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A Dassault Dossier: Aircraft Acquisition in France

Robert Perry

A Report prepared for

UNITED STATES AIR FORCE PROJECT RAND

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PREFACE

This study is concerned with Avions Marcel Dassault-Breguet,[1] generally held to be one of the most efficient aircraft development and production firms in the western world. Its purpose is to examine and evaluate the policies, strategies, operating practices, and external relationships that appear to be responsible for that reputation and for the achievements that underlie it. A principal object of the study is to identify those Dassault attributes that might beneficially be adapted to an American setting and to estimate the feasibility of so doing.

The high regard accorded Dassault aircraft is partly attributable to their widely publicized role in the Six-Day War of 1967. Israel, having only some 70 Mirage III fighters and an indifferent lot of aging aircraft of other types, humiliated antagonists individually far better equipped and collectively possessed of a massive air power advantage. Although quality of flying personnel and brilliance of strategy and tactics clearly influenced events, the Israelis were quite willing to credit the Mirage with giving their fliers a performance margin that made the strategy and tactics feasible. Most students of the Six-Day War have endorsed that judgment.

Entirely apart from the Six-Day War, Dassault has for two decades maintained an enviable reputation arising in qualities other than the combat performance of Mirage fighters. The low cost of aircraft development as conducted by Dassault, the rapidity of that development, and the high quality of Dassault aircraft compared with those of other makers began attracting attention in the 1950s. That reputation had more than academic credentials; by 1970, the air forces of 14 nations had bought Mirages in preference to other available combat aircraft. Price, performance, prompt delivery, and adaptability to a wide range of applications were major attractions. With relatively few exceptions, regional or hemispheric politics, subsidies and credits granted by the United States or the Soviet Union, or some combination of those factors explained most of the occasional choices of competing aircraft.[2]

[1] To distinguish the company from its founder, the term "Dassault," standing alone, refers to the firm and "M. Dassault" refers to the man.

[2] Of "modern fighters (which generally implies supersonic flight capability), only the F-104, the F-5, and the MiG-17 and MiG-19 were exported or built abroad in greater numbers in the 1960s than were the several Mirage fighters. Such aircraft as the Fiat G-92 are not counted in that estimate. Export of the F-4 and the MiG-21 did not begin until quite late in that decade. Insignificant quantities of SAAB J-35 (Draken) and BAC Lightning fighters were exported from Sweden and Great Britain. In some instances the United States was reluctant to sell high performance fighters to developing nations; on other occasions price was a determinant. Such circumstances suggest that Mirage aircraft were almost always preferred to others when neither subsidy nor politics was a factor and when either politics or price made acquisition of the superb F-4 (more adaptable but more costly) infeasible.

Development cost and development style are the central interests of this study. The increasing costs of aircraft in the United States and the various cost-induced problems of the American aerospace industry in the 1970s are enough to make Dassault's practices and their effects of interest to our Air Force and to those parts of the Department of Defense concerned with the cost-quality attributes of aircraft acquisition.

The most important source material used in this study is a file of largely unpublished data collected by the author and by colleagues and associates in Rand, government, industry, and academia. The oldest date from 1958, the most recent from 1971. Most detail individual contacts with Dassault. Some are largely quantitative, others are more concerned with reactions to the Dassault achievement. Probably least significant of the source materials used here are items that have appeared in print from time to time.

Such sources are rarely in complete agreement. A persuasive explanation for the contradictions was casually provided by Dassault management in 1967. When asked which of two sets of manpower figures, one from American sources and one from British, was more nearly correct, a Dassault spokesman provided a third set of figures that straddled the two originals and explained that most visitors were unwilling to believe how few engineers the company invested in aircraft development. So in answering questions from the British, for instance, Dassault accommodatingly inflated its manpower costs. In dealing with Americans, who may be less ready to discount remarkable achievement, Dassault may have deflated the real numbers.

A second and more supportable explanation is that Dassault will not disclose information that may compromise the firm's competitive position in the world market. And because of close ties with the French Ministry of Aviation and a special relationship with the French government, Dassault is very discreet in discussing military programs. Finally, it seems likely that interpreters of the Dassault legend ask questions that will elicit answers to confirm their own options.

The cynic may conclude that most of what is said about Dassault combines distortion, folklore, misinformation, wishful thinking, prejudice, preconception, and deliberate misdirection—all overlaid on scant fact. This study attempts to determine what propositions are probably correct and to avoid perpetuating fantasy. The usual criteria of source respectability, internal evidence, general credibility, and the existence of confirming data have been brought to bear. Whether the attempt has succeeded is a question that probably only M. Dassault can answer with assurance.

This report should be of use to various Air Force and other agencies engaged in R&D and acquisitions processes and decisionmaking; particularly DCS/Research and Development, DCS/Systems and Logistics, and ACS/Intelligence in Hq. USAF, the Air Force Systems Command, the Air Force Logistics Command, and the Directorate of Defense Research and Engineering.

SUMMARY

Avions Marcel Dassault-Breguet Aviation is, in American terms, a very small company. Dassault is not even the largest French aircraft firm, merely the biggest privately owned aircraft company in a nation with a largely nationalized aircraft industry, severely limited defense budgets, and an R&D base incomparably smaller than that of the United States. Yet in the last two decades, Dassault has provided nearly the entire combat aircraft complement of the French Air Force and, if one discounts aircraft purchased by the United States government for delivery abroad and those delivered to the allies of the Soviet Union, has exported more high performance aircraft to more nations than any other builder, and at prices that are generally lower than the competition can match. In many respects those aircraft have been as capable in performance as any in the world, possibly excepting some much more expensive American and Russian models. Since the early 1950s, Dassault has built more than 20 basic variants of the Mirage fighter plus engineering or operational prototypes of variable-sweep and vertical takeoff models.

The company's ability to compete successfully with the aircraft industries of Europe and America arises in a combination of circumstances, most of them consciously created by Dassault with the full backing of the French government. The company differs from most of its western contemporaries in emphasizing development rather than production; in employment and personnel practices that are uniquely European; in commitment to a prototype development strategy; and in a preference for gradual, incremental, and evolutionary design growth rather than the aircraft development patterns more generally favored elsewhere in the western world. That Dassault is consistently able to create and produce high performance aircraft comparable to and competitive with those of the Soviet Union and the United States is almost paradoxical, given the resources of the company and the international environment in which it operates.

The French aeronautical weapons acquisitions process seems to function on the assumption that good weapons will appear at a reasonable cost if the military do not unduly detail requirements and if design, development, and program management proceed without overmuch interference by government monitors.

Dassault's fundamental development policy is to minimize the extent of technical risk that is incurred at any single point in time. A given aircraft design, although it may appear to be novel, usually incorporates no more than one or two unique major design features. The company is almost totally committed to reliance on prototypes for design verification and for validating "new" elements of structure,

aerodynamics, propulsion, and the like. Almost all prototypes are derived in large part from predecessor aircraft. With few exceptions, Dassault aircraft are built around an available and thoroughly tested propulsion system, although some prototypes may be flown initially with an engine different from that intended for the production article. A new engine or an improved version of an existing power plant may eventually be substituted for that used in early prototype testing. A single prototype may use three or four sequentially improved engines during its flight test life, but the production aircraft rarely, if ever, incorporates a "new model" engine that has not been extensively flight tested in a prototype of the production airframe. Further, before being adopted, the new or modified engine is invariably validated in a flight test aircraft comparable to the intended production version.

This study examines the characteristics of the organization, of its owner and founder, and of its products. The goal of that examination is to provide improved understanding of the apparent paradox. The special qualities of the Dassault organization appear to be attributable to skillfully chosen company policies, astute and adroit management, the personal influence of M. Dassault, and a set of engineering policies that reconcile low risk technology and design simplicity with high performance. But such qualities are not so singular, or so dependent on some irreproducible setting in which the company operates, that they cannot be applied elsewhere. It seems feasible to adopt several of the basic Dassault policies in the development of aircraft in the United States, with potentially great advantages in cost and with long-term benefits for stability of the aircraft industry in the United States. Such adoption would undoubtedly cause major changes in the structures of the American aerospace complex, government and civil.

