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Making Collaboration Work:

Examining Sub-Optimal Performance and Collaborative Combat Aircraft

I. Introduction

One of the most dramatic developments in the field of armaments has been the rise of international and, especially, intra-European collaboration over the last several decades. Beginning in the 1960s and gaining momentum in subsequent decades, collaborative armaments projects today account for a large proportion of European defense procurement budgets. However, the success of collaborative armaments programs has been erratic and varied substantially from one sector to another. In the domain of missiles and helicopters, collaborative European projects have produced innovative and cost effective products that are in some cases market leaders.[1] Contrarily, collaboration of armored vehicles has produced a succession of aborted projects that were cancelled before they could enter production.[2]

Within this context, the combat aircraft sector represents a unique case. Rather than being populated by either examples of commercial and technological successes or cancelled projects, the dominant trend in the combat aircraft sector has been one of consistently suboptimal collaboration. Since the 1970s, one intra-European collaborative combat aircraft after another has been developed and produced, and only one major project, the Anglo-French Variable Geometry Aircraft (AFVG), was cancelled. Each of the resultant aircraft were produced in sizeable numbers, including approximately 600 Jaguars, 900 Tornados and 700 Eurofighters. However, each of these programs suffered from excessive delays and cost overruns, and not one of them can be judged a technical or economic success.[3]

This dynamic of sub optimal collaboration poses critical questions for political scientists and policymakers alike. If collaborative projects have performed so poorly, why have states persevered with them until completion and agreed to further follow-on projects? In other domains, the failure to collaborate efficiently has either precipitated the abrupt cancellation of the collaborative project or made states reluctant to collaborate on future endeavors. Furthermore, why have collaborative combat aircraft projects been so disappointing when successes have been common in related aerospace fields, such as civilian aircraft (Airbus and ATR), missiles (Milan and HOT), jet trainers (Alpha Jet) and helicopters (Puma and Cougar)? Finally, is there any alternative to the hitherto dominant pattern of suboptimal collaboration? Can states collaborate more efficiently in the future; are there any realistic alternatives to collaboration; or are European states condemned to repeat the errors of the past?

This paper attempts to provide answers to these questions. To preview the conclusion, I argue that the reasons for the suboptimal performance of collaborative combat aircraft projects are inherent in how the projects have hitherto been structured. Overly detailed requirements reconciling conflicting military requirements, the lack of integrative joint venture structures, the deliberate exaggeration of initial orders, the duplication of assembly lines and testing facilities, and the politicized allocation of development contracts have all contributed to the vicissitudes faced by European collaborative combat aircraft programs.

Despite disappointing results in the past, there are few alternatives to building aircraft collaboratively. The escalating costs of combat aircraft and the need to achieve economies of scale renders it unlikely that any European state will be able to develop purely national aircraft in the future. Likewise, the perceived strategic and symbolic importance of the combat aircraft industry, and its spin-off effects on the civil aerospace industry, make exiting the market unlikely. For this reason, European states appear condemned to collaborate.

Fortunately, an accurate prognosis of the ills afflicting combat aircraft collaboration and lessons provided by successful collaboration in related hi-tech sectors highlight ways that the collaborative process can be improved.

II. The Collaborative Imperative

Since the 1960s, intra-European collaboration on combat aircraft has gradually come to be viewed as a functional necessity and normative good. The exponential increase in combat aircraft prices, the search for economies of scale and learning economies, and the operational benefits to be reaped from interoperability are frequently cited as justifying collaborative combat aircraft projects. Although all of these arguments for collaboration were acknowledged as early as the 1960s, national European combat aircraft programs have endured until the present day (the French Rafale and Swedish Gripen). However, cost increases, low defense spending and tight export markets today augur an end to "national" combat aircraft developed by European states acting alone.

The ineluctable dynamic driving European combat aircraft collaboration is the fact that the real unitary cost of combat aircraft is growing at an annual rate of between seven and nine percent.[4] In the meantime, Europe's advanced industrial economies are lucky to sustain growth rates of over two percent per annum. This gap between aircraft price increases and GNP growth means that a constant commitment to defense procurement (measured in terms of the percentage of national wealth spent on defense) will buy fewer and fewer combat aircraft. By itself, the tendency of aircraft costs to outstrip GNP growth has the potential for undermining the economies of scale achieved by European aircraft producers. Recognizing the nearly inevitable nature of this dynamic, the United Kingdom's independent advisory committee, chaired by Lord Plowden, recommended as early as 1965 that all future British aircraft projects be conducted collaboratively.[5]

The decline in European defense expenditures since the end of the Cold War is rendering this situation more acute. Since the collapse of communism in Eastern Europe, almost all European states have substantially cut their defense expenditures. Many states, such as Germany, spend approximately half as much on defense, as a percentage of GNP, as they formerly did, and the overall burden of European defense expenditure remains comparatively light

(1.74 percent of GDP amongst Europe's NATO members and 1.16 percent of GDP in non-NATO Europe).[6]

Historically, certain European states compensated for the limited size of their internal markets with vigorous export policies. For example, between the 1950s and 1970s, the Italian, British and French combat aircraft industries benefited respectively from the export successes of the Fiat G91, the Hawker Hunter and the Dassault Mirage III, all of which received more foreign than domestic orders. Unfortunately, export successes on this scale are becoming increasingly difficult to obtain.[7] Since the end of the Cold War, the United States and Russia have both pursued vigorous export promotion strategies, displacing European competitors from certain markets. Meanwhile, Asian countries (China, India, Japan and South Korea) are struggling to develop indigenous aircraft industries, which will free them from the necessity of importing combat aircraft. As a result, European combat aircraft producers face a small, politicized and highly competitive export market. In this environment, it would be highly imprudent for them to count on substantial exports when they plan their next generation of aircraft.

Because of the growing difficulties of achieving minimally adequate economies of scale, Europe's traditional producers of combat aircraft face a stark choice of abandoning the industrial sector and importing foreign aircraft or building combat aircraft collaboratively as part of multinational consortia. However expedient it may appear, the importation of foreign aircraft is unlikely to be attractive to any of the states currently involved in producing them domestically. Combat aircraft are amongst the most strategic and prestigious weapons systems.[8] Importing them from abroad entails both a real loss in national autonomy and a symbolic retreat from great power status. Moreover, technologies developed through combat aircraft programs have long contributed to the vitality of Europe's civil aviation industry. In the recent past, many of the bedrock technologies employed on Airbus passenger jets or Dassualt business jets have been spun-off from combat aircraft programs.[9] Therefore, forgoing the future development of combat aircraft would likely cripple European civil aviation industries.

The alternative to importing foreign combat aircraft consists of developing them collaboratively on a multinational basis. In theory, the collaborative development of combat aircraft presents four advantages:

1) Greater economies of scale and learning economies can be achieved through larger production runs.
2) Development costs are spread amongst multiple partner states.
3) Produced by companies according to their comparative advantages, the final product should be qualitatively superior to national combat aircraft.
4) Armaments are standardized amongst allied states, facilitating military cooperation.

Because of its potential advantages, multinational aircraft collaboration has become the favored option of many European ministries of defense and the armaments producers.

The problems of economies of scale and learning economies are crucial to many debates about combat aircraft collaboration. Today, it is generally agreed that the minimum number of combat aircraft that can be produced efficiently is between 400 and 500.[10] Considering that the largest European states tend to order between 200 and 300 aircraft of a given generation, efficient production cannot be achieved relying on a single national market alone.[11] Supporters of collaboration frequently argue that American combat aircraft are more cost effective than their European counterparts because of higher production rates and larger aggregate orders. For example, while the United States procured 133 F-16s per year every year between 1988 and 1992, the French Air Force's procured only 29 Mirage 2000s annually.[12] As a result of this difference, the Mirage 2000 cost a third more to produce than the F-16, despite the fact that the two aircraft were otherwise highly comparable.[13]

Related to economies of scale, learning economies provide another justification for collaboration. There is significant evidence that the number of man-hours needed to produce an aircraft declines by about 75 to 80 percent for each doubling of output. Overall, such learning economies can result in up to a 10 percent decrease to the unit production price of aircraft over long orders.[14] Thus, by expanding the number of aircraft ordered, international collaboration should permit states to obtain a cheaper unitary cost of aircraft through economies of scale and learning economies.

Besides producing a product with a lower unitary cost, collaboration also permits states to share the cost of developing sophisticated new weapons systems. This is particularly important for combat aircraft, whose development costs can reach astronomic levels. Today, developing a sophisticated combat aircraft can cost anywhere between $7 billion and $60 billion.[15] By way of comparison, most armored personnel carriers are developed for $500 million, while main battle tanks require approximately $1 billion to develop.[16]

In theory, collaborative projects permit states to share such high development costs amongst several partner states. It has long been recognized that the transaction costs entailed in managing multinational projects are greater than those for national projects. However, the costs are still usually argued to be lower *per partner*. The rule of thumb most often employed, which is illustrated in Table I, is known as the "√n Rule."[17]

Table I:
The "√n Rule"

$$DC(\text{collaborative aircraft}) = DC(\text{national aircraft}) \times \sqrt{n}$$

DC = Development Cost
n = number of partner states

According to this "rule," the development cost of a collaborative project will exceed that of a national project by a factor equal to the square root of the number of partner states.[18] However, the greater aggregate cost of developing a collaborative product will be divided amongst several partners. As a consequence, participating in a collaborative project should cost each partner less than conducting an equivalent national project.[19]

In addition to lowering production costs and divvying up development costs, collaboration has frequently been supported because it can theoretically lead to a better final product. Because different armaments producers possess distinct comparative advantages, it stands to reason that a collaborative weapons system will be superior to a national program so long as each participating company contributes items that they can develop better or more cost effectively than their partners. Within the European context, it has long been argued that aircraft can be developed by "dream teams" comprised of Europe's best producers.[20] Since the 1960s, many observers have argued that future aircraft should feature Dassault designed airframes, Rolls Royce engines, and Mauser automatic cannons.[21]

Finally, for many European leaders, intra-European armaments collaboration should be a normative objective whether or not it yields cheaper and better products. It has long been recognized that states equipped with identical weaponry face fewer challenges in operating together within a multinational coalition. Contrarily, when levels of equipment standardization and interoperability are low, joint operations suffer from complex supply arrangements, incompatible communications and complicated mission planning. In this context, European states will be better able to operate militarily together if they develop and procure their weaponry collaboratively.[22]

For all of the reasons mentioned above, multinational collaboration is considered by many to be the best strategy for maximizing Europe's military power, ensuring an independent supply of high quality weaponry and promoting a hi-tech industry. In theory, collaborative aircraft should be better and cheaper than national equivalents, and the standardization of Europe's armaments should contribute to the ability of European states to operate within multinational military alliances, such as the North Atlantic Treaty Organization or an invigorated European Security and Defense Identity.

