly established, but already solidifying EFA network, became a major issue for the network actors and started to prevail over the interests within the underlying networks. The participating radar companies actually reinforced the process towards a stronger network through strategical moves within this new framework, such as through mergers and cooperations with electronic companies from countries of the competing consortium.

When at last, in May 1990, agreement was reached on the choice of radar, not only was the main threat to the EFA network removed, but the network was actually reinforced. Its resilience has increased and it has become more resistant to a new threat that is looming, namely whether EFA is still necessary, in view of the fall of the old regimes in Eastern Europe, and the reorientation of Soviet defense.

New fighter questioned

Until recently none of the actors questioned whether a new fighter aircraft was really needed. Nobody asked whether air defense might be performed mainly by ground-based air defense missiles like the Patriot, rather than by fighter aircraft.111

This tacit agreement was prised open only recently by what might be called ‘external’ events — the changes in the Soviet Union and East European countries that virtually imply the falling apart of the Warsaw Treaty Organization. Some parliamentary actors, notably in West Germany, now question the need for EFA: both the Social Democratic Party and the Liberal Party are calling for an end to the development.112 This implies a serious threat to the EFA-project and to the EFA network. Consequently, other actors within the network are now addressing this issue: the topic is becoming part of the interactions within the network.113

This implies, inter alia, that the actors in a network, together with their “definitions of the situation”,114 should never be considered as isolated from the environment, and that network dynamics should not be analyzed exclusively in terms of the network itself. That is, there is always (the possibility of) an open exchange with the environment, which may give an impetus for drastic reforms of the network.

It is of interest to note which actors are likely to pick up such ‘external events’ and be able to import them in the network interactions. The actor in the military network that is potentially the most ‘destabilizing’ one, is parliament.

Parliament is concerned with a broad scope of political and budgetary items, and is, through its members, an actor in other networks as well. So parliament is a nodal point in which very diverse issues can be connected to each other. As (members of) parliaments are embedded in so many different networks this makes them rather unpredictable. Items that become an important issue in one network can be taken by them to other networks and turn a number of things upside down.

In this way the German Bundestag, by setting limits to the budget, heavily influenced the radar network dynamics. As a result of the events in Eastern Europe it is even possible that the Bundestag would set things in motion aimed at killing the EFA project as a whole.

However, the resilience of the network has grown to such an extent that it is more likely that the result of such an action would be the reduction of the number of aircraft to be produced (which would increase the price per unit).115

So we may conclude that the development of a network in the making can to a large extent be understood by studying the dynamics of relevant underlying networks, that are to be linked to each other. Having applied this approach to the development of the EFA, three important conclusions can be drawn:

- The composition of the new international EFA network may be understood primarily through the structure of the underlying networks, rather than by the actions of single actors.
- In understanding the process of building military technological networks one should, on the one hand, distinguish between dedicated network builders and more reactive network actors, but, on the other hand, recognize their mutual dependence. Dedicated network builders are also instrumental in the process of solidification of the network.
- Network actors, like parliaments, with a relatively low ‘inclusion’ in the ‘network game’, for instance because they are embedded in many different networks, constitute a source of instability for the network.

Weapon innovation revisited

How can this analysis of network dynamics more specifically be related to the shaping of military technology? Is it military requirements that have directed military technological developments, or maybe the other way around? How do military requirements
The military does not appear to have a predominance in technological developments, at least in the case of EFA, nor do military technological developments simply follow an internal logic. relate to the influence of other aspects of network dynamics?

To answer these questions in detail, further research is needed into the role of military requirements and whether they, to a certain extent play the role of the guiding principles that were more specifically defined earlier in this article. But from the argument presented above, some important insights can already be inferred.

Our first observation is that, within the military technology network structure, military requirements function as an important vehicle in the interactions between the military and other network actors, like the ministry of defense and the military industries. At first sight one might then expect a hierarchical relationship between military requirements and military technological developments, the former determining the latter. That assumption, however, ascribes the military a predominance in technological developments that, at least in the case of EFA, they do not appear to have.