The author wishes to acknowledge the assistance provided by several Rand colleagues, particularly Giles K. Smith and George R. Hall, who were sometime participants in research on Dassault; and Arthur J. Alexander, who, with Messers. Smith and Hall, contributed both insight and substance. E. Brunner made substantial contributions through comments on early drafts. Unpublished manuscripts, notes, and documents earlier compiled or collected by T. F. Cartaino, R.M. Smith, William Meckling, Burton Klein, and Thomas K. Glennan, all formerly of the Rand staff, and by the late R. L. Johnson, were extensively used for this study. Among many non-Rand contributors of data and viewpoints were Marvin Cetron (formerly of Stanford Research Institute), Albert Shapero (University of Texas), J. Ronald Fox (Harvard University), and Lester Fettig (on the staff of the Senate Committee on Aeronautical and Space Sciences). None is, of course, in any way responsible for the present interpretation. Their interest in the topic, and their knowledge of it, were central to this study, but such faults as it may still exhibit are solely the responsibility of the author.

CONTENTS

I. DASSAULT: THE MAN AND THE COMPANY

Perhaps more than any other aircraft firm in the western world, Avions Marcel Dassault[1] is an extension of the personality of its founder and owner. His senior employees describe M. Marcel Dassault, now 80 years old, as an exceptionally talented aircraft designer with unique executive abilities and a very forceful personality. Dassault is reputed to be France's richest man; his interests extend not only to aircraft but also to electronics, publishing, and real estate. He has been designing aircraft since World War I and still looks on the process as more art than science, frequently citing the precept that an aircraft pleasing to the eye generally flies well.

As Marcel Bloch,[2] M. Dassault was responsible for one of the few good fighters in the French inventory, the MB.150/152, which—with the Dewoitine D.520—provided the only French competition for German fighters in May and June of 1940.

An aircraft company M. Dassault established in 1930 was nationalized under the Popular Front in the mid-1930s; its 1938 successor met the same fate under the government of postwar France. That does much to explain both M. Dassault's political views and his unique outlook on company growth. M. Dassault has refused to create a production capacity that would represent a competitive threat to the nationalized elements of the French aircraft industry, and he has diversified only modestly into other than aircraft work.[3] Keeping the company small and minimizing its production dependence (by subcontracting the bulk of manufacturing work to other French aircraft companies) are generally acknowledged to reflect M. Dassault's personal preferences. In 1971 the company was capitalized at $61 million, had a cash flow of $310 million—two-thirds arising from export sales—and a 1970 order backlog in excess of $610 million.

After spending the late years of the war in a German concentration camp, and after nationalization of most of his prewar facilities, M. Dassault reentered the aircraft field in 1946, won a few small contracts, and subsequently developed the subsonic Ouragon and Mystère. Both became standard fighters of the French Air Force. Small numbers were exported. The Étendard, a Navy fighter, followed, to be succeeded by the Mirage.

M. Dassault has continually avoided involvement and opposed French participation in multi-national aircraft programs, and not solely because he had Dassault-

[1] More precisely, Avions Marcel Dassault-Breguet Aviation, but for the purpose of this discussion identified by its traditional name.

[2] He changed his name in 1946 as tribute to a friend who had died in a German concentration camp.

[3] The Dassault family of firms has developed small missiles and various aircraft subsystems, however.

developed alternatives to offer, although that sometimes has been the case. That M. Dassault had his own variable-geometry fighter in development by 1965 (the Mirage G-4) may partly explain his lack of enthusiasm for the Anglo-French variable-geometry fighter of the late 1960s, but it does not explain his disapproval of the Concorde (SST) program or his reluctance to participate in the MRCA[4] program. After Dassault bought a controlling interest in Breguet in 1967, the new Dassault-Breguet combination inherited responsibility for the Jaguar program,[5] originally a Breguet-British Aircraft Corporation joint enterprise. Even though Dassault can offer a two-place version of the Mirage 5 that is directly competitive with the Jaguar, there has been no indication that the French government is willing to accept the political consequences of canceling yet another Anglo-French project, despite the seemingly lower purchase costs of the Mirage.

At least until 1971, M. Dassault still controlled the details of company operations. Through the week he was in regular telephone contact with his senior managers, and they usually spent Saturday afternoons discussing company affairs with him. He personally made the final decisions on substantial expenditures of company funds, reviewed all major technical problems, and in some cases imposed his own solutions. He personally decided to proceed with production of the Falcon 20 executive transport (earlier called the Mystère 20) against the advice of his principal engineers and his market research staff. Further, he insisted that the production version have a longer fuselage (providing greater fuel capacity) than the prototype, an option that his engineering staff had explicitly rejected earlier. Although M. Henri Deplante was the principal designer of all Mirage series aircraft, M. Dassault had such a direct and continuing role in that process that his staff refers to the various Mirage models as "designed by M. Dassault."

His age may to some extent be limiting his direct participation in the details of Dassault engineering and management, but M. Dassault still controls corporate policy. He is notoriously contemptuous of most "modern management methods" and market assessment techniques. Although most Dassault profits come from aircraft exports, M. Dassault insists that none of his military aircraft designs has ever been conceived with an export market in mind.

By M. Dassault's account, his company can develop aircraft for about one-sixth of the American cost for comparable products.[6] He explains that phenomenon largely in terms of his reliance on generalist but highly skilled engineers; each of Dassault's senior engineers is reputedly capable of designing a complete aircraft; most of them routinely design such major aircraft subassemblies as empennages or wings.

That the only privately held aircraft firm of any importance in France is totally controlled by a skilled engineer and designer explains a good deal about the character and practices of the company. Each year, Avions Marcel Dassault hires most of the honor graduates of the three best technical universities in France *(les grandes écoles)*.[7] Marcel Dassault himself interviews many of the candidates, decides whom

[4] MRCA: Multi-Role-Combat-Aircraft, an enterprise involving, at one time or another, German, Dutch, Belgian, and Italian interests and aimed at the production of a general purpose, multi-national fighter. Dassault holds that the highly detailed requirements and specifications for multi-national aircraft drive costs upward and that the design compromises needed to satisfy multi-national requirements tend to make the production unattractive to subsequent buyers.

[5] The Jaguar is a multi-purpose fighter-trainer with close air support capability—not unlike the Northrop F-5, but a decade younger.

[6] And about one-third those of other French aircraft companies.

[7] The École Polytechnique, the Instituts Nationaux de Sciences Appliquées, and the Ecole National Supérieure d'Ingénieurs.

to hire, and selects an initial assignment for each novice. The prestige of the Dassault organization may be judged from the fact that 35 or 40 of the most sought-after new engineering graduates in France annually agree to work for two years as draftsmen and very junior members of rather small Dassault design teams. But if they survive the probationary period, they may expect eventual promotions to project team leadership or to department management posts. And thereafter they are very well paid, even by American standards.

Graduates of the lesser French technical schools who join Dassault generally are neither expected nor expect to become project heads; *les petites écoles* graduates apparently accept with equanimity the prospect of careers that will not lead to the higher echelons of the Dassault organization. But they too are generally better paid than their counterparts elsewhere in France.

By either American or British standards, Avions Marcel Dassault is almost compulsively committed to simplicity and austerity in facilities, organization, and staffing but with a countervailing emphasis on modernity. In striking contrast to many British and many American plants, the Dassault design, development, and production facilities at St. Cloud and Merignac are bright, clean, and new—if Spartan in their fittings.[8] Few buildings antedate 1946, and probably half are less than 15 years old. The only large Dassault facility of prewar vintage is a factory at Talance. The offices at Vaucresson, which house Dassault's senior executives and most of the corporate administrative staff, are in a relatively small villa distant by some 10 kilometers from the large development and assembly facilities at St. Cloud. The apparently inefficient separation of facilities is explained, quite seriously, as a device to keep "administrators" from dabbling in technical routine.