III. Theories of Collaborative Failure

Despite the many theoretical benefits to be derived from collaboration, the track record of collaborative projects is extremely varied. Certain civil and military programs have proven remarkably successful, including the Roland, HOT and Milan missiles, the Airbus A320, Ariane launch vehicles and the CFM-56 jet engine.[23] Many other projects have been cancelled before they could reach fruition, including the MBT-70 and MBT-80 tanks, the Viking submarine, and the NFR 90 and Horizon frigates.[24] Finally, other programs fit into neither of these categories because they resulted in a mass produced weapons system, but one that has proven disappointing in terms of effectiveness and cost. It is into this latter category that most collaborative combat aircraft programs fall, including three out of the four intra-European projects to date.

Regrettably, the reasons for cancellation or technical disappointment have received much less attention than the theoretical benefits to be derived from collaboration and the imperatives necessitating it. Thus far, scholars have advanced four distinct theories explaining the diverse fortunes experienced by collaborative programs.

Writing in 1993, Andrew Moravcsik examined the reasons why certain collaborative armament projects were cancelled while others were pursued until completion. Drawing on the analytical framework of two level games, Moravcsik argued that armaments producers possess a "de facto veto" over the "ratification" of collaborative agreements negotiated between governments. In this context, domestic firms will prevent international collaboration if they believe that their export potential or comparative technological advantage will suffer in the process.[25]

Examining why collaborative aerospace projects have met diverse fates, Pierre Dussauge and Bernard Garrette compared the influence of how collaborative programs were structured and organized on their ultimate fate. Using statistical methods to probe a large number of cases, Dussuage and Garrette concluded that the success of collaborative programs correlates positively with the institutional robustness of joint venture management and sales organizations. As a consequence, the main requirement for an aerospace program to succeed is for it to possess a centralized umbrella-like authority capable of resolving technical disputes, ensuring product sales, and managing after-sales support.[26]

Drawing on the concept that corporate partners are also rivals in other markets and will potentially compete in the future, Jonathan Tucker contends that the nature and capabilities of the firms involved are the key determinant of the success or failure of collaborative projects. Firms possessing equivalent technology, financial resources and access to international markets are unlikely to collaborate efficiently because of their fear that their current partner will exploit their relationship to gain market share at their expense. For this reason, the most constructive collaborative relationships are those amongst companies with divergent technical and financial resources.[27]

Scrutinizing cases of aerospace collaboration, Mark Lorell and Julia Lowell concluded inductively that the needless duplication of development, testing and production processes added measurably to the cost of programs. Likewise, collaborative programs established between states with divergent military requirements are unlikely to result in success. As a consequence, the most successful projects are likely to be those built around similar military requirements and rejecting any redundancy of industrial processes.[28]

Examining different variables, each of the authors mentioned above proposes a different explanation for why collaborative programs fail or disappoint. Table II, below, illustrates these theories.

Table II: Theories of Collaborative Failure	
Author(s)	**Theory**
Andrew Moravcsik	Arms producing firms possess a de facto veto over collaborative project. Joint projects will fail when one of the participating firms believes that a national project holds better technological and economic prospects.
Pierre Dussauge and Bernard Garrette	Projects will prove disappointing when collaboration is unstructured. Strong joint venture structures are necessary to make collaboration productive.
Jonathan Tucker	Collaboration will fail when it involves companies with similar technological and financial resources. Success is likely when firms of vastly different capabilities collaborate.
Mark Lorell and Julia Lowell	Collaboration will be problematic when military requirements differ widely. The cost-effectiveness of collaborative projects will suffer if industrial processes are needlessly duplicated.

The pages that follow will test the above theories against the track record of intra-European combat aircraft collaboration. To date, Western European states have collaborated together on the development of four combat aircraft, of which three were ultimately produced. Because combat aircraft are amongst the most complicated, costly and prestigious of weapons systems, they form a critical case for evaluating the prospects of multinational armaments collaboration. Moreover, a narrow focus on combat aircraft will likely yield different results from the more eclectic mixture of cases examined by previous scholars. Needless to say, because of the small numbers of collaborative combat aircraft yet produced, this study will rely on process tracing and fine-grained data obtained in archives, parliamentary reports and interviews.

IV. The Anglo-French Variable Geometry Aircraft (AFVG)

The first efforts to develop European combat aircraft collaboratively debuted in 1965 when the two states possessing the largest aircraft industries, the United Kingdom and France, independently concluded that they could no longer pursue their most ambitious programs on a purely national basis. In the United Kingdom, the Cabinet's April 1965 decision to cancel the behind schedule and over-budget TSR.2 provided the impulse for collaboration.[29] Prior to the TSR.2 debacle, the British government still considered its aerospace industry as capable of independently and cost-effectively surmounting the most daunting technical challenges. However, the TSR.2 overtaxed the United Kingdom's financial resources and its cancellation brought Britain's aerospace industry to the brink of disaster. For the British Aircraft Corporation (BAC), the cancellation of TSR.2 eliminated fifty percent of the firm's anticipated profits and led the company to project laying-off nearly two thirds of the company's personnel.[30]

Meanwhile, the French air force formulated a requirement for a sophisticated variable geometry aircraft. Although France's aircraft industry had grown rapidly in the preceding decade, it still suffered from the technological gap that had accumulated while the country was occupied during the Second World War. To compensate for the deficiencies of its engine and radar technology and achieve adequate economies of scale, Defense Minister Pierre Messmer argued for collaboration with the United Kingdom.[31]

Driven by their joint interest in collaborating, the British and French ministers of defense concluded an ambitious memorandum of understanding on 17 May 1965. According to this memorandum, the two countries would jointly develop and produce two jet aircraft--a cutting-edge variable geometry combat aircraft and an advanced jet trainer. The two programs and the companies projected to collaborate on them are detailed in Table III, below:

Table III: Collaborative Programs (1965)

	France	**United Kingdom**
Anglo-French Variable Geometry Aircraft (AFVG)	Dassault Aviation SNECMA	British Aircraft Company Bristol Aero-Engines
Advanced Trainer	Breguet Aviation Turbomeca	British Aircraft Company Rolls Royce

Concluded with haste and considerable enthusiasm, the memorandum neither established the specifications of the Anglo-French Variable Geometry Aircraft (AFVG) nor set the industrial division of labor between Dassault, BAC, SNECMA and Bristol.

As a consequence, both airframe manufacturers (Dassault and BAC) began independent work on variable geometry designs in the hope of obtaining design leadership of the overall program. Meanwhile, the British and French air forces began to negotiate the definitive requirements that the manufacturers would have to meet.

Ultimately, it proved much harder than anticipated for the two air forces to negotiate a joint set of requirements. On the one hand, the French wanted a fighter aircraft that would be sufficiently lightweight to take off and land on France's small aircraft carriers. On the other hand, the British hoped to obtain a large strike aircraft optimized for bombing enemy targets far away.[32] Reconciling these widely divergent French and British requirements necessitated two years of negotiations.[33]

From the beginning, this process frustrated the French airframe manufacturer, Dassault. In preceding years, Dassault's lightweight fighters (Mirage III) had achieved significant export successes. Dassault's leadership was concerned lest it not receive design leadership and worried that the new AFVG would be too expensive for most export customers. As a result, Dassault began to prepare an alternative to the AFVG. Dassault proceeded to build a prototype of a smaller and cheaper national variable geometry aircraft. Using existing components, Dassault hastily produced a variable geometry prototype, entitled the Mirage G, in 16 months and at the comparatively low cost of $35 million.[34]

Because of Dassault's haste and the glacial progress of Anglo-French negotiations, Dassault's variable geometry prototype was complete by the time that the British and French armed forces agreed on common requirements. Only on 8 May 1967, nearly two years after the signing of the memorandum of understanding, did the British and French Air Staffs agree on a definitive set of performance requirements. Along with the definitive requirements, an industrial package was agreed upon between the two governments whereby BAC would serve as prime contractor for the airframe and SNECMA for the AFVG's jet engine. Dassault Aviation and Bristol Aviation would each serve in a subsidiary role on the airframe and engine respectively.

For Dassault's leadership, a subordinate position to BAC on the AFVG threatened the company's long-term objective of becoming a premier prime contractor for combat aircraft.[35] Dassault, therefore, began to actively undermine the AFVG project. On 28 May 1967, less than three weeks after the United Kingdom and France signed the agreement on AFVG collaboration, Dassault unveiled the Mirage G prototype at the Paris Air Show. Dassault's inauguration of France's purely national variable geometry aircraft disrupted the AFVG's leisurely progress by outraging British decision-makers and exciting the French press, prompting the newspaper *Le Figero* to comment that, "this aircraft is the finest, sleekest, most elegant and purest that one can see [at the Air Show]."[36]

Dassault drew on all of its lobbying skills and public relations resources to convince French elected leaders that Dassault could develop a better aircraft, at less cost, than the collaborative project. Swayed by the Mirage G prototype and lobbying by the French Ministerial Delegation for Armament (the DMA, later renamed the DGA in 1977), the French government decided to withdraw from the AFVG. On 22 June 1967, French Minister of Defense Messmer informed the British government that France would withdraw from the AFVG, a decision publicly announced on 5 July.[37] The circumstances behind France's withdrawal from the AFVG program led BAC's president to categorize their behavior as "French chicanery" and prompted Britain's Defense Minister to despair that the program that "lay at the heart" of his aviation policy was suddenly cancelled.[38]

Thus, after two years of negotiations and design studies, costing approximately £5 million, the AFVG program collapsed.[39] The principal cause for the program's failure was that one of the major industrial partners, Dassault, concluded that a purely national project suited its interests better than international collaboration. The previously tense relations between Dassault and BAC aggravated this situation because the two companies' rivalry for the preeminent position within Europe's aerospace sector made it impossible for either company to accept a subordinate position to its partner. The contradictory military requirements and the slow negotiation of industrial arrangements provided Dassault with the time it required to sabotage the project.

V. The SEPECAT Jaguar

The program that ultimately gave birth to the Jaguar strike (i.e. ground attack) aircraft began as the advanced trainer envisioned by the 1965 Anglo-French memorandum of understanding. Unlike the more sophisticated AFVG, the Jaguar was projected to be an easy project, which could quickly be launched on the basis of a design study that the French company, Breguet Aviation, had already conducted.[40] When complete, the new aircraft would replace the United Kingdom's Jet Provost and France's Potez Magister trainers. Initially projected as a lightweight (3,500 kg) aircraft, the new aircraft should have been comparatively cheap.