On the other hand, neither do military technological developments simply follow an internal logic, nor do scientists and engineers simply develop new technological options which subsequently prescribe military requirements, or even military doctrines and strategies, as has been suggested by several authors. Current practice is not that simple, as the EFA case shows.

What we see is that both the role and content of military requirements change in the process of network-building that shapes military technology. In the EFA case, as we already pointed out, the military requirements initially played an important role in starting an international network-building process, partly by defining the technology to be developed. At that stage the air forces (along with the governments) played a predominant role.

Later on, when four countries continued the EFA process, the NEFMA coordinating organization was established and the industries became more substantially involved through newly established consortia such as Eurofighter GmbH and Eurojet GmbH: the commitments to the network grew, thus solidifying the network. At the same time, a great variety of more concrete aspects played a role (finance, capabilities of the participating industries, concrete technological designs chosen for various fighter (sub)systems) and started to compete with military requirements. This subsequently resulted in refinements or adaptations of these requirements.

At the beginning of this article the guiding principle concept (as an inter-organizational concept that specifically applies to the interactions between network actors and that constitutes an interface between military doctrines or strategies and weapon innovation) was introduced as an instrument for intervention in the military technological innovation process. The basic idea is that such guiding principles should, to a large extent, regulate the direction of military technological developments, by becoming an integrated part of network interactions.

The fact that technological developments are the result of many interactions within a network of organizations implies that these developments cannot be steered in detail from one position in the network, for instance, by the Ministry of Defense. A possible option for control of military technological innovation might be some sort of decentralized regulating process.

This would mean some kind of institutionalization of interaction processes that regulate technological developments in a such way as to avoid undesirable effects and developments (such as destabilizing weapon systems). Whereas governments cannot control the content of the innovation process directly, they can, because of their special position in the network (as main buyers, and having legal oversight) orchestrate the institutionalization of such a process.

Elsewhere it has been argued that Defense Technology Assessments (DTAs), that evaluate the implications of military technological developments in relation to military doctrines arms control requirements, should be part and parcel of such a process. There it was also argued, for the case of 'non-provocative defense' as a guiding principle, that such DTAs should preferably be carried out as a cooperative enterprise between NATO and WTO countries (or within other international settings).

The prospects for such cooperative activities have much increased since the recent political changes in Europe. Moreover, carrying out DTAs should be a continuous process of monitoring technological developments, rather than a once-only activity. This might imply, not only an orchestrating of the interactions within the innovation network, but also an extension of the network with new types of actors.

Actually our network approach, together with the guiding principle concept as a regulating agent, shows great affinity to the Policy Network approach proposed by Wright for comparative industrial policies analysis. There it is emphasized that, to understand (industrial) policy processes, one should not look at too high a level of aggregation, like industry and government. Rather one should look at the level of the firm and individual government organizations, which together may constitute (industrial) policy communities, or may, through interdependencies, be linked to each other in policy networks.

The policy communities are supposed to be
The guiding principle concept has similarities with both the 'systemic norms' and the 'rules of the game'. The similarity with the former pertains mainly to the inter-organizational character of both concepts and to their regulating claims. However, whereas the systemic norms may entail any type of norm, the guiding principle is a much more specified concept, that should act as an interface between military doctrines or strategies and its technological developments.

Moreover the guiding principles are supposed to play a role in networks, or in more structured and stable relationships, particularly related to the development of military technology. In that respect they would correspond more to the 'rules of the game' of a policy network.

However, when applied to networks in the development of military technology, the 'rules of the game', as presented by Wright, seem to pertain more to weapon innovation, more insight should be gained into the dynamics of this competition. It might be argued that behaviour in reality may deviate from the professed or preferred systemic norms, often because the particularity of the situation puts constraints on the room available for decision. One may expect this to apply to the guiding principles as well. In the EFA case this was indicated by the competition that emerged between military requirements and many other requirements posed by the various actors.