The entire Vaucresson complex, one large building and four smaller buildings, relies on the services of one male receptionist who also acts as a guard, mail clerk, information center, telephone operator, and company driver. Only one company-owned car was assigned to visitor service at Vaucresson in 1967 and that was a well-used two-year-old Citroen carryall, the least expensive four-passenger station wagon made in France. (It also serves for package delivery.) The only installation at St. Cloud that might be considered uncharacteristically American is an elevator that runs between the ground floor and the first floor and is equipped with an emergency telephone. According to local folklore, it is the sole company concession to M. Dassault's advancing years.

If a reluctance to invest in elaborate facilities says something about the work ethic that dominates Dassault's executive and management echelons, a reliance on sparse amounts of complex, high-precision, very adaptable fabrication machinery and test equipment is also significant. Ultra-modern machine tools are scant by American standards, but at least one or two examples of almost every variety of fabricating machine to be seen in American plants can be found in Dassault shops, and they have more of such equipment than do larger British plants. The Dassault assembly shops also appear to have lower densities of people than do comparable British or American facilities.[9] Drafting rooms are small, holding 12 or 14 tables,

[8] The third-ranking man in the Dassault organization occupies a 12 × 20 foot office that holds some folding chairs, two file cabinets, a couple of bookcases, and a minimum of plain wooden office furniture. He has one secretary who functions exclusively as a secretary; her office can be entered only through his office, so there is no way for her to serve as a receptionist, waitress, or errand girl.

[9] Dassault managers suggest that Northrop was the American firm closest to Dassault in operating philosophy and plant.

and very simply furnished, but the lighting and acoustics are excellent, the quality of the equipment is high, and the layout of the design rooms is certainly up to American standards.

British aircraft plants today expect to get roughly six and one-half hours of reasonably productive work in an eight-hour work day; many American factories base their production estimates on equivalent seven and one-half hour days; Dassault plant managers insist that they get eight hours work for eight hours pay, that workers do not start late, quit early, or take compensated work breaks. Managers and senior staff routinely put in 45- or 50-hour work weeks.

Unlike British or American firms concerned primarily with jet aircraft, Avions Marcel Dassault concentrates its efforts on design and development and deliberately avoids the production emphasis that is dominant elsewhere. That policy has sometimes been attributed to the acquired prudence of the twice-burned proprietor of the only large private aircraft company in a nation with a largely nationalized aircraft industry. That the French government supports its nationalized industry to the extent of actually withholding orders from Dassault in order to distribute workload is beyond doubt. And Dassault, anxious to avoid any risk of being nationalized, does not want to disturb a satisfactory *status quo*. But there is more. As an operating maxim, Dassault concedes the inherently spasmodic character of aircraft production work and the relative constancy of demand for improved design and for technically advanced aircraft—if they do *not* cost too much. The capacity of the French Air Force to acquire quantities of new aircraft is limited by many factors, not the least being a tight budget.[10] Yet the appetite of the French Air Force for the most advanced aeronautical items it can obtain within its constrained budget seems insatiable, and Dassault's capacity to create interesting but low cost options that *may* lead to production programs seems unlimited. *But whereas most American aircraft companies seem to look on development as an unavoidable and not particularly attractive prelude to production, Dassault seems to view production as a buffer work assignment to fill capacity not absorbed by development.*

The role of production in Dassault operations illustrates a striking difference in viewpoint between that firm and the large aerospace companies in the United States. The Falcon 20 and Mirage III, the former an executive jet and the latter a lightweight fighter available in several variants, are Dassault airplanes even though Dassault manufactures less then 50 percent of the airframe of each (by weight). The manned bomber element of the *force de frappe*, the Mystère IV, is a Dassault aircraft although Dassault manufactures only 18 percent of the airframe and 25 percent of the finished aircraft. In all cases, of course, Dassault has reserved the tasks of assembly and of acceptance testing.[11] Apart from airframes, through Electronique Marcel Dassault (EMD), Dassault is also responsible for the design and manufacture of the hydraulic-electronic controls with which all Dassault and most other high performance French aircraft are equipped. When nobody else in France could successfully build advanced flight control systems, Dassault took on the task in preference to buying such control systems abroad. (EMD also designed and built the airborne computer for the Mirage IV bomber.)

[10] Sometimes the reality is overlooked: For a decade and more, France has invested in the development and production of its own medium range land-based *and* submarine-launched missiles, and its own nuclear weapons, in addition to modernizing its aircraft inventory.

[11] Large American aircraft, particularly transports, are sometimes built in the same way. But that is rarely true of trainers, fighters, executive jets, and the like.

Ordinarily, Dassault does not subcontract aircraft design work, although in the case of the Falcon-20 the detailed design of the wing was done by Sud-Aviation under the general supervision of Dassault engineers. Some part of the detailed designs of the Mirage IV and III-V (vertical takeoff fighter) were also assigned to Sud, Dassault's principal production subcontractor, but in the normal state of affairs subcontractors are responsible only for production and for tool design.[12]

Apart from the executive office complex at Vaucresson and the site where most of the activities of Electronique Marcel Dassault are carried out (near Paris), Dassault owns eight separate plants or test stations and has the use of four airfield complexes, three of them immediately adjacent to production or test facilities. The principal sites are St. Cloud, which is chiefly concerned with the design and fabrication of military prototypes; Meleun-Villaroche, where the flight test and modification of pre-production aircraft are performed; and Merignac, which is responsible for the design, development, and production of civil aircraft and for the final assembly and acceptance testing of production versions of military aircraft. Of the three, only Merignac is predominantly devoted to production. Argenteuil and Boulogne, on the outskirts of Paris, are smaller production facilities. Cazaux and Talance, which like Merignac are near Bordeaux, have production capability but specialize in prooftesting subsections or components. Istres is a flight-test airfield, lacking either development or production facilities. Argonnex does some production of components and minor subsystems, but it also has some testing responsibilities.

Altogether these facilities employ 8,600 people, of whom about 2,300 are concentrated in St. Cloud. Another 2,300 people are employed in the facility at Merignac. More than half of the Dassault work force is occupied in aircraft or subsystem development, the rest in production, assembly, and acceptance testing.[13]

The national role of the Dassault organization is suggested by the fact that 32,000 people, or about one-third of the total manpower of the French aircraft industry in the mid-1960s, were engaged in the Mirage III project, although only about 5,000 in that total were Dassault employees. Sud-Aviation, near Toulouse, which employs a total of 23,000 people, traditionally supplies the bulk of the manufacturing capacity that Avions Marcel Dassault neither possesses nor envies.

Of the 2,300 people at St. Cloud, about 1,000 are occupied with the design and test of prototype combat aircraft and subsystems for them. The 700 skilled craftsmen at St. Cloud fabricate and assemble prototypes and build specialized components, principally control systems.

Another 800 employees represent, with the executive contingent at Vaucresson, the total administrative personnel employed by the company. Dassault counts as administrative personnel all those concerned with such diverse functions as parts procurement, stock maintenance, general supply, and contract negotiation. Like most of the skilled laborers, many of the administrative people have been with M. Dassault at least 10 years and some since before World War II.

About 150 of the Dassault employees at Merignac are engineers or draftsmen assigned to the design office. The remainder are primarily assembly line personnel,

[12] Dassault engineers usually provide finished production drawings and the eventual manufacturer does his own tooling design. That policy has been applied to licensed production of the Mirage by Australia, South Africa, and Switzerland as well as to French subcontractors.