Unlike the AFVG, the industrial roles of British and French companies were clear from the onset of the Jaguar project. Because France's Breguet had conceived the aircraft's basic design, it would exercise leadership over the aircraft's development. To counterbalance French leadership on the airframe, Rolls Royce would oversee the design of the jet engines. Because French and British companies would undertake construction of the trainer on a 50/50 basis, BAC and the French engine manufacturer Turbomeca would collaborate on the project in secondary capacities. Because the division of labor was clear from the beginning, the Jaguar did not suffer from the two years of corporate rivalry that the AFVG experienced as requirements were written and the work-share agreement negotiated. However, many of the advantages of economies of scale were sacrificed because both the United Kingdom and

France insisted on assembling the aircraft in separate national facilities and conducting flight tests in parallel, in both countries.[41]

Unfortunately, the collaborative jet trainer began to suffer serious problems barely two years after its conception. After the AFVG's cancellation in 1967, the British Royal Air Force found itself confronted with a pressing need for new ground-attack aircraft. As a result, the United Kingdom redefined its aircraft requirement. Rather than acquiring a dedicated trainer, the British now wanted a dual-purpose aircraft, which could both bomb enemy targets and be used to conduct advanced training. To fulfill these new demands, the aircraft needed a longer range and would have to carry an increased payload.

Because the revised design would be more complex, obtaining adequate economies of scale demanded increasing the number of aircraft to be produced. In this context, the United Kingdom and France agreed in 1970 to increase their Jaguar orders from 300 aircraft (150 apiece) to 400 aircraft (200 apiece). Whereas the United Kingdom originally planned to purchase 150 Jaguar two-seat trainers in 1965, it now expressed a need for 165 strike Jaguars (the Jaguar-S model) and 35 trainers.[42] Likewise, the French augmented their order to 200 aircraft, but rejected the costly avionics the British incorporated into their strike Jaguars. As a result, the French acquired 40 trainers and 160 unsophisticated ground attack Jaguars (the Jaguar-A model).[43]

Despite the increased number of aircraft ordered, the modifications to the Jaguar's specifications proved hazardous to the aircraft's capabilities and cost-effectiveness. To transform the Jaguar from a training aircraft to a strike (ground attack) fighter, the aircraft had to be strengthened and enlarged to accommodate more fuel and carry more bombs, and its aerodynamics modified to maximize high-speed low-level flight rather than provide the stability and handling needed in a training aircraft.

To provide stability during low-level flight, the aircraft's wings were entirely redesigned.[44] Because the wing surface area was reduced, more of the aircraft's fuel had to be stored in the fuselage, which entailed lengthening the aircraft. However, the new requirement to fly at low altitudes meant that the Jaguar's redesigned fuselage had to be reinforced. To carry a large payload of bombs (10,000 lbs), the aircraft's underside also needed strengthening. When taken as an ensemble, these many modifications to the Jaguar's design increased its weight from a light 3,500 kg to a hefty 7,000 kg. It also became progressively subject to drag, as a result of its increasingly un-aerodynamic shape.[45]

Unfortunately, coming late in the design process, these changes were implemented after the aircraft's jet engines had reached a stage where further modifications were impossible. In 1965, Rolls Royce and Turbomeca were tasked with building the aircraft's power plant—two Adour 101 jet engines, to power an aircraft weighing 3,500 kg. When the Jaguar's mass doubled as a result of the 1970 redesign, it was too late to modify the engines. As a consequence, the Jaguar remained one of the world's most underpowered aircraft throughout its long career.[46]

Worse, as a result of the need to redesign the Jaguar, the program's costs exploded. Ultimately, the Jaguar cost seven times more to develop as originally anticipated. Table IV, below, compares the original cost estimate with final development costs.[47]

Table IV: Projected and Final Development Costs (In French Francs)	
Projected Development Cost	120 million FF
Final Development Costs	864 million FF

For an aircraft of its size and capabilities, such heavy development costs were exceptional. In fact, the costs of getting the Jaguar to the production stage were astronomic, even when compared to contemporaneous French efforts to develop more sophisticated aircraft. Table V, below, compares the pre-production costs (research, development, testing and tooling) of the

Jaguar with a bi-sonic fighter (the Mirage F1) and a supersonic long-range bomber (the Mirage IV).[48]

Table V: Comparative Pre-Production Costs (In French Francs)	
Jaguar	1200 million FF
Mirage F1	670 million FF
Mirage IV	635 million FF

As is evident from these figures, the Jaguar's high development costs exceeded even Moravcsik's "√n," which predicts that a bi-national aircraft will cost 140% as much to develop as an equivalent national system. Because of its high costs and limited capabilities, the head of the French air force derided the Jaguar as, "The most expensive and disappointing aircraft in French history."

Because of its higher cost and greater fuel consumption, the Jaguar proved an inefficient training aircraft. As a consequence, the British dedicated all of their trainer Jaguars to combat units and the French embarked on a joint Franco-German project to develop a more appropriate jet trainer (the Alphajet).

Despite the fact that the aircraft was no longer suitable as a trainer, the British still hoped to market it as a lightweight attack aircraft. In 1973, the year the Jaguar entered service, BAC's Managing Director, George Edwards, waxed confident about the aircraft's future commercial success. According to Edwards, "The great thing about the Jaguar programme is that it gives us the chance to work from an initial order base of 400 aeroplanes for the two sponsoring countries, and thus provide the opportunity to go on to sell off the thin end of the learning curve [meaning after production costs had dropped] instead of the more usual thick end."[49] Soon BAC sales teams were targeting over 30 states as potential Jaguar clients.[50]

Unfortunately for the British aircraft industry, BAC soon encountered an unexpected obstacle in exporting the aircraft—the company's French partner. When British and French governments signed the 1965 Memorandum of Understanding to develop the Jaguar, they intended to produce a training aircraft that would not compete with either states' existing product line. However, when the RAF changed its Jaguar requirement from a jet trainer to a lightweight ground-attack aircraft weighing 7,000 kg, it inadvertently placed the Jaguar in the same market niche as France's Mirage F1 fighter. Although the Mirage F1 was a fighter with a secondary ground-attack capability and the Jaguar was a ground-attack aircraft with marginal air-to-air combat potential, the two aircraft were of similar size (7,400 kg for the Mirage and 7,000 kg for the Jaguar), priced competitively with one another and appealed to the same potential customers, who could generally afford to purchase only a single type of aircraft.

When Dassault Aviation acquired Breguet via a two-step process in 1967 and 1971, its interests clearly lay in suppressing Jaguar sales, so as to favor the Mirage F1. In acquiring Breguet, Dassault became the producer of half of the Jaguar's airframe and obtained privileged information on the aircraft's strengths and weaknesses. From this position of inside knowledge, Dassault did everything in its power to impede Jaguar sales and favor Mirage F1 exports. According to BAC's publicity manager, Charles Gardner,

> There were acute problems on the sales side from the time Dassault took control of Breguet…. Quite often the French were trying to sell the Dassault F1 fighter… against the Jaguar. To help them in this they had, of course, all Jaguar performance and cost data, and were able to highlight any development problem of the day, while keeping silent on any hitches with the Mirage F1. The French were, by various stratagems, also able at one time, to keep the cost quotation of possible export Jaguars high and to delay deliveries.[51]

Understandably, Dassault's efforts to sabotage Jaguar exports produced considerable animosity at BAC, leading Edwards to publicly question the French understanding of "partnership."[52] Dassault also hindered Jaguar upgrades because they would increase the aircraft's export potential vis-à-vis the Mirage F1. When the French Air Force later proposed upgrading its Jaguars by equipping them with more powerful Adour jet engines, jointly developed by Rolls-

Royce and Turbomeca, and a French-designed inertial navigation system, the DGA likewise blocked the proposal because it would increase the Jaguar's attractiveness to foreign clients and lead to a portion of France's aircraft procurement funds budget being spent in the United Kingdom.[53]

Although it is difficult to ascertain how many Jaguar sales were lost as a result of Dassault's interfering with Jaguar exports, there is strong circumstantial evidence that the Jaguar would have been a greater commercial success if not for the behavior of BAC's partner/rival. Having both entered service in 1973, the Jaguar and Mirage F1 competed in many foreign markets. Ultimately, 192 Jaguars were exported to four states (Oman, Ecuador, India and Nigeria), while 457 Mirage F1s were sold to ten clients. Although the aircraft was jointly produced, BAC and its successor (from 1977) British Aerospace negotiated all four Jaguar contracts in the face of stiff French opposition. In open competition, India and Oman chose the Anglo-French Jaguar over French aircraft.[54] Nigeria was only persuaded to purchase the Jaguar because of the United Kingdom's offer of soft loans (never repaid) financing the purchase. Egypt, Kuwait, Abu Dhabi and Pakistan, however, chose Mirages in direct competition with the Jaguar.[55] Ecuador eventually acquired both the Jaguar and the Mirage F1, indicating that at least one state considered the two aircraft complementary.

In short, the Jaguar program suffered from considerable problems throughout its development history. The need to accommodate irreconcilable British demands for a strike aircraft and French requirements for a trainer meant that the Jaguar was too costly for training and too underpowered to be an optimal strike aircraft. The redesign effort to incorporate these conflicting priorities precipitated an explosion in development costs. Finally, the fact that the Jaguar competed in the lightweight combat aircraft market with France's Mirage F1 led the French government and Dassault to sabotage efforts to export the Jaguar.

VI. PANAVIA Tornado

The tri-national PANAVIA Tornado, which became Europe's largest combat aircraft project of the late Cold War, developed initially as a result of unconnected events in the United Kingdom, West Germany and Italy. Despite the Jaguar's development, the United Kingdom's aerospace industries lacked a large scale, high technology project after the AFVG's cancellation. Having not altered its requirements for a variable geometry attack aircraft, the British Royal Air Force still demanded an aircraft technologically similar to the AFVG. However, British policymakers felt that such an aircraft could only be developed in partnership with other states.

Meanwhile, five NATO members--West Germany, Italy, Canada, Belgium and the Netherlands--collaborated on a joint project to replace their Lockheed F-104 Starfighters. Having never purchased F-104s, the United Kingdom was never invited to join the coalition of states searching for a replacement. Moreover, because the F-104 replacement was envisioned as a single-engine lightweight fighter, it would not meet the RAF's requirement for sophisticated low-level ground-attack capabilities.

Despite problems with the AFVG and Jaguar, British policymakers preferred collaborating with the French to working with other potential partners. In the eyes of the British, only the French aircraft industry possessed the requisite technological capabilities needed to produce a world-class aircraft. As the British Chief Science Advisor observed, "a reasonable solution [for the British aircraft industry] will only be found through some adequate tie-up between our own and French firms."[56] However, the French had already committed to the Mirage F1 and lacked the funds for another aircraft project. In this context, West Germany and Italy were the United Kingdom's only two allies with aircraft industries and defense budgets large enough to collaborate on a sophisticated aircraft.

For their part, the members of the F-104 replacement consortium were deeply ambiguous about allowing the British to join them. On the one hand, the United Kingdom's aircraft requirements were diametrically opposed to those of the consortium members (a large strike aircraft versus a small lightweight fighter). On the other hand, the British aircraft industry was much larger and more sophisticated than those of the consortium's five members. The British therefore offered hope for the other states to improve the competitiveness of their own aircraft industries.