To develop guiding principles into an effective instrument of decentralized control in the process of weapon innovation, more insight should be gained into the dynamics of this competition. It might be argued that behaviour in general, including that in relation to military technological developments, will, at most partly, be in agreement with the guiding principles. This, however should not stop us from trying to orchestrate military technological network interactions with the purpose of integrating specific guiding principles into the weapon innovation process. In the same way violations of export controls have never been a reason to abolish all export controls.

Notes and references


5. H F York, "On the dynamics of missile and satellite development" in Technological Innovation: a Socio-Political Problem (University of Twente, Boerderijcaher 7701, Enschede, 1977) page 78.


10. These actors can then be seen as point-representations of underlying networks. In this respect we follow Latour/Callon's actor-network approach. The main difference is that we do not consider non-human entities to be nodes in our networks.


12. Thus, using a network approach, we will be able to focus on the transitions between the various phases that Evangelista has distinguished. By doing so we will be able to make his scheme more dynamic and also less linear. We are also able to show why certain transitions do not take place (killing a weapon system) or why sometimes a phase is 'redone'.


14. To promote European cooperation on military technology the governments of European NATO countries (including France), for instance, had in 1984 revived the Independent European Programme Group (IEPG), an informal governmental consultation association. See eg reference 13, page 237.

15. An excellent overview of the 'prehistory' of the European Aircraft has been given by Ivan Yates, Deputy Chief Executive (Engineering) of British Aerospace and Chairman of Eurofighter GmbH, in a paper Evolution of the new European Fighter; A British Industrial Perspective (British Aerospace Public Limited Company, London, 1986).


17. Ivan Yates, see reference 15; especially the Arms Race programme.


21. The very active weapon export policy of France has brought this country to third place on the world list of arms export countries,


23. The same argument made Spain and Italy incline to the British position.

24. Anon, see reference 22.

25. Erhard Heckman, see reference 16, especially page 17.

26. Ivan Yates, see reference 15, especially page 36.

27. David A Brown, "British offer French design lead for future fighter project", Aviation Week & Space Technology, 18 February 1985, pages 16-17, especially page 16.

28. David A Brown, see reference 27, especially page 17.


30. Erhard Heckman, see reference 16, especially page 17.


33. Anon, see reference 22.

34. Erhard Heckman, see reference 16.

35. Anon, see reference 18.

36. Erhard Heckman, see reference 16, especially page 17.


38. Erhard Heckman, see reference 16, especially pages 17-18.


42. See T J Pinch, and W E Bijker, "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), pages 399-441.


45. Michael Feazel, see reference 44; Frederick Bonnart, "The European fighter aircraft — an update", NATO's Sixteen Nations, 11(26) 1 July 1989, pages 56-58, especially page 57.


49. Keith F Mordoff, see reference 46, especially page 17.


58. Anon, see reference 22, especially page 20.


60. These radar manufacturers have been appointed by their governments as lead radar contractor for the EFA.


63. Anon, see reference 61, especially page 158.


65. Michael Feazel, see reference 47.


67. Nick Cook, see reference 57.

68. Gregor Ferguson and Gerard Murphy, "Aircraft retrofit and upgrade", Defence Attaché, 3 (1987), pages 43-49, especially page 44.

69. Michael Feazel, see reference 47.

70. For Spain the MSD-2000 radar is attractive for similar reasons as for West Germany, namely its commonality with the Hughes radar that will be installed in the McDonnell Douglas F-18s that Spain has bought.

71. Anon, "EFA radar proposal may include improved signal proces- sor", Aviation Week & Space Technology, 8 September 1986, page 30.


78. This situation changed in 1990, when ironically GEC took over Ferranti, after this company had run into financial difficulties due to the take-over in 1987 of the International Signal & Control Group.


82. The Ministry of Defence in Bonn said that adoption of the ECR 90 would result in DM 300-500 m in additional costs. See Nick Cook, "UK, W Germany, move to defuse EFA radar row", Jane's Defence Weekly, 11(8) 6 March 1989, page 340.


84. Nick Cook, see reference 79.

85. Nick Cook, see reference 79.

86. Nick Cook, see reference 79.


89. Anon, "Consortium led by GEC Ferranti Defence Systems awarded contract to develop ECR 90 radar for EFA", Aviation
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