[13] Including Breguet, which Dassault took over in 1968, the total 1971 work force of about 12,500 occupied facilities that included 5.2 million square feet of "factory" space. The number and responsibilities summarized on these pages are representative of 1970-1971 arrangements.

and of these most are concerned with final assembly and production testing functions. The prototype shop at Merignac, which is only peripherally involved in the production activities of that facility, employs about 150 skilled workers. Because the Merignac establishment has engineering responsibility only for civil aircraft and light military transports, the prototype workload sometimes is light. During those periods the prototype specialists turn their hands to the completion of "one-off" aircraft (for example, a special soft-field Falcon-20 built to the order of the Royal Australian Air Force), do custom modifications, and fit unique equipment to special-order Falcon-20 aircraft.

St. Cloud employs about 400 graduate engineers and 600 draftsmen. Between 150 and 200 of the engineers at St. Cloud, the graduates of *les grandes écoles,* are either current or potential project heads or department heads.[14] When they join the Dassault organization, those engineers are not specialists. Instead, they have what is generally represented to be a superior general education in the aeronautical sciences. Dassault does not consider specialist engineers from the lesser technical schools of France to be attractive employment prospects. Of the 500 people concerned with prototype design and development at St. Cloud, 350 are graduates of the engineering schools, and the rest are draftsmen. About half of the engineers are graduates of the lesser schools. Although 60 percent of a design group consists nominally of "draftsmen," in many cases the title is misleading because the assigned individuals do more than routine blueprint work. They function much as do junior engineers in the United States, and in the main they appear to have educations comparable to those offered at the Bachelor of Science level by the better American universities.

The Dassault design-development organization has a matrix structure, small vertical-element project teams being superimposed on relatively stable department groups. Project personnel tend to move from project to project as work emphasis shifts; department personnel have less transient assignments. Prototype design specialists are not usually associated with production engineering, although that may be partly because almost all production changes are first tested in prototype aircraft. Production engineering, as a separate function, is a rarity in the Dassault organization; engineers are expected to design "producibility" and such into aircraft as a matter of course. Apart from such features, the Dassault organization is distinguished from its technical counterparts elsewhere in the world chiefly by a uniquely high ratio of product output to resource input.

[14] Obviously, both project groups and departments are much smaller than their American counterparts.

II. DESIGN APPROACH

Dassault's fundamental development policy is to minimize the extent of technical risk that is incurred at any single point in time. A given aircraft design, although it may appear to be novel, usually incorporates no more than one or two unique major design features. The company is almost totally committed to reliance on prototypes for design verification and for validating "new" elements of structure, aerodynamics, propulsion, and the like. Almost all prototypes are derived in large part from predecessor aircraft. With few exceptions, Dassault aircraft are built around an available and thoroughly tested propulsion system, although some prototypes may be flown initially with an engine different from that intended for the production article. A new engine or an improved version of an existing power plant may eventually be substituted for that used in early prototype testing. A single prototype may use three or four sequentially improved engines during its flight test life, but the production aircraft rarely, if ever, incorporates a "new model" engine that has not been extensively flight tested in a prototype of the production airframe. Further, before being adopted, the new or modified engine is invariably validated in a flight test aircraft comparable to the intended production version.

Much the same approach characterizes progress of new avionics, aerodynamics, structure, or entire airframes. An airframe may be scaled up or down without departing substantially from the basic layout of its progenitor, as illustrated by the derivation of the Mirage IV from the much smaller Mirage III and the transition from the Mirage F-2 to the smaller F-1.

Major design changes are made incrementally and in isolation. The progression from the well-tried Mirage III-E to the Mirage F-1 involved the substitution of a sharply swept, long-chord wing and a low horizontal stabilizer for the delta wing used on all the Mirage aircraft of the 1950s and early 1960s. Fuselage and cockpit design changed very slightly. The Mirage III-V prototype was created by imbedding lift engines in an existing airframe and making such other adaptations as were absolutely essential in order to test the vertical-rise concept. The variable-sweep Mirage G prototype used an airframe originally built to confirm Mirage F-2 design features, incorporating as new elements only a sweep mechanism, a suitably modified wing, and essential structural changes imposed by these features. The final step in the progression from the conceptual to the "operational prototype" variable-sweep Mirage G-8 involved substituting two smaller engines for the single more powerful engine used in concept demonstration. Most other design details were held constant.

The Dassault design philosophy is to concentrate effort, in any time segment, on a few design parameters or on integrating a small set of new design features into an existing design. A strikingly new design is rare. When one does appear, it tends to be very conservative, embodying few items of radically new technology, and wherever possible it incorporates thoroughly proven subsystem elements (engines, landing gear, avionics, and the like).

The design is entrusted to small teams of highly skilled designers accustomed to working together. Once a decision to proceed with a given aircraft project has been made, the preliminary design staff is promptly expanded to the maximum size requried for the period of prototype design. In the typical case of the Mirage IV, the design staff grew from an initial total of 20 to a maximum of 83 over a period of 11 months. It remained roughly at that level for almost one year, then dropped to near zero in four months. The design of the Mirage III-V was begun by a team of about five engineers in the fall of 1960. When detailed design was started the following year, the engineering-draftsman work force increased to 25 or 30, supported by 30 people from Sud. (Dassault executives felt that Sud's staff was about two-thirds larger than necessary.) In the 10 months before first flight, while prototype fabrication proceeded, the Dassault engineer-draftsman work force decreased to about 10; the Sud staff remained at its earlier manning level.

For the Balzac vertical-rise fighter prototype, fewer than 30 engineers and draftsmen were employed during the first 11 months of the program, 10 in the next nine months (which included the early flight test period), and only five for the concluding five months of the original flight test program. Approximately 30 additional engineers were employed by Sud-Aviation on details of fuselage design over this period of roughly two years.

In the case of the Mirage IV, four subgroups of engineers were charged with discrete parts of the total aircraft design and another subgroup with the armament system. Fuselage, wing and tail, drag, and "general aerodynamics" were separate design subprojects. The original Mirage IV prototype, intended to demonstrate flight attributes, was followed by three system (pre-production) prototypes. With no appreciable increase in the numbers of engineers and draftsmen assigned to the project, Dassault began to design the Mirage IVA production aircraft almost immediately after pre-production prototype design was completed. The main differences between the production aircraft and its four prototype predecessors appears to have been in details of fuselage, wing and tail, and in aircraft equipment.[1] Structural redesign of parts of the fuselage accounted for nearly 80 percent of the final configuration design cost. Throughout the whole period, there was a rapid and steady backflow of information from the prototype flight test program to the design of the production aircraft.[2]

In essence, such an approach embodies an attempt to minimize the investment in new—and hence uncertain—system elements. The airframe and engine-airframe interface tend to receive the largest share of design effort. However, in the case of the Mirage IV, one critical subsystem (the armament subsystem) absorbed roughly

[1] Between prototype and production, the fuselage size and structural weight of the Mirage IV grew by about 20 percent in consequence of early uncertainty about the size and weight of the nuclear weapon to be carried.

[2] Of all Dassault aircraft developed since 1948, the Mirage IV represents the nearest approach to "concurrency."

as many design hours and manhours as did structures and aerodynamics. System integration problems are "solved" by requiring demonstration of satisfactory subsystem performance and interface functioning before the specification requiring a given subsystem is approved. Propulsion and electronics subsystems and interfaces with other parts of the complete aircraft are customarily tested in specialized flight vehicles after the usual tests in ground rigs.

Although such a technique has been called a low-risk approach to aircraft acquisition that excludes high-technology elements, it may more accurately be described as a process of identifying high-risk technology areas as early as possible and thereafter concentrating attention on them. Final design of the hydraulic, electrical, and fuel subsystems, for example, is put off until the main features of the airframe design have been settled. The probability of having to do a complete redesign of major aircraft subsystems because of late changes in the airframe or the structure is thus substantially reduced.

Aircraft development contracts between Dassault and the government are commonly of the fixed-price incentive type. Contract target prices are initially established by various methods, but the total contract usually includes agreements covering relatively compact subphases of effort for which both specific objectives and probable costs can be identified with considerable accuracy.