In this context, the United Kingdom strove for admission to the F-104 replacement consortium with the secret ambition of altering its goals to suite British interests.[57] On the day following the AFVG's cancellation, the British RAF sent a delegation to Canada to capitalize on its privileged relations with the Royal Canadian Air Force (RCAF) and persuade the Canadians to convince the other F-104 replacement cartel members to allow the United Kingdom to join their group.[58]

Eventually the F-104 replacement consortium agreed to let the United Kingdom join the cartel, but as a non-voting observer. By 1969, British diplomats and the RAF convinced the West Germans and Italians to abandon the cheap lightweight fighter for a large variable geometry aircraft. As the United Kingdom's Chief Science Advisor confided to the Prime Minister in 1970, "By joining [the F-104 replacement consortium], the RAF also changed the character of the project, and succeeded in injecting their own ideas for a two-seater aircraft designed primarily for the strike role, rather than a single-seat fighter."[59] However, the Dutch, Belgians and Canadians abandoned the program when the RAF changed the nature of the aircraft being developed. The Canadians, who were responsible for bringing the United Kingdom into the F-104 replacement cartel, were particularly embittered at having to abandon the group because it no longer corresponded to their needs.

Because of the initial disagreement over requirements, all specifications for the new Multi-Role Combat Aircraft (MRCA), which was later renamed Tornado, were subjected to painstaking negotiations. Ultimately, the aircraft requirements exceeded 200 pages in length. Table VI, below, illustrates the industrial partners involved in the MRCA/Tornado:

Table VI: MRCA/Tornado (Industrial Partners)	
United Kingdom	BAC Rolls Royce
West Germany	MBB MTU
Italy	Aeritalia FIAT SPA

Overall, the MRCA was designed for low-altitude strike missions in all weather conditions, but was also supposed to have a high-altitude speed of Mach 2.2. The aircraft had to have two crewmembers, two engines and variable geometry wings.

The industrial work share arrangements to meet these requirements were also subject to painstaking deliberation. Each partner attempted to obtain as advantageous a share of the design work as possible, both quantitatively in terms of a percentage of the work and qualitatively in terms of specific development tasks. To boost their negotiating position for critical development contracts, West Germany and Italy initially exaggerated the number of aircraft they intended to buy. The West Germans initially claimed they would purchase the disproportionately large number of 600 aircraft, while the Italians expressed a need for 200. In both cases, the British suspected that their partners' claims were deliberately exaggerated, but the British decided to lodge a realistic order for 385 aircraft. [60] Predictably, after initial discussions aimed at setting requirements and establishing the program's contours, the Germans reduced their order to 420 aircraft and the Italians to 100.[61]

Recognizing that its participation was viewed as symbolically important, Italy demanded a disproportionate percentage of the production work on the aircraft and significant financial guarantees. While Italy intended to purchase 11 percent of the MRCAs produced (100 of 900), it demanded 15 percent of the aircraft’s production work and asked that its partners reimburse its expenditures if the project collapsed. After tough negotiations, the British and Germans agreed to the first, but not the second of these two demands.[62]

Skeptical that West Germany would maintain its large order, the British insisted on an equal work share. Thus, the United Kingdom and West Germany both agreed to a 42.5 percent participation in the program. However, the West German government was adamant that German firms develop the center section of the MRCA's fuselage, which contained the aircraft's complex variable geometry pivot. Calculating that variable geometry was a critical technology, the Germans desperately wanted to develop the expertise needed for future variable geometry programs. Unfortunately, West German companies had no experience whatsoever with variable geometry, whereas BAC had been developing the technology since the mid-1940s. Nevertheless, political imperatives triumphed over economic logic and the contract for the center fuselage and the variable geometry wing pivot was awarded to Messerschmidt-Bölkow-Blohm (MBB).[63]

To make matters worse, the Tornado partners insisted on establishing separate assembly lines and testing the aircraft at distinct national facilities. Thus, Tornados were tested at Boscombe Down, Manching and Pratica di Mare, and assembled at Warton, Manching and Turin.[64] This unnecessary duplication of assembly line and testing facilities eliminated many of the economies of scale anticipated from a joint aircraft.

Because of suboptimal work share arrangements and overly detailed specifications, the Tornado began accumulating cost overruns and development problems. As early as July 1971, the MRCA partners judged that aircraft's performance would be "somewhat lower than envisaged" but "still acceptable to all three air forces."[65] By May 1973, British records demonstrate that the MRCA's development costs had already risen by 15 percent, while the aircraft's projected entry into service was now two years later than originally anticipated.[66] Meanwhile, the cost of developing the aircraft's avionics rose 70 percent.[67]

From an industrial point of view, the work share arrangements underlying the aircraft were further complicated when the West Germans further reduced their Tornado order from 420 aircraft to 324, on the eve of the aircraft's production.[68] Coming after the aircraft's development was complete, such a reduction in their order was calculated to preserve West Germany's advantageous work share arrangements, while limiting the country's outlays for the aircraft's production. Unsurprisingly, this tactic did little to endear the West Germans to their partners and upset financial calculations of the Tornado's cost. Table VII, below, illustrates the progressive reduction in Tornado orders:

Table VII:
Tornado Orders

State	1969	1973	1976	Percentage Reduction
West Germany	600	420	324	46%
United Kingdom	385	385	385	0%
Italy	200	100	100	50%
Total	1,185	905	809	32%

Because each reduction in orders entailed some renegotiation and reallocation of development and production work, every one of these unilateral decisions introduced delays into the aircraft's development and increases to its cost.

Although data on the Tornado's overall cost overruns are unavailable, it is evident that the aircraft's price continued to rise. Worse still, the aircraft only entered service in 1982, six years after originally anticipated. Whatever its technical qualities, the ground-attack Tornado was a commercial failure. Because of its sophistication, the Tornado was expensive. Costing approximately £25 million ($38 million) in 1993, it was significantly more expensive than many contemporary combat aircraft, such as the F-16C ($18 million), Mirage 2000 ($24 – 27 million) and F/A-18C ($21 million).[69] The Tornado was also expensive to maintain as its variable geometry wings and sophisticated avionics required intensive maintenance by well-trained technicians.[70] As a consequence, the average annual operating costs of a Tornado (£10.4 million) were nearly twice those of other combat aircraft.[71]

Because of its high cost and technical shortcomings, the Tornado proved a commercial disappointment. Despite its cache as a collaborative European aircraft, not a single European country purchased the aircraft besides the three partners in the Tornado consortium. In fact, the only country that ultimately acquired the Tornado was Saudi Arabia. In many respects, this lone success confirms the commercial unattractiveness of the Tornado. One of the wealthiest arms importers, Saudi Arabia was one of the few states that could afford the Tornado. Even so, Saudi Arabia only opted for the Tornado once the United States Congress blocked the sale of American F-15E aircraft. To seal the Tornado deal, Defense Minister Michael Heseltine rushed to Saudi Arabia every time it was rumored the Saudis would purchase another aircraft and Prime Minister Thatcher herself negotiated much of the deal with Prince Bandar, son of Saudi Defense Minister Prince Sultan.[72]

The most prolific collaborative combat aircraft to date, the Tornado embodied many of the worst aspects of the collaborative process. Because of the initial discord over the aircraft's mission, the Tornado was developed around an unwieldy and over-specified set of requirements. In order to maximize their role in the aircraft's development, two of the consortium's three partners exaggerated their initial orders with the intention of later scaling them back. When these reductions were implemented, the overall program suffered from delays, acrimony and the renegotiation of work share arrangements. To make matters worse, many of the Tornado's development and production tasks were allocated to companies ill-equipped to fulfill them, but desirous of using the Tornado program to underwrite developing new technologies. When combined with redundant assembly lines and testing facilities, these dynamics contributed to the Tornado's high cost and disappointing performance.

VII. The Eurofighter (EDF2000/Typhoon)

As early as 1975, it became apparent that European aircraft industries needed a project to keep their workforces employed and preserve industrial expertise after the projected completion of their existing programs.[73] In the absence of a collaborative European project, it was feared that European air forces would be obliged to purchase or coproduce American aircraft, and that such a decision would precipitate the decline of Europe's aerospace industries. As the British Chief Scientific Advisor dramatically indicated in 1976, absent European collaboration on a future combat aircraft, Europe's aerospace industries would cease to exist.[74] Because of the vicissitudes encountered in previous European collaborative programs, it was felt that 15 years constituted the minimum time needed to develop and agree on a program.

Driven by the imperative to find a project to succeed the Tornado and Mirage 2000, European states formed the European Independent Sub Group on tactical combat aircraft. Gradually, multinational discussions permitted European states to exchange information about aircraft replacement schedules and requirements. By 1979, France, the United Kingdom and West Germany had all decided that collaboration was in their mutual interest and that they would focus their efforts on developing highly agile aircraft with two engines.

However, the British and French competed for influence within this project from the onset. Possessing the only two aircraft producers (British Aerospace and Dassault) capable of acting as prime contractors/systems integrators and the only two European companies capable of developing jet engines (Rolls Royce and SNECMA), the United Kingdom and France struggled to maximize the advantages that each of their industries would derive from a collaborative project. In search of design leadership, both the British and the French financed the efforts of their national companies to develop technology demonstrators. To sustain their pretensions to equality, West Germany's MBB joined this race to produce technology demonstrators. As a consequence, the British Agile Combat Aircraft (ACA), the French Avion de

Combat eXperimental (ACX) and the German Taktisches Kampfflugzeug 90 (TKF 90) all evolved in the early 1980s.[75]

Long debated and considered the only reasonable solution, the United Kingdom, West Germany and France provisionally agreed in December 1983 to collaborate on a future aircraft.[76] However, efforts to negotiate the technical details and work share arrangements of the project soon created animosity between the three partners. France demanded that Dassault receive the status of prime contractor for the new aircraft's fuselage and argued that the engine's most sophisticated elements be jointly developed by SNECMA and Rolls Royce. Willing to accept French pretentions to leadership on the airframe, the British insisted that Rolls Royce receive a similar status on the engines. In their struggle for leadership over the new aircraft, both the French and British cultivated the West Germans, whose main interest was to negotiate formal parity with their partners and obtain concessions regarding the development crucial subsystems.[77]

Ultimately, the fate of Europe's future combat aircraft was decided at a meeting of British, French, West German, Italian and Spanish armament directors in August 1985. When the West Germans sided with the British, and the French refused a final offer that accepted some of Dassault's pretensions but not SNECMA's, the French withdrew from the collaborative project.[78] Thus, the Eurofighter was launched in 1985 on the basis of tri-national collaboration between the United Kingdom, West Germany and Italy.

The Spanish initially hesitated over whether to join the multinational consortium or form a partnership with the French. Although Spain's aerospace industry was considered backwards in comparison to the Eurofighter's other participants, Spanish adherence to the consortium was considered politically and economically advantageous. If Spain refused to adhere to the Eurofighter consortium, it was feared that domestic critics of the project would be strengthened in West Germany and the French could give a multinational veneer to the their national project by partnering with the Spanish. For these reasons, the Spanish became the subject of substantial diplomatic attention until November 1988, when Spain agreed to participate in the Eurofighter's development. However, Spain's assent to joining the Eurofighter consortium was contingent upon British support for Spain's application to join the Western European Union and advantageous work share arrangements.[79] Table VIII, below, illustrates the partner states and companies involved with the Eurofighter:

Table VIII: Eurofighter (Industrial Partners)	
United Kingdom	British Aerospace Rolls Royce
West Germany	MBB MTU
Italy	Aeritalia FIAT SPA
Spain	CASA CESA

Because of the complex diplomacy underlying the creation of the Eurofighter consortium, development and production contracts were divided according to a political, rather than industrial, logic. Lacking any experience with active control technology (ACT or "fly by wire"), the West Germans wanted to break into this critical industrial sector. However, the British already possessed more than a decade of experience with ACT and had mastered the technology. To obtain West Germany's support in their confrontation with the French, the British agreed to allow the West Germans to develop the Eurofighter's ACT.[80] Diplomatically necessary, this decision lengthened the Eurofighter's development and augmented its cost.

Likewise, obtaining Spain's 13 percent contribution to Eurofighter required numerous industrial concessions. In order to meet Spanish demands to help develop the Eurofighter's carbon fiber wings, the Eurofighter became the first aircraft in history whose wings are built in separate countries, by multiple companies. In effect, while the left wing is built in Italy, the right wing is built in Spain, but incorporates British control surfaces.[81]

Because of the underdeveloped nature of Spain's aviation industry, the Eurofighter imposed exceptional strains on the country. During certain years, Eurofighter expenditures consumed 65 percent of Spain's total defense research and development investment. Spain's aerospace industries possessed inadequate scientific and technical resources to adapt to such a sudden influx of R&D funds. In fact, drawing on a combination of state and foreign involvement, Spain was obliged to create a new jet engine company (Industria de Turbo Propulsores) and hydraulic controls company (Compania Espanola de Sistemas Aeronauticos) to handle Spain's contribution to these particular aspects of the Eurofighter's development.[82]

Considering that comparative industrial and technological capabilities were not taken into account in the allocation of Eurofighter contracts, it should come as no surprise that the aircraft's development was much slower and cost significantly more than anticipated. By the time the Eurofighter's development was complete, the program cost nearly 70 percent more than originally anticipated.[83] In comparative terms, this meant that the quadripartite Eurofighter cost more than three times as much to develop than the French Rafale (21.6€ billion versus 6€ billion).[84] In this context, Eurofighter's development costs far exceed those predicted using the "√n Rule."[85] Moreover, the program slipped more than five years behind schedule, as inexperienced contractors encountered difficulty developing technologically sophisticated components.[86]

Ultimately, the Eurofighter faced a crisis in 1992. Many of the Eurofighter participants exaggerated their intended orders in 1985 and 1988. As a result, when the aircraft neared the production stage, they rushed to reduce their orders. Meanwhile, cost overruns threatened the program's financial health. In March 1992, German Defense Minister Volker Ruhe urged the Eurofighter consortium to cancel the Eurofighter and invest in a cheaper aircraft. Meanwhile, the British Treasury recommended that the United Kingdom withdraw from the Eurofighter and purchase American F-18s. Faced with the seeming collapse of the Eurofighter, the Italian government discreetly approached McDonnell Douglas about purchasing the F-18.[87]

With disaster looming, the United Kingdom struggled diplomatically to save the Eurofighter. Ultimately, development work on the Eurofighter came to a virtual standstill between July and December 1992 as the partner states negotiated the program's future.[88] After debating various options for a smaller and cheaper Eurofighter, the partner states agreed upon a series of measures to save the program. To begin with, many of the Eurofighter's capabilities were downgraded in order to obtain cost savings of between 13 and 30 percent, depending on the version ordered.[89] Meanwhile, all of the Eurofighter participants reduced their intended orders and renegotiated work share agreements. Table IX, below, compares the original agreement with the final compromises.[90]

Table IX:

Eurofighter Orders and Work Share Percentages

State	**1985 Orders**	**1985 Work Share**	**1998 Orders**	**1998 Work Share**	**Percentage Decrease (Orders)**
Germany	250	33%	180	30%	28%
United Kingdom	250	33%	232	37.5%	7%
Italy	165	21%	121	19.5%	27%
Spain	100	13%	87	13%	13%
Total	765	100%	620	100%	19%

Although necessary for the Eurofighter's survival, the change in work share arrangements heightened the program's production difficulty. Aircraft components designed in one country now had to be manufactured in another. Moreover, countries that significantly cut their orders, such as Germany and Italy, benefitted from a disproportionate percentage of development contracts compared to those that remained more steady.

Taken as an ensemble, these difficulties have added further to the Eurofighter's excessive cost. Despite the difficulty in finding comparable figures for contemporary combat aircraft prices, Table X, below, presents the best estimates that can be drawn from available sources.[91]

Table X: Comparative Contemporary Aircraft Prices (2006)		
Aircraft	**Unit Cost**	**Program Cost Per Unit**
Rafale C (France)	€51.8 million ($62.1 million)	€113.2 million ($135.8 million)
JAS-39C Gripen (Sweden)	$68.9 million	unknown
F-18E Super Hornet (USA)	$78.4 million	$95.3 million
Eurofighter (German)	€85.7 million ($102.8 million)	€118.3 million ($141.9 million)
Eurofighter (UK)	£64.8 million ($118.6 million)	£78.6 million ($143.8 million)

Although published combat aircraft prices must be treated with skepticism, available data indicate that the Eurofighter is much more expensive to produce than equivalent aircraft developed on a purely national basis.

Even worse, the Eurofighter does not appear to have benefitted markedly from the economies of scale or learning economies usually cited as reasons for multinational aircraft collaboration. Despite the Eurofighter's large production base of 620 aircraft, the aircraft's unitary cost is higher than that of the Gripen (213 produced), Rafale (294 produced) and the F-18E (462 produced). Even taking development costs into account, which are amortized over longer production runs, the Eurofighter is still more slightly more expensive than the Rafale and significantly more so than the F-18E. Although such price differentials would be justified if the Eurofighter was a significantly more capable aircraft, there is little evidence that this is the case.[92]

Thus, as a result a stormy development process, the Eurofighter has developed as an overpriced aircraft. From the program's inception, development and production contracts were distributed based on political and technological considerations that ran contrary to any notions of comparative advantage. Moreover, most participants exaggerated their initial orders in order to maximize their bargaining power when it came to determining work shares. Lacking a strong central administration, the Eurofighter accumulated delays and cost overruns. Although the program survived the 1992 crisis, the aircraft that emerged was less capable and much more expensive than originally intended.

VIII. Judging Collaboration

From the cases examined above, it is evident that collaboration yielded few of the benefits anticipated. Although three out of four projects were carried to their term, each of these encountered numerous vicissitudes. Each collaborative aircraft ended up behind schedule, more costly than anticipated and less capable in terms of performance. Moreover, such anticipated benefits of collaboration as shared development costs and lower unit production costs appear absent.

Overall, developing collaborative aircraft proved much more costly than equivalent national aircraft. Although classic theories of collaboration allow for inefficiencies through the "√n Rule," the actual additional cost of developing an aircraft collaboratively was much higher than even this rule predicts. With the Jaguar's aggregate development costs of 1200 million FF, the aircraft cost both the United Kingdom and France more to develop than it would have cost either state to develop an equivalent national aircraft.[93] Likewise, because the Eurofighter's development cost of 21.6€ billion is more than three times that of the comparable Dassault Rafale, both the British and German contributions to the Eurofighter were equivalent to what it would have cost either state to independently develop such an aircraft.[94]

If savings were absent from the development stage, it is also difficult to detect any sign of the economies anticipated at the production phase, despite the large production runs of each collaborative aircraft (approximately 400 for the Jaguar, 900 for the Tornado and 700 for the Eurofighter). For example, the Eurofighter's unit (i.e. production) costs are significantly higher than the available figures for comparable combat aircraft. Even accounting for the amortization of development costs over a larger number of production aircraft, the Eurofighter still yields no visible economies.[95] In its own time, the Tornado was also amongst the most expensive aircraft of its generation.[96]

Although performance is difficult to objectively gauge, collaborative aircraft also appear unremarkable in this respect. According to Dussauge and Garrette, aerospace executives do not view any of the collaborative combat aircraft as particularly innovative.[97] Throughout its long existence, the Jaguar suffered from heavy drag and insufficient power. Likewise, more than a decade before the aircraft became operational, the Tornado consortium was force to accept that the aircraft would never meet its performance objectives. Although possessed of excellent avionics, the aircraft lacked operational flexibility and could resist little damage.[98] Finally, in 1992 the Eurofighter consortium agreed to significantly downgrade the aircraft's capabilities in order to save the faltering program. In the cases of the Jaguar and Tornado, high costs and performance shortfalls translated into few international sales. As yet, it is too early to judge whether the international marketplace will validate the Eurofighter.[99]

In terms of program delays, collaborative programs also stand out as problematic. For example, the Tornado entered service six years later than anticipated, while the Eurofighter did so five years late. Although the Jaguar's originally anticipated debut is unknown, the eight years it took to develop this modest aircraft seems excessive.

Taken as an ensemble, collaboration on European combat aircraft appears much less efficient than even pessimistic theories (such as the $\sqrt{n}$ Rule) anticipate.[100] Bloated development costs, high production costs and disappointing technical characteristics appear to be a constant for each of the collaborative aircraft programs. Given the poor results of collaboration, the major paradox that emerges is why intra-European collaboration on combat aircraft has been pursued with such consistently?

Here the reasons appear multiform. For many European states, collaboration is the only feasible means of participating in an aircraft's development. Amongst European states, only France, the United Kingdom and Sweden possess companies capable of undertaking the complicated project management and systems integration tasks associated with developing a combat aircraft.[101] Meanwhile, only the United Kingdom and France are capable of designing the combustion chambers for modern turbofan engines.[102] As a consequence, Germany, Italy and Spain are obliged to collaborate if they wish to participate in the development of a combat aircraft.

To make matters worse, the escalating cost and complexity of combat aircraft is rendering national products unaffordable to even those states that hitherto developed them independently. In fact, the costs of developing the French Rafale and Swedish Gripen were such that both governments considered cancelling the projects on a number of occasions. Today, both Dassault and SAAB recognize that collaboration offers the only realistic opportunity for either company to continue to develop and produce combat aircraft.[103] Thus, despite the deficiencies of past programs, European states appear condemned to collaborate if they want to maintain a footing in the combat aircraft sector.

IX. The Reasons for Inefficiency

Given the magnitude of the inefficiencies attending collaboration, it should come as no surprise that the causes are varied and multitudinous. In this section, I will analyse the explanatory power of the four existing theories of collaboration and then inductively examine other phenomena detracting from the cost-effectiveness of collaborative programs.