Dassault uses both "built-up"[3] and parametric cost estimating techniques for preliminary planning and forecasting,[4] relying heavily on experience factors drawn from 25 years of experience during which the company has built 24 military aircraft prototypes (not including pre-production or service test prototypes). That alone serves to explain much of the apparent precision of Dassault's cost estimating, which the company maintains is normally no more than 10 percent in error. Normal error for recent U.S. programs is 40 to 80 percent. The other contributors to such uncharacteristic accuracy in anticipating actual costs probably are summed up in Dassault's avoidance of tasks that embody substantial technical risk. The estimates generally cover small increments of technical advance, and Dassault's fund of information on the costs of designing, constructing, and testing hardware that embodies such increments probably is better than any other similar data stockpile in the western world.

It is theoretically possible for Dassault to be liable for a nonperformance penalty of as much as six percent of the gross contract price in a given program.[5] The company maintains that it has not lost money on any program of the past 15 years. Critics have suggested that the conservatism of Dassault's design and development process precludes losses. But there is an apparent paradox in that such risk aversion does not end in performance-inferior aircraft, as one would expect to happen eventually. Other explanations may be better candidates.

For those phases of the design process in which neither cost nor time factors can be confidently defined, a maximum or target price is stipulated without incentive

[3] "Built-up" estimates are system estimates composed by summing up the estimated costs of subsystems, functional tasks, and purchased elements.

[4] Dassault includes in its preferred parametric cost estimating model a density factor (which includes provision for components), a factor for the number of machined parts, and a technical advance factor. Dassault project managers were fully conversant with the parametric cost estimating techniques developed by Rand and other U.S. organizations.

[5] The Balzac (Mirage III-V prototype) contract had a six percent bonus, six percent penalty range. It seems to be typical.

clauses. Such contracts cover only brief periods of time, eliminating the potential for large overruns. Contracts covering both flight test and ground test, for instance, are often written for successive month-long increments; they are basically time-and-materials contracts. Incentive contract clauses emphasize one or two principal objectives rather than a set of specifications covering a broad range of excellence. Thus one performance parameter, or a set of key delivery dates, may be specified and other "milestones" ignored. General excellence is expected, but so are rational tradeoff decisions.

Certain high level Dassault engineering personnel are motivated toward superior performance by substantial bonus payments. "Superior performance" seems to mean satisfying company-established objectives, although those objectives obviously are related to the goals specified in contracts with customers.

For the Balzac vertical-rise fighter prototype, three contracts were signed in February 1961 covering the entire period of development and prototype construction. The first provided $1,070,000 for study costs and the second $4,300,000 to cover prototype design and fabrication.[6] Of this total $1,010,000 was allocated to aircraft construction. The third contract, covering flight test phases, stipulated a maximum cost but provided that the flight test program would be proposed, approved, and paid for on a month-to-month basis. The total cost of the Balzac program through 1965, including all preliminary studies, research and design, fabrication and construction of a prototype, purchased subsystems, and a test experience extending through 14 months and 124 flights, came to somewhat less than $6 million, of which about $2 million went to engines. The program as a whole experienced an overrun, but it was incurred by the Sud-Aviation group rather than by Dassault.

Dassault's stated goal is to create the best obtainable composite of ability and low costs; the chief mechanism is design simplicity. Engineers strive for the simplest design that will satisfy contract objectives. Minimizing both immediate costs and the probability of high incurred costs at some later date is almost a fetish. Design for the sake of design elegance is severely discouraged; there is a pronounced emphasis on using off-the-shelf subsystems and components. Such simplistic maxims underlie all design engineering everywhere in the world; for Dassault designers, they are commandments to be obeyed unquestioningly.

In the design, construction, and test of prototypes, much the same philosophy is followed. The early Mirage I prototype was chiefly intended to provide comprehensive information on the flight characteristics of a small, light, delta-wing fighter aircraft. In the case of the Balzac, an existing airframe was modified only to the extent necessary to accommodate unique features and equipment that permitted instrumented demonstrations of vertical takeoff and landing.

It is the practice of the French Air Force to put test aircraft, including prototypes, into an operational environment as soon as possible after a flight program has begun. Extensive data on aircraft or engine performance are not collected merely because such data are assumed to be inherently desirable. The elaborate exploration of aircraft or engine characteristics typical of American testing does not occur in normal French experience. The dominating objective of early testing is to detect, identify, and correct problems that would be of consequence to an operational aircraft. The policy contracting for flight test in monthly increments certainly contrib-

[6] All costs are stated in current dollars unless otherwise specified.

utes to that approach. The correction of individual deficiencies is the subject of separate negotiations when the time comes to resolve the terms of flight test contracts. As in the case of the basic development program, failure to satisfy cost and time objectives can make the contractor liable for significant penalties.

One Dassault device for holding down the number of changes to production aircraft is to remove most engineers from the project staff once the production design period has closed. Engineers remaining with the development program may not make changes thereafter unless excellent reasons occur for each, while the draftsmen who make up the bulk of the staff have neither the inclination nor the ability to modify the accepted configuration. Changes that occur after a production design has been established, or during its inception, generally stem from extended flight test experience with the prototype aircraft. The Mirage IV program provides an example of that policy. At the time the first operational aircraft was delivered in January 1964, only 20 Dassault engineers and draftsmen were still assigned to the program, and during the next six months program manning dropped to about 15 engineers.

Modifications to aircraft design after production has begun are ordinarily funded on a fixed-price basis. In one period of two years, 120 such changes affected the Mirage III program. They ranged from the substitution of improved components to a basic change in manufacturing process—the introduction of chemical milling. Most, however, were of slight consequence.

Dassault draftsmen and non-management engineering personnel generally earn less than their equivalents in the United States.[7] Top management personnel often earn as much as their American counterparts, partly through bonus accounts. Also, because of the tax structure in France, a Dassault project engineer may pay as little as $7,000 in taxes on a gross income of $50,000. Middle and top management personnel also have full time use of company-owned, company-maintained automobiles. An engineer in the top three percent of the Dassault staff will have a base salary rather below that of his American equivalent. But if he has made a substantial contribution to the profits of the company in a given year, his base salary reportedly may be increased by a factor of 1.5 to 3.0. If that is true, the large potential bonus is an obvious incentive to competent and efficient management. Its effect on minimizing systems development cost may be readily appreciated. Knowledge that only by minimizing costs and increasing reliability can an individual expect to acquire a substantial year-end bonus would restrain the drive toward technical complexity and inhibit the construction of engineering empires.[8]

Dassault's engineering costs (direct plus overhead) for a specific development program are normally between 35 and 45 percent of those incurred by American companies working on comparable programs.[9] However, it appears that a policy of risk aversion, the presence of effective incentives, and a general distaste for major program changes have a great deal more to do with the low cost of development at Dassault than any basic advantage in direct or overhead engineering labor costs.

[7] In 1965, a Dassault draftsman received from $170 to $740 a month, and a Dassault engineer from $360 to $980 a month, depending on experience and performance.

[8] Several competent observers have reported—and favorably commented on—Dassault's bonus practices. I was unable to confirm them; the Dassault people to whom I addressed questions shrugged off the issue as not important and the reports as greatly exaggerated.

[9] In 1965, an engineering hour at Dassault, including overhead, cost from $4.50 (for production engineering) to $6.00 (for prototype engineering). Overhead contribution is uncertain, but direct charges were at least $3.00 an hour, and for senior engineers exceeded $5.85.

III. PROGRAM CONTROL: THE GOVERNMENT'S FUNCTION

The French aeronautical weapons acquisition process seems to function on the assumption that good weapons will appear at a reasonable cost if the military do not unduly detail requirements and if design, development, and program management proceed without overmuch interference by government monitors.

The French Air Force has obviously concluded that exceptional aircraft can be obtained from Dassault without any close military supervision of the design and development process. Sud is more closely supervised than Dassault. Thus the policy does not extend to all French suppliers to the degree that it applies to Dassault, but it does seem to be a policy to be applied whenever possible. Further, the Ministry of Aviation has thus far been willing to cancel government sponsored and funded development programs in favor of entirely different, independently developed Dassault aircraft with greater promise or potential. Such cancellation was the fate of the Vautour, a development of Sud-Aviation; the Dassault design adopted in its stead became the Mirage IV. Similarly, the privately funded Mirage III supplanted Sud's Durandel at an early stage of their parallel development.

Requirements stated by the French Air Force or its organizational counterpart, the French Air Ministry, are general, minimal, and performance oriented. They are defined by the operating commands in concert with Dassault and represent a compromise of Dassault's evaluation of what can be done in the sense of cost and technology with the military's evaluation of what should be done to satisfy perceived operating needs. The French equivalent of an American systems command (or research and development command) participates in requirements definition only to the extent required to validate or certify technical feasibility. In all important respects the using command is responsible for defining military requirements within the general context of national defense objectives specified by the government and detailed by the Air Ministry.

Once the need for a new system has been acknowledged, a staff officer reporting to the Chief of the Air Force prepares the original three- or four-page formal statement of military requirements. It is immediately reviewed by the Defense Ministry's Materiel Agency for technical feasibility. The Materiel Agency is loosely comparable to the U.S. Directorate of Defense Research and Engineering and has direct access to technical specialists in the several branches of the French Air Force. Concurrently, a body of scientific advisors (in some respects similar to the Defense Science Board in the United States) reviews the requirements document for the

Ministry of Defense. (The agencies involved are DREMA and the Ministère des Armées.) Once the military staff (which means the using command) and the materiel staff (the technical branches) are substantially in agreement, the requirement is reviewed, revised, and expanded by the military staff to reflect that agreement.

The coordinated requirement is then submitted to a special committee on fabrication techniques, which meets every three to five months. (That committee is composed of the military staff, of technical specialists from the materiel agency, and of scientific advisors.) A final review of the requirement involves senior officials of the Ministry of Defense, the Minister himself, the Chief of the Air Force, the Chief of the Defense Materiel Agency, and the head of the Scientific Advisory Group. After that approval has been granted, revisions to the approved requirement are extremely difficult to obtain.[1]

In its final and approved form, the official requirement is prepared by the military staff, transmitted to the material agency, and there transformed into a technical requirement for dispatch to the approved contractor. The final statement of technical requirement normally runs about 10 to 12 pages.

Once the requirement has been fully reviewed and certified, the Air Force acquires total and ultimate responsibility for the conduct of the design and development stages, the test phases, and the subsequent operational life of the system. The staff of the air force materiel agency (DIT, roughly equivalent to the U.S. Air Force Systems Command), even though military, has no influence on the content of the military requirements statement once the initial discussion stage has been passed. The only role of DIT at that stage is to confirm that the technical objectives stated in the basic military requirement are feasible.

A senior officer from the regular Air Force establishment becomes chairman of a weapon system committee that follows the program through its design, mockup, and test stages. He has full and final authority to approve or reject proposed changes, acting as a one-man configuration control board.[2] Sometimes that officer is designated to command the first operational unit. Both an R&D flight test establishment (CEZ) and a separate organization for operational suitability testing (CEAM) are part of the test and acceptance structure. Pilots from CEAM have an early and active role in the program (a CEAM pilot flew the Mirage IV less than a month after its initial test), and military pilots account for about 10 percent of the flight time of a prototype aircraft.

Several elements in the French requirements approval process and in the program management structure for French militry aircraft are strikingly different from those characteristic of the United States.[3] Both are Spartan. But not because the French are immune to the temptation to indulge in "the lust for higher and faster." Insofar as funds will permit there are occasional investments of that sort.

[1] The Soviet habit is similar. See A. J. Alexander, *R&D in Soviet Aviation*, R-589-PR, The Rand Corporation, November 1970.

[2] However, a production configuration conference can involve as many as 30 participants (the number involved in the Mirage G decision), and maintenance inspection conferences (10 to 20 people) are also held. But a special test program ordinarily is conducted to validate maintenance assumptions.

[3] French institutional structures are more like those of Sweden and the Soviet Union than of any other aircraft producing nation. British practices, in general, do not differ greatly from those of the United States. Sweden has but one aircraft manufacturer and one engine manufacturer, and thus is a special case. Nevertheless, the relationship between SAAB and the Swedish Ministry of Defense is remarkably similar to that between Dassault and the French Ministry of Defense.

From time to time since the mid-1950s the French have made successful assaults on world speed, altitude, and load-over-distance records; and persistence in support of the Concorde supersonic transport program, notwithstanding steady cost growth and uncertain demand for the aircraft, partly reflects a national appetite for technological achievement. But the Concorde is an exception to the rule, and the several record-seeking aircraft projects have been surprisingly cheap compared with their U.S. counterparts.

French defense policy, however grandiose in concept, is severely constrained by finances. Apart from its substantial continuing investment in Dassault aircraft, the French have also developed and bought a small lot of intermediate range ballistic missiles, a missile-launching submarine program, several advanced aircraft engines, the Concorde, and a variety of technically advanced army weapons (chiefly tanks and infantry-assigned battlefeld missiles). All are expensive, if not by American standards at least by comparison with most other west European investments in technology. Good, cheap aircraft are highly valued. Only rarely has Dassault exceeded program cost estimates submitted to the Air Ministry, and then by small margins. Therefore, when Dassault proposes an aircraft that can satisfy a valid requirement, the Air Ministry tends to accept the validity of the cost estimate. Discussions with Dassault officials suggest that Dassault is aware of general program funding limitations, and that informal reconciliation of costs and budgets is an iterative preliminary to the final statement of requirements. Both estimates and final bids tend to be realistic. Dassault will not promise more than available funds will cover, whether in quantity or system performance. Not having to indulge in price competition is an undeniable advantage; being effectively a participant in the requirements generation process is another. The French defense budget is not rigid; within its boundaries allocations to the individual services and to various expenditure categories may vary from year to year. But the amount available for the development and production of new aircraft is, in U.S. terms, small. The total cost of all Dassault fighters for the French Air Force between 1960 and 1970 probably did not exceed one billion dollars, a sum that accommodated development as well as production.

In such circumstances, the requirements approved by the French Ministry of Defense could not conceivably resemble those characteristically issued by the Department of Defense in the United States. Dassault and the several agencies of the Ministry of Defense appear to understand that performance has a price and to operate accordingly. If any requirement is unreasonably demanding, either Dassault will be unable to deliver or the eventual cost of satisfying it will exceed the amount available. Neither outcome is tolerable to any of the participants.

Both the statement of requirements for a new aircraft and the subsequent budget allocation for satisfying it are realistic. No other outcome is admissible in the circumstances. And given those circumstances, the need for government supervision of Dassault's subsequent operations becomes minimal. Dassault is fully aware of the high costs of program management in the United States, and so is the French Air Force. Both seem determined to avoid incurring such costs. That too is a factor in the subsequent role of the government in Dassault's development and production programs.

The number of government people assigned to a given program is small. In the case of the Mirage IV, the government project staff numbered less than 40, and no larger government project establishment has been noted. Of that total, 20 were from the materiel agency, 10 from the air staff, five from the electronics development group in the materiel agency, and five from the military R&D test group responsible to the research and development group within the materiel agency. In the case of the Mirage III-C, which is perhaps more typical, two engineers from the research and development establishment were assigned full time, plus 15 to 20 laboratory personnel who devoted less than 20 percent of their time to the program. Generally the research and development flight test establishment will assign one pilot, one test engineer, and an average of three additional instrumentation and data reduction personnel to the program. The average CEZ member will spend about 50 percent of his time on the project at hand.