Moravcsik's theory that arms producing companies possess a de facto veto over collaborative projects is confirmed by the cases above, but also contributes relatively little in explaining the inefficiencies inherent in programs that were carried to completion. As predicted, programs failed despite government support when one of the major industrial partners concluded that it stood to lose economically or technologically. Dassault's sabotaging of the AFVG and SNECMA's prompting France to withdraw from the Eurofighter are both examples of this phenomenon. However, the Jaguar, Tornado and Eurofighter were all ultimately developed by companies that concluded that collaboration was in their self interest. As a consequence, corporate opposition cannot account for the inefficiency of these programs.

Contrary to Moravcsik's theory, Dussuage and Garrette's hypothesis about the institutional determinants of the success or failure of collaborative programs applies to all of the multinational combat aircraft examined. In fact, none of the collaborative combat aircraft programs possessed the joint venture management and sales organizations considered necessary for success. Lacking permanent institutions to coordinate their activity, numerous problems emerged amongst partner companies relating to the transfer of technologies and the responsibility for specific engineering tasks. Moreover, the absence of permanent cross-company teams meant that opportunities were lost as to how to identify and exploit corporate synergies and comparative advantages. In a particularly egregious example, the absence of a common marketing structure left the British to market the Jaguar alone, while the French attempted to thwart these efforts.

Tucker's concept of partners and rivals helps explain the physiognomy of European combat aircraft collaboration, but not the disappointing results of projects carried to completion. As Tucker predicted, collaboration was most efficient when it concerned companies possessing a large disparity of economic and technological resources. Contrarily, collaboration was highly problematic when it involved firms with analogous capabilities. Within this context, the tense and painful relationship between Dassault and BAC/British Aerospace was a natural outgrowth of the similarities of the two companies' resources. The unwillingness of these two firms to collaborate contributed to the collapse of the AFVG, damaged the Jaguar's export prospects (after Dassault's acquisition of Breguet) and led to France's withdrawal from the Eurofighter.

However, the three combat aircraft programs carried to completion involved a dominant airframe (BAC/British Aerospace) and engine (Rolls Royce) producer collaborating with less capable firms. As such, these arrangements satisfy Tucker's criteria for collaborative success. Thus, while correctly predicting the inability of corporate rivals to collaborate, the partners and rivals theory cast less light on the cost overruns and technological disappointments attending those programs that reached the production stage.

Finally, Lorell and Lowell's emphasis on needless industrial redundancies and divergent military requirements is validated in all of the programs examined. Final assembly and testing facilities were duplicated in all three of the aircraft that entered service. Each country assembled its aircraft at a distinct national assembly line and prototypes were built and tested in all member states (except Spain). This uneconomic replication of activities partially counterbalanced the economies of scale that should have been obtained from collaboration.

Divergent military requirements also played a role in complicating three of the four programs. Dassault's efforts to sabotage the AFVG were facilitated by the long time it took to negotiate a compromise between British and French requirements; the Jaguar was fatally undermined by the effort to reconcile requirements for a trainer and an attack aircraft and the Tornado initially suffered from the contradictory requirements of the United Kingdom and the members of the F-104 consortium. Perhaps worse than the dissonance between initial requirements is the fact that the compromises negotiated were excessively detailed, occupying over 200 pages in the case of the Tornado. As previous studies have been apt to demonstrate, overly detailed requirements are contrary to established best practices in aircraft design, which leaves a large degree of freedom to engineers and technologists.[104]

Thus, all of the major theories of collaborative failure contribute to understanding some of the vicissitudes experienced by intra-European collaborative programs. Table XI, below, illustrates the applicability of these theories to the four collaborative combat aircraft programs.

Table XI:

Theories of Collaborative Failure and their Application

	De facto corporate veto	**Absence of joint venture institutions**	**Partners and Rivals**	**Redundant facilities**	**Divergent Military Requirements**
AFVG	Yes	Yes	Yes		Yes
Jaguar		Yes	Yes (eventually)	Yes	Yes
Tornado		Yes		Yes	Yes
Eurofighter	Yes (SNECMA)	Yes	Yes (Dassault and BAe)	Yes	

While all existing theories of collaborative failure contributed to the problems suffered by combat aircraft projects, not one is capable of accounting for the magnitude of the disappointments.

In addition to the aforementioned reasons for collaborative failure, a detailed examination of the cases indicates that two other dynamics contributed to the inefficiency of collaborative combat aircraft programs.

Certain programs, particularly the Tornado and Eurofighter, suffered from perverse work share negotiating strategies. Because the allocation of critical development contracts is normally done on a pro-rata basis for the number of aircraft that each state intends to purchase, there is an incentive for states to exaggerate the number of aircraft they intend to acquire. Then, when the collaborative aircraft reaches the production phase, partner states tend to scale their purchases back. In the Tornado's case, West Germany and Italy cancelled 376 aircraft before the Tornado entered production. In the Eurofighter's case, the reduction was one of 145 aircraft. Unfortunately, the need to renegotiate work share agreements and the attendant disruption of financial calculations are deleterious to the efficiency of collaborative programs.

In addition to perverse work share negotiating strategies, collaborative combat aircraft programs suffered from the least qualified contractor problem. Many corporations participating in collaborative projects viewed their involvement as a means of developing critical technologies and production processes they did not yet possess. Contrarily, corporations proved much less interested in producing systems for which they were already qualified or possessed a comparative advantage.

As a consequence, many of the critical development contracts associated with collaborative aircraft programs were allocated to corporations that were the least capable of effectively fulfilling them. Thus, the wing pivoting mechanisms of the Tornado and active control technology of the Eurofighter were confided to the West Germans despite their lack of experience in the domain and the United Kingdom's demonstrable expertise. Similarly, the Spanish were awarded the carbon fiber sections of the Eurofighter's right wing regardless of the fact that the Italians had already invested heavily in the technology needed to fabricate the left wing. Not surprisingly, contracts awarded to companies ill-equipped to execute them added to the delays and expenses of combat aircraft programs.

In sum, a variety of factors contributed to the sub-optimal nature of combat aircraft collaboration. Not all programs suffered from the same ills, but multiple problems dogged each project. Given the magnitude of the inefficiencies plaguing collaborative combat aircraft projects, the existence of a multitude of causes should come as little surprise. Nevertheless, the rising cost of developing and producing modern combat aircraft leaves European states with few choices but to persevere with intra-European collaborative projects. The question must therefore be posed, are European states condemned to sub-optimal collaboration?

Considering the specific reasons why cooperation has been inefficient, it strikes me that there are good reasons for believing that the collaborative process can be improved. Many complex collaborative aerospace programs, including the Ariane space launch vehicle, Airbus aircraft and Euromissile's antitank missiles, have all benefitted from robust joint venture structures. There is no reason why such institutional arrangements cannot be applied to the combat aircraft sector.[105] Likewise, perverse work share negotiating tactics can be suppressed by introducing a system of contractual penalty clauses akin to those implemented by the Airbus consortium after the failure of the A300 and before the launching of the A300B. In Airbus' case, the obligation to pay damages in the event of reduced or cancelled orders suppressed the tendency to exaggerate orders in order to capture increased work share. Even the problem of divergent military requirements can be mitigated by early consultations between air forces, as occurred during the Eurofighter program with nine years of consultations preceding the elaboration of definitive requirements.[106]

Thus, while European states will continue to find themselves force to collaborate, there is no reason why they must repeat the same sub-optimal schemas that have marked their efforts thus far.

[1] Notable examples are the Milan and HOT anti-tank missiles, and the Cougar and Puma helicopters.

[2] For example, the Franco-German tank of the 1950s, the German-American MBT-70 and the Anglo-German MBT-80.

[3] It is very difficult to examine the success or failure of a defense-industrial project. The true costs of combat aircraft are rarely published, technical capabilities are deliberately misrepresented (either in a positive or negative light) and the profitability of the venture is never reported. The case studies below examine what data are available to determine the success of a project. Relying on expert responses to a questionnaire on economic and technical criteria, Pierre Dussauge and Bernard Garrette rated past collaborative combat aircraft projects as less successful than other forms of aerospace collaboration (helicopters, missiles and civilian aircraft). See Pierre Dussauge and Bernard Garrette, "Determinants of Success in International Strategic Alliances: Evidence from the Global Aerospace Industry," *Journal of International Business Studies*, Vol. 26, No. 3. (3rd Qtr., 1995), 521-24.

[4] Jean-Paul Hébert, *Production d'armement: Mutation du système français* (Paris: La Documention française, 1995), 148-52.

[5] The British government established an independent advisory committee under the leadership of Lord Plowden to study the United Kingdom's aircraft industry. This committee concluded that the United Kingdom should purchase its most complex military aircraft from the United States and develop the rest in cooperation with other European states. PRO T 225/2685 *Committee to Redecide the Aircraft Industry*, 1 February 1966.

[6] *The Military Balance 2008* (London: The International Institute for Strategic Studies, 2008), 101-204.

[7] Jean-Paul Hébert, *Les exportations d'armement: A quel prix* (Paris: La Documention française, 1998), 11-42.

[8] On the techno-nationalist appeal of aircraft, see David Edgerton, *England and the Aeroplane: An Essay on a Militant and Technological Nation* (London: Macmillan, 1991).

[9] To justify his support for the Eurofighter rather than purchasing an American aircraft, British Defense Minister Michael Heseltine argued, "If we follow that route we will end up with all American equipment and that can't be in the legitimate interests of the British and American people. We should end up as the metal bashing end of the Alliance." Warren Chin, *British Weapons Acquisition Policy and the Futility of Reform* (Aldershot: Ashgate, 2004), 163. For information on the importance of combat aircraft development on civil aviation programs, see: Alfred Bodemer and Robert Laugier, *L'ATAR et tous les autres moteurs à reaction français* (Riquewihr, France: J.D. Reber, 1996); Claude Carlier, *Serge Dassault: 50 ans de defies* (Paris: Perrin, 2002); and Susan Willett, Michael Clarke, and Philip Gummett, "The British Push for the Eurofighter 2000," *The Arms Production Dilemma: Contraction and Restraint in the World Combat Aircraft Industry* (Cambridge, Massachusetts: MIT Press, 1994), 155-57.

[10] Chin, 168.

[11] In the recent past, France has ordered 294 Rafales, the United Kingdom 235 Eurofighters, and Germany 180 Eurofighters.

[12] Jean-Paul Hébert, Production d'armement: Mutation du système français (Paris: Documentation Français, 1995), 76-78.

[13] Aircraft prices are notoriously difficult to compare. Contracts vary widely in terms of the electronics included on an aircraft, whether completed aircraft are delivered or kits for assembly, what spare parts are included in the order, whether or not industrial offsets are part of the deal and the margin that the exporting state negotiated with a particular client. Nevertheless, on virtually all lists of aircraft prices, the Mirage 2000 comes out at least a third more expensive than the F-16. A list of published estimates of aircraft flyaway costs in 1991 evaluated the F-16C/D as $18.4 million, while the Mirage 2000 as ranging between $24 million and $27 million. An online database of recent aircraft contracts lists the unit cost of F-16C/Ds sold to nine states as varying between $27.5 million and $37.5 million, while the unit costs of Mirage 2000s sold to four states vary between $40 million and $45 million. See Venik's Aviation, "Military Aircraft Prices," www.aeronautics.ru (last consulted 1 July 2007); and Yolande Simon, *Prospects for the French Fighter Industry in a Post-Cold War Environment: Is the Future More than a Mirage?* (Santa Monica: RAND Dissertation, 1993), 63.

[14] Keith Hartley and Stephen Martin, "The Political Economy of International Collaboration," *Defence Science and Technology: Adjusting to Change* (Chur, Switzerland: Harwood, 1993), 178-79.

[15] At the low end of the spectrum, the Dassault Rafale was developed for 6€ billion. At the high end, the current estimated development cost of the F-35 Lightening II is $60 billion. See "L'impasse Rafale," *La Forêt des Médias* at forestent.free.fr/rafale.html (last consulted February 3, 2009); and James Dunnigan, "F-35 Fading Under Budget Pressure," *Strategy Page*, December 18, 2008 at www.strategypage.com/articles/200812180573.asp (last consulted February 3, 2009).

[16] Olivier Brochet, *Armored Vehicle Industry in Europe: Battle lines drawn ahead of corporate manoeuvres* (A.D. Reference Report, 2006), 37-38.

[17] Although frequently cited in the literature about collaborative armaments projects, there is no theory or systematic analysis of cases underpinning the √n Rule. Rather, it appears to be a common rule of thumb and a heuristic tool.

[18] Hartley and Martin, 189.

[19] For example, take the case of two states collaborating on a project. Using the "√n Rule," a collaborative development project involving two partners should cost 1.4 times as much as a national project. However, because the two states share the costs evenly, the collaborative project will cost each of them only 70% as much as an equivalent national project.

[20] Perhaps the first example (1869) of this form of reasoning can be found in Captain Nemo's *Nautilus*. According to Jules Verne, the submarine's keel was produced by France's Creusot; England's Lairds was responsible for the hull; Penn of London furnished its propeller shaft; the Clydeside firm of Scotts turned out the propeller; and Germany's Krupp built the engine. To readers of Verne's generation, this combination of companies represented the

acme of European design and manufacturing skills. Daniel Todd and Michael Lindberg, *Navies and Shipbuilding Industries: The Strained Symbiosis* (Westport, Connecticut: Praeger, 1996), x-xi.

[21] Henri Deplante, *A la conquête du ciel* (Aix-en-Provence: EDISUD, 1985), 185-90.

[22] Seth Jones, *The Rise of European Security Cooperation* (Cambridge: Cambridge University Press, 2007), 148.

[23] Dussauge and Garrette, 524.

[24] Hébert, *Production d'armement: Mutation du système français*, 131.

[25] Andrew Moravcsik, "Armaments Among Allies: European Weapons Collaboration, 1975-1985," in Peter Evans et al., ed., *Double-Edged Diplomacy: International Bargaining and Domestic Politics* (Berkeley: University of California Press, 1993), 128-67.

[26] Dussauge and Garrette, 505-530.

[27] Jonathan B. Tucker, "Partners and Rivals: A Model of International Collaboration in Advanced Technology," *International Organization*, Vol. 45, No. 1. (Winter, 1991), 83-120.

[28] Mark Lorell and Julia Lowell, *Pros and Cons of International Weapons Procurement Collaboration* (Santa Monica: The RAND Corporation, 1995).

[29] Between 1959 and 1964, the estimated research and development costs of the TSR.2 tripled while its anticipated production cost grew by 60 percent. PRO AVIA 65/1678 TSR-2 Survey, 23 November 1964.

[30] Robert Gardner, 174.

[31] PRO PREM 15/1290 "Extract from meeting Prime Minister/Pompidou," May 22, 1973.

[32] Tony Butler, *British Secret Projects: Jet Fighters Since 1950* (Hinckley, the United Kingdom: Midland, 2000), 178-79.

[33] According to an internal British memorandum, building an aircraft to meet only the British requirement for low-level strike capabilities would cost £1.6 million per plane. Including the French requirement for an interceptor would increase the unitary cost to £1.8 million. A compromise solution fulfilling most of both countries' desiderata entailed an aircraft with an estimated cost of £1.75 apiece. PRO CAB 148/32/35 AFVG Aircraft: Memorandum by the Secretary of State for Defence and the Minister of State for Technology, May 10, 1967.

[34] Perry, 20.

[35] Déplante, 187.

[36] Jean Guisnel, *Les généraux: Enquête sur le pouvoir militaire en France* (Paris: La Découverte, 1990), 214. *Jours de France*, a newspaper owned by Marcel Dassault, also

waxed eloquently about the Mirage G lyrically describing it as "rapid as an arrow, yet capable of landing [gently] as a flower." Jean-Pierre Bechter, Luc Berger and Claude Carlier, *L'épopée Dassault* (Boulogne, France: Timée-Editions, 2006), 49.

[37] PRO CAB 148/32/47 Cabinet-DOP Committee, "The Aircraft Programme," 23 June 1967.

[38] Charles Gardner, 138-39.

[39] British design studies consumed £5 million. Charles Gardner, 116. I assume that France spent a similar amount on purely AFVG research.

[40] The Breguet design, the Br.121, was an adaptation Breguet's design submission, the Taon, for NATO's lightweight fighter competition in the late 1950s. See Andy Evans, *SEPECAT Jaguar* (Ramsbury, United Kingdom: Crowood, 1998), 7-10.

[41] Frédéric Lert, *SEPECAT Jaguar* (Paris: Histoire et Collections, 21006), 9.

[42] Butler, *British Secret Projects: Jet Bombers Since 1949*, 174-75.

[43] Evans, 21-27.

[44] The Jaguar ultimately was equipped with a thin highly-swept wing, mounted high in the aircraft's fuselage. This wing was a direct product of a decade of research. Research was conducted in-house by BAC and at the Royal Aircraft Establishment (RAE), which provided basic scientific advice to both British aircraft manufacturers and the RAF. The RAE developed a formula for predicting how aircraft would respond to gusts of wind at low levels and various speeds. Using this formula, English Electric and Vickers both developed TSR.2 proposals with wings mounted high in the fuselage. PRO AIR 20/10576 *ASR 343 – Historic Diary*.

[45] Evans, 20.

[46] Lert, 11.

[47] The Jaguar was originally anticipated to be a fairly cheap program, costing approximately half as much as the Mirage F1 to develop. Cost growth was produced by a number of factors, including the aircraft's redesign, engine troubles and duplication of design and prototype testing effort. Originally, 120 million francs had been allocated for the Jaguar's development to the prototype stage. Development ultimately cost 864 million francs. A RAND Corporation study indicates that the program suffered a 309 percent increase in development costs, but specific costs are not given. See Andy Evans, *SEPECAT Jaguar* (Ramsbury, the United Kingdom: Crowood, 1998), 20; and Mark Lorell and Julia Lowell, *Pros and Cons of International Weapons Procurement Collaboration* (Santa Monica: Rand Corporation, 1995), 18.

[48] Evans, 20.

[49] Robert Gardner, 217.

[50] Andy Evans, *SEPECAT Jaguar* (Ramsbury, the United Kingdom: Crowood, 1998), 101.

[51] Charles Gardner, 146.

[52] Ibid, 147.

[53] According to General Jean Fleury, the total cost of upgrading France's Jaguar fleet would have been a comparatively modest 1 FF billion. The government would not have opposed the Air Force's demand, but the DGA would have subsequently refused to fund the upgrade. According to Fleury, France deliberately limited the capabilities of its Jaguars, adopting a "poor man's navigation system" and electronics so rudimentary that France initially refused to send Jaguars to the United States for "Red Flag" exercises "so as not to appear ridiculous because of our under-equipped aircraft." See Jean Fleury, *Faire Face: Mémoires d'un chef d'état majeur* (Paris: Jean Picollec, 1997), 129-44.

[54] Oman chose the Jaguar in 1974, while the Indian decision came in 1978. PRO DEFE 11/653 *I.S. McDonald, Director of Sales to Hd/DS13*, January 28 1974; PRO DEFE 11/653 Chiefs of Staff Committee, Defence Policy Staff, *British Military Assistance to Oman*, February 15, 1974; and Robert Gardner, 217.

[55] Egypt originally expressed an interest in Jaguars in 1972; however, the United Kingdom was not willing to sell them at this point, when they would have likely been employed in a future Arab-Israeli War. When Egypt's relations with Israel improved later in the decade, the United Kingdom changed its position on selling Egypt Jaguars. However, France now offered the Mirage 2000, which Egypt purchased, albeit with Saudi financial assistance. Kuwait was unsatisfied with the reliability of the English Electric Lightnings they had purchased in the 1960s and chose the Mirage F1 as a consequence. PRO CAB 148/121 Defence and Oversea Policy Committee, *The Supply of Arms to Egypt*, September 13, 1972; and Evans, 101.

[56] PRO PREM 15/1374 Solly Zuckerman to Prime Minister, *The Multi-Role Combat Aircraft*, July 8, 1970.

[57] In a secret memorandum addressed to the United Kingdom's Prime Minister, the Chief Science Advisor Solly Zuckerman admitted after the fact, "Essentially we moved in on what was originally a German-Italian-Dutch-Canadian [Belgian] plan, and altered it to suit our needs." PRO PREM 15/1374 Solly Zuckerman to Prime Minister, *The Multi-Role Combat Aircraft*, July 8, 1970.

[58] Charles Gardner, 138-39.

[59] PRO PREM 15/1374 Solly Zuckerman to Prime Minister, *The Multi-Role Combat Aircraft*, July 8, 1970.

[60] PRO PREM 15/1374 Solly Zuckerman to Prime Minister, *The Multi-Role Combat Aircraft*, July 8, 1970.

[61] PRO CAB 148/130 Cabinet Defence and Overseas Policy Committee, March 1, 1973.

[62] In July 1970, the British government was still uncertain as to whether Italy would join the MRCA or not. The Italians also, in collaboration with the West Germans, pushed for the aircraft to be equipped with an American radar, which would presumably be more economic than a British radar. PRO PREM 15/1374 Solly Zuckerman to Prime Minister, *The Multi-Role Combat Aircraft*, July 8, 1970.

[63] Lorell and Lowell, 14.

[64] Jon Lake and Mike Crutch, *Tornado Multi-Role Combat Aircraft* (Hickley, the United Kingdom: Midland, 2000), 15-25.

[65] PRO PREM 15/1374 Burke Trend (Cabinet Secretary) to Prime Minister, *The Multi-Role Combat Aircraft (MRCA)*, July 28, 1971.