Comparisons with American practices in manning and staffing scarcely seem necessary. It is enough to observe that similar U.S. functions are manned at least five and occasionally 10 times as heavily.

IV. THE DEVELOPMENT PROCESS

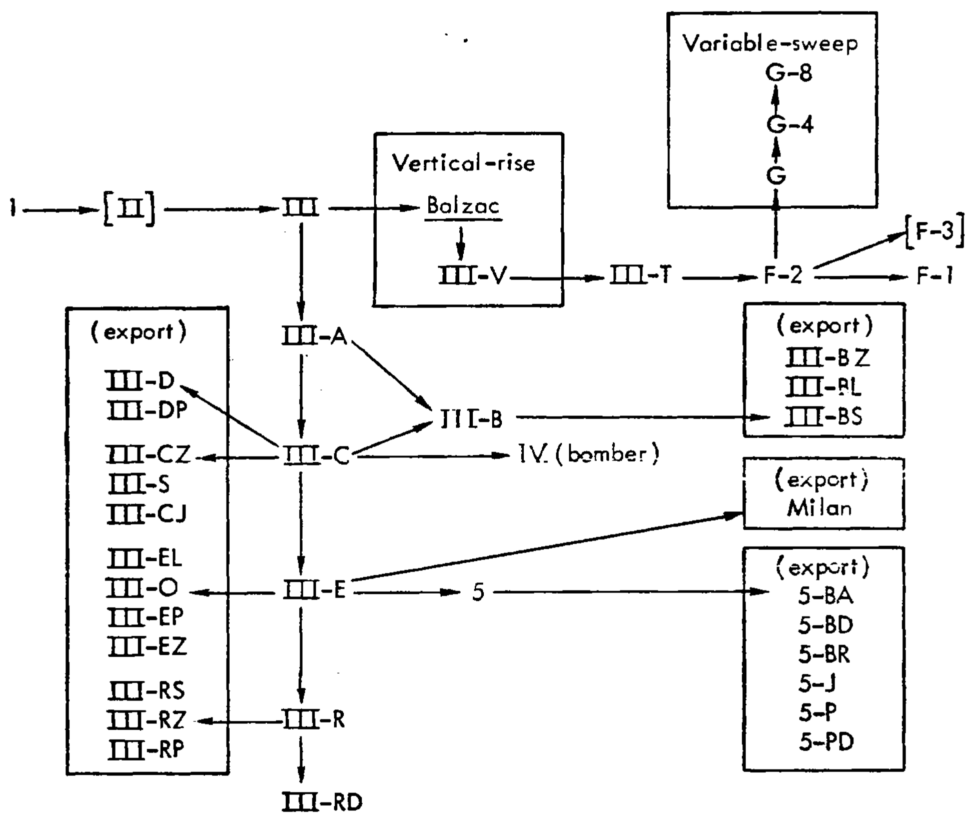
That Dassault aircraft are derived by an incremental, evolutionary process, one model leading into another, has been remarked. A review of the generation of the Mirage series fighters, in their several major variations, illustrates that process and provides insight into the way in which the Dassault organization ordinarily performs development. Figure 1 traces the descent and antecedents of the 24 variants and 41 models that had flown by 1972.

The Mirage I (originally the MD 550), built only in prototype, was intended to be a small, lightweight interceptor directed to its target by ground-based controllers, much in the fashion of the classic air defense systems of World War II. It incorporated a delta wing and was powered by two Viper engines (a British design scheduled to be built in France under license) as well as an accessory rocket engine, but in other respects it owed rather a lot to earlier Dassault experience with Mystère and Étendard fighters.[1] The prototype first flew in June 1955; a liquid rocket engine included for speed augmentation was first operated during a December 1955 flight. The Mirage I subsequently reached a speed of Mach 1.9 with rocket boost and an unaugmented speed of Mach 1.25, relatively good for the era. It had generally attractive flight characteristics, although test pilots encountered some buffet problems that had to be corrected by altering the fuselage. But because of changes in the operational philosophy of NATO, where the aircraft had been intended to serve, dependence on ground control of intercept was deemed unrealistic and a larger aircraft was specified to accommodate self-contained interceptor avionics.

The Mirage II never emerged from its prototype construction stage. M. Dassault concluded that the French Air Force would eventually need a larger aircraft capable of carrying a more complete complement of interceptor avionics and stopped work on the prototype, instead allocating company funds to a new design, the Mirage III. Unlike its twin-engine predecessors, the Mirage III was built around a single engine of French origin, the SNECMA Atar. It used the general layout and the wing design of the Mirage I and the basic fuselage of the Mirage II but incorporated "area rule" technology. Detailed design of the aircraft began in early 1956; the prototype (001) first flew on November 18 of that year.

[1] British designers sometimes remark on the general resemblance of the Mirage delta-wing fighters to their postwar Fairey F.D.1., but there is more wishful thinking than substance to the implied derivation. Apart from their use of a delta wing, the two aircraft have almost nothing in common. Actually, the Mirage III more closely resemples the Convair XF-92A of 1948 than the F.D.1, but in fact all three ultimately stem from the World War II designs of A. Lippisch, who conceived what became the Me-163, the world's first operational delta-wing fighter.

(24 variants, 41 individual models, based on 19 prototypes, including 2 prototypes not completed)



Bracketed models were not completed as originally laid down but were subsequently used in test programs of one sort or another

Fig. 1—The Mirage Family Tree: 1954 – 1970

Dassault assigned only 14 engineers and draftsmen to the design phase of the Mirage III prototype, and only 70 shop people were occupied in its fabrication. It demonstrated a speed of Mach 1.5 on its sixth flight, in January 1957, and proved so attractive that the French government canceled plans to procure the proposed Durandel interceptor from Sud-Aviation and ordered production quantities of the Dassault aircraft.

The first production prototype, the Mirage III-A, flew on 12 May 1958 and in October reached a maximum speed of Mach 2.0 in level flight. Nine other service test prototypes were subsequently constructed. The quality of the aircraft may be judged, in part, by its achievement in setting a world's speed record in June 1959 (100-kilometer closed course) and in eventually reaching a speed of Mach 2.2 and an altitude of 82,000 feet during flight test. (In a period of 20 months, the old record, held by the United States, was exceeded first by the Mirage III-A, then by a Republic F-105B, still later by a Russian fighter, and again, in September 1960, by an American F-4.)

The French Air Force initially ordered 95 production versions of the Mirage III-A, designating it the Mirage III-C. An all-weather interceptor with strike capability, the Mirage III-C in modified form was exported to South Africa (III-CZ), Switzerland (III-S), and Israel (III-CJ). A two-seat derivative of the Mirage III-A was built as the III-B and this, too, was exported to Switzerland and South Africa in small numbers.

Following the III-C, Dassault developed and later produced the Mirage III-E, the prototype of which first flew in May 1961. It was this version, carrying more avionics than its predecessors, that was exported to Australia as the Mirage III-0. A modification of the III-E with reconnaissance capability became the III-R, the prototype first flying in October 1961. It also was ordered by the French Air-Force. Small numbers were exported as the Mirage III-RS, and an improved version was produced as the III-RD.

The Mirage III, substantially scaled up, provided a design foundation for the Mirage IV bomber. The original prototype flew for the first time on June 15, 1959 and reached Mach 1.9 in July. Two stages of growth occurred between the original prototype and the third pre-production prototype, which was the first aircraft with full operational equipment. The Mirage IV eventually demonstrated a maximum speed of Mach 2.2 and had an operating radius of more than 1,000 miles—which included a brief period of supersonic dash at high altitude.

The briefly retired prototype of the Mirage III was withdrawn from storage and modified to become the prototype of the first French vertical takeoff and landing fighter, the Balzac, which made its initial flight on October 12, 1962. The Mirage III-V followed, scaled up from the original 15,000-pound Balzac to become a 32,500-pound aircraft. It began hovering tests in February 1965 and converted from hovering to vertical flight for the first time in March 1966. A second prototype, with a different engine, was flown in June 1966, 10 days after the initial trial of the Mirage III-T, intended to be a flying test bed for a still more advanced engine. The III-T became one of the progenitors of the Mirage F-1, discussed below.

Two further direct derivatives of the original Mirage III have appeared. One, the Mirage 5, based on the airframe and engine of the III-E, was a simplified, low-cost ground attack aircraft developed chiefly at the instigation of the Israeli Air Force and with inputs from that service. The prototype was first flown on 19 May 1967.

By 1971 Dassault had built six other export variants of the Mirage 5. The Milan, a Mirage III-E derivative for the Swiss, incorporated several improvements over its progenitor, notably a retractable canard foreplane, which improved low-speed maneuverability and short field capability.[2] The prototype, a modified Mirage III-E, flew in late 1968 and participated in comparative trials with Viggen (SAAB), G-90 (Fiat), and A-7 (LTV) fighters in 1969 and after. The Swiss eventually selected the A-7 for purchase, but in mid-1972 decided against buying any of the several fighters.[3]

By the end of June 1970, Dassault had produced (or was manufacturing) a total of 1,063 Mirage III aircraft in 10 basic configurations. Of these, 38 percent were for the French Air Force and the remainder for export. All export aircraft were purchased at standard world market prices, although the French government provided attractive loan rates in several instances, and Dassault was always willing to make concessions in the matter of licensing production or assembly rights. Other aircraft licensed or exported by other makers had been built in larger numbers (the Germans bought and built 869 Lockheed F-104G fighters, for example), but in all such instances governmental subsidies of one sort or another were involved.

An excellent example of the way in which Dassault aircraft evolved in graduated steps, taking advantage of technology as it unfolded, was the Mirage F-1, the by-product of an attempt to create a Mach 2 vertical-rise strike fighter for the French Air Force. To test the concepts embodied in such an aircraft, Dassault decided to build two prototypes—or, more precisely, test beds. One, the Balzac, was intended to test a lift engine system, while a separate airframe was constructed (by modifying a Mirage III-T) to flight test the TF-306 engine proposed as the main power source for an ultimate operational article. Early flight testing demonstrated that a modified Mirage III-T was not a suitable test bed for the TF-306 (a license-built Pratt & Whitney TF-30). Therefore, Dassault set about constructing a new two-place prototype, installing a new swept wing on a slightly enlarged Mirage III fuselage.[4] Initially known as Mirage F, the aircraft subsequently became the F-2. Its performance almost immediately made it a candidate for development as a close support fighter, and Dassault promptly proposed building it for use by the French Air Force between the phaseout of Mirage III-E fighter bombers and the eventual introduction of the projected Anglo-French variable sweep fighter. The F-2 was to be two-place long range fighter with nuclear weapons delivery capability.

The prototype F-2 flew on 12 June 1966 (powered by a TF-30). By that time, Dassault was well along with studies of a smaller version of the F-2, also built around the TF-306 power plant. The resulting design became the F-3, a single-place air superiority and close support fighter.

The potential operational usefulness of the F-3 induced Dassault to undertake, with company financing, studies of yet another single-seat variant of the F-2: the F-1, intended to replace the III-C (in an air superiority role) rather than the III-E (a fighter-bomber). Thus for a time the F-3 and the proposed F-1 were concurrently in preliminary design and the F-2 in development.

[2] The Russians copied that foreplane for the Tu-144; ironically, overstressing of that canard appeared to have contributed to the crash of the Russian supersonic transport prototype during the Paris Air Show of 1973.

[3] Referring to their near-constant military budget and the increasing unit cost of newer fighters, a Swiss spokesman was reported to have commented, "250 Venoms, 100 Hunters, 60 A-7s, 12 F-15s, then what?" *(Air Enthusiast,* June 1973, p. 268.)

[4] All Mirage aircraft until that time had delta wings.

Changes in French national defense policy arising from the deteriorating French relationship with NATO led to abandonment of plans to produce and deploy the F-2. Studies of the proposed F-3 indicated that it would be a larger and more costly aircraft than the French Air Force wanted for close support use, so that project too was canceled. On its own, Dassault undertook the construction of an F-1 prototype. Apart from different roles—the F-3 being designed principally for close support and the F-1 for interception and air superiority assignments—the F-1 differed from the F-3 in using a SNECMA Atar 9K50 engine, a derivative of the power plant in earlier Mirage III aircraft, rather than the license-built TF-306 originally intended for the F-3.[5]

In mid-1964, after Dassault had decided to use company funds to build an F-1 prototype, the French Air Force agreed to support development of the F-1 as a possible replacement for the Mirage III-C when that aircraft became obsolete. Delayed by budgetary problems, the prototype did not begin flight tests until December 1966. It early demonstrated exceptional performance, reaching a speed in excess of Mach 2 on its fourth flight, although a crash attributed to flutter problems caused its destruction in May 1967. Notwithstanding that mishap, the French Air Force reaffirmed a decision to adopt the F-1, ordering three pre-production prototypes and a structural test airframe. By 1971 all three prototypes were in flight test and 85 production versions had been authorized. Deliveries began in early 1973.

Although the F-1 was intended to be a Mirage III-C replacement, which implied an intercept role, Dassault embodied features in the aircraft that made it adaptable to both the ground attack and the air superiority roles. In terms of range and munitions capacity, the F-1 was a less capable close-air support aircraft than the considerably larger American F-4D,[6] for example, but the F-1 appeared to be able to operate effectively in both modes.

In proceeding from the Mirage III series to the Mirage F-1, Dassault succeeded in reducing landing approach speeds by 20 to 25 percent, increasing range by 40 to 50 percent, and extending combat time by about 65 or 75 percent. The F-1 uses basically the same engine as two other current Mirage derivatives, the Milan and the variable-geometry Mirage G-8. More advanced engines may be fitted to later production versions to provide the F-1 with a maximum speed capacity of about Mach 2.5 (Mach 2.2 was attainable in the prototype). Dassault has also proposed both a two-place trainer version of the aircraft and a lightweight, low-cost version that could be offered to foreign air forces unable to afford, or without need for, the advanced avionics installed in the original.

When Dassault decided to invest in a variable-wing-sweep design, the F-2 became the basis for the prototype. The F-2 had demonstrated good matching of engine and air intake, it embodied a low horizontal tail desirable in a variable-sweep fighter, and the wing box was appropriately located. To create a prototype variable-sweep fighter, little more was needed than a new wing and a pivot. The resulting aircraft, which became the Mirage G, went from prototype go-ahead to first flight in 16 months. The total cost of the program, including all propulsion systems, was about $35 million. Although the performance of the Mirage G was highly acceptable

[5] Decreased dependence on an American-designed engine may also have been a justification for the shift. The Atar 9K was also used in the Mirage IV.

[6] Which also had begun its flight career with an air-intercept mission.

(it could reach Mach 2.5 at altitude and retained supersonic capability at ground level), Dassault and the French Air Force concluded that a multi-role twin-engine version was preferable. Dassault therefore substituted two Atar engines for the TF-306 used in the Mirage G prototype and thus created the G-4 Mirage. Further improvements were incorporated to create the G-8, in advanced flight test in 1971.

Although the Mirage fighter development program has been extremely successful, on the whole, at least one of the Mirage derivatives, the Mirage III-S, was troublesome in much the same way as several recent American aircraft development programs. A review of the events of its development and production indicates that if the circumstances are right, even the best of aircraft programs can occasionally come a cropper.

In 1958 the Swiss air defense force decided that obtaining a new fighter aircraft to replace its complement of 100 aging Hunters could no longer be put off. (The Hunter was developed by the British at the time of the Korean War.) After considering many candidates, the Swiss reduced their options to the Mirage III-C and the J-35 Draken (produced by SAAB). Swiss pilots put them through a fly-off demonstration in November and December 1960. The Swiss government