[66] PRO CAB 148/130 Defence and Oversea Policy Committee, *The Multi-Role Combat Aircraft – Review of Progress*, March 1, 1973.

[67] PRO CAB 148/130 Defence and Oversea Policy Committee, *The Multi-Role Combat Aircraft – Review of Progress*, March 1, 1973.

[68] Jon Lake and Mike Crutch, *Tornado Multi-Role Combat Aircraft* (Hickley, the United Kingdom: Midland, 2000), 13.

[69] House of Commons, Hansard Debates, Mr. Aitken, June 17, 1993; and Yolande Simon, *Prospects for the French Fighter Industry in a Post-Cold War Environment: Is the Future More than a Mirage?* (Santa Monica: RAND Dissertation, 1993), 63.

[70] Because of the complex engineering involved in permitting an aircraft's wing to pivot, variable geometry aircraft were maintenance intensive. In the United States, the variable geometry F-111 and F-14 were amongst the least mechanically reliable American aircraft, being unavailable for combat missions 46.7 percent of the time. Joshua Epstein, *Measuring Military Power: The Soviet Air Threat to Europe* (Princeton: Princeton University, 1984), 28.

[71] Specifically, each Tornado cost twice as much annually to operate as the Jaguar and Tornado squadrons consumed 37 percent more. House of Commons, Commons Written Answers, October 12, 2004; and House of Commons, Commons Written Answers, January 20, 1993.

[72] By mistake, the United Kingdom's National Archives released documents relating to the 1985 Al Yamamah arms deal under a freedom of information act. Although the National Archives later withdrew the documents, a non-profit organization had copied them by that time. The *Guardian* newspaper has published the documents on line, as a complement to an article published by the paper. R.C. Mottram, *Briefing for the Prime Minister's Meeting with Prince Sultan*, September 25, 1985, image.guardian.co.uk/sys-files/Politics/2006/10/25/PJ5_39BriefforThatcherSept85.pdf (last consulted August 2, 2007).

[73] Initially, it was predicted that both the Tornado and Mirage 2000 would cease to be produced in 1990. However, the six years of delays accumulated by the Tornado meant that the aircraft remained in production until 1993 (in its British air defense variant) and was pro-

duced until 1998 to fulfill the Saudi export order. Similarly, the Mirage 2000 production line remained open until 2006 to fulfill export orders. See Lake and Crutch, 139-68.

[74] PRO DEFE 72/52 Ministry of Defence, Defence Equipment Policy Committee, June 9, 1976.

[75] Germain Chambost, *Rafale: La véritable histoire* (Paris: le Cherche Midi, 2007), 67-70.

[76] Warren Chin, *British Weapons Acquisition Policy and the Futility of Reform* (Aldershot: Ashgate, 2004), 162-63.

[77] Alexandra Schwartzbrod, *Dassault: Le Dernier Round* (Paris: Olivier Orban, 1992), 137-41.

[78] The opening negotiating position of the French was to demand that Dassault receive prime contractor status and 46% percent of the research funds allocated to the airframe's development. SNECMA and Rolls Royce would form a joint design bureau to develop the engine. The West Germans rejected the notion that any company should have prime contractor status and demanded industrial relations based on formal parity. The British position was that if prime contractor status was accepted, then Rolls Royce should dominate the engine's development. Ultimately, France was offered a compromise wherein Dassault would receive prime contractor status, but only a share of the development work equivalent to France's participation in the project (33%). Rolls Royce would alone develop the most sensitive parts of the engine. Schwartzbrod; and Jean Guisnel, *Les généraux: Enquête sur le pouvoir militaire en France* (Paris: La Decouverte, 1990), 207-15.

[79] Spain was tempted to either join the French or to proceed with an unsophisticated, but exportable, national aircraft, the AX. If the French could obtain Spain's adherence to the Rafale, they hoped that West Germany could also be lured into a French-led program. The Spanish and French prime ministers met as late as October 1988 about Spain's possible adherence to Rafale. Worried about such an eventuality, Prime Minister Thatcher of the United Kingdom visited Spain in September to encourage Spain's continuation with the Eurofighter. Schwartzbord, 170-71; and Jordi Molas-Gallart, *Military Production and Innovation in Spain* (Harwood, 1992), 131-33.

[80] Chambost, 170-71.

[81] Hugh Harkins, *Eurofighter 2000: Europe's Fighter for the New Millennium* (Earl Stilton, the United Kingdom: Aerofax, 1997), 37.

[82] Molas-Gallart, 127, 134-35.

[83] As with most aspects of aerospace economics, precise figures for cost overruns are difficult to obtain. The Eurofighter's development in the United Kingdom was originally estimated to cost £2.99 billion, but ultimately cost over £5 billion. However, elsewhere a figure of £4.38 billion is cited for the final development cost. This difference may be attributed to the fact that one figure counts prototype testing, while the other counts only R&D. Chin, 170, 223.

[84] Charles Edelstenne, Président de Dassault Aviation, Audition, Commission de la Défense Nationale et des Forces Armées, June 23, 2004.

[85] Counting all four Eurofighter members as equal partners, the "√n Rule" predicts that the Eurofighter should cost twice as much as an equivalent national project. In this context, each partner would pay half as much as they would have had they built the aircraft alone. If Spain is counted as a junior partner and counted for half as much as a full partner, the Eurofighter's development costs should be 1.9 times as much as an equivalent national aircraft. In fact, the development of the French Rafale cost less than one third as much as the Eurofighter. In this context, France's investment in the Rafale's development is actually lower than the United Kingdom's contribution to the Eurofighter's development (6€ billion versus £5 billion).

[86] From the time serious development work began in 1980, the Eurofighter took 22 years to bring into service. Ibid, 162.

[87] Ibid, 166-68.

[88] The Germans refused to authorize further Eurofighter expenditures from 30 June 1992. Ibid, 167-69.

[89] Ibid, 169.

[90] "Background Information," Eurofighter Typhoo www.eurofighter.com/news/article37.asp.

[91] "Sticker Shock: Estimating the Real Cost of Modern Fighter Aircraft," www.defense-aerospace.com/dae/articles/communiqués/FinalJuly06.pdf.

[92] Exaggerated claims are made for all of the aircraft considered. If size is taken as a proxy for capabilities, the Eurofighter is smaller than the F-18E, slightly larger than the Rafale (9,750 kg versus 9,400 kg) and significantly larger than the Gripen (5,400 kg). Compared to the Rafale, the Eurofighter benefits from greater speed, but also possesses a much larger radar cross-section than the Rafale.

[93] The rationale for this statement is the fact that the Jaguar cost nearly twice as much to develop as either the Mirage F1 or Mirage IV, both of which were more sophisticated national aircraft. Evans, 20.

[94] For example, the British contribution to the Eurofighter's development, which accounted for 33% of the aircraft's development costs, was ultimately £5 billion. By way of contrast, the French total expenditure on the Rafale's development was 6€ billion. Charles Edelstenne, Président de Dassault Aviation, Audition, Commission de la Défense Nationale et des Forces Armées, June 23, 2004; and Chin, 170.

[95] "Sticker Shock: Estimating the Real Cost of Modern Fighter Aircraft," www.defense-aerospace.com/dae/articles/communiqués/FinalJuly06.pdf.

[96] House of Commons, Hansard Debates, Mr. Aitken, June 17, 1993; and Yolande Simon, *Prospects for the French Fighter Industry in a Post-Cold War Environment: Is the Future More than a Mirage?* (Santa Monica: RAND Disseration, 1993), 63.

[97] Dussauge and Garrette, 524.

[98] During the 1991 Gulf War, six Tornados were shot down between 16 and 22 January 1991. Considering that overall coalition aircraft losses were comparatively light, only 17 aircraft through 22 January, more RAF Tornados were lost than any other single type of coalition aircraft. Because the RAF Tornado force in the Gulf was small compared to American contingents, Tornado losses were massively disproportionate given the size of units involved. In fact, the Tornado's overall attrition rate was four percent per sortie. Worse still, Tornados proved exceptionally vulnerable to even minor damage and no damaged Tornado succeeded in returning to base. "The Gulf War Campaign Diary," Royal Air Force, www.raf.mod.uk/gulf (last consulted August 1, 2007); and House of Commons, Commons Written Answers, Archie Hamilton, Column 166, March 20, 1991.

[99] So far, the Eurofighter has been sold to two export clients--Saudi Arabia and Austria. In each case, strong political factors influenced the sales. As part of its strategy of using arms purchases as a means of cultivating foreign powers, the Saudis have purchased British (and American) aircraft since the 1960s. The Saudis were one of only two states to purchase the English Electric Lighting and were the only state (besides the consortium members) to purchase the Tornado. The Eurofighter purchase appears to be only the most recent manifestation of this policy. For Austria, considerations of interoperability played a significant role in the Eurofighter purchase. By acquiring the Eurofighter, the Austrian air force obtained a high degree of interoperability with those of its German and Italian neighbors. Moreover, the ability to service the Austrian Eurofighter fleet directly at German facilities in Manching, Bavaria, reduces the life-cycle costs of the aircraft.

[100] Critically examining the inter-sectoral record of collaboration, Hartley and Martin argue that collaborative programs produce savings in development costs on a per nation basis, but probably do not yield cheaper production costs. See Hartley and Martin, 171-203.

[101] The Swedish aircraft industry has not been hitherto discussed in this paper because SAAB has not yet engaged in a collaborative combat aircraft project. Despite the size of the German aircraft industry, Germany has not independently developed a combat aircraft since 1945. In many respects, it appears as though the disorganization attending the decade of post-war (1945-1955) disarmament led to a contraction in German program management capabilities. The aerospace industry was only gradually reinvigorated with co-production (F-104) and collaborative (Alphajet, Airbus, Tornado and Eurofighter) projects. Italy has developed two unsophisticated ground attack aircraft--the Fiat G.91 and AMX--but does not appear capable of producing anything more sophisticated.

[102] In engineering circles, the "hot" part of a jet engine is generally referred to as a "black art." Only three companies--General Electric, Pratt and Whitney and Rolls Royce--are at the cutting edge in this field. Two other entities--France's SNECMA and Russia's Klimov--can also produce credible products. Europe's other engine manufacturers are reduced, by necessity, to working on less complex elements such as compressors, thrust reversers, afterburners, monitoring systems and the fuel injection system.

[103] Interview with Gilles Marcoin, Dassault Aviation, Paris, April 2008.

[104] James Stevenson, *The Pentagon Paradox: The Development of the F-18 Hornet* (Annapolis: Naval Institute Press, 1993); and Robert Perry, *A Dassault Dossier: Aircraft Acquisition in France* (Santa Monica: The RAND Corporation, 1973).

[105] Dussauge and Garrette, 505-530.

[106] The European Independent Sub Group on tactical combat aircraft was formed in 1976, while the Eurofighters definitive requirements were not established until 1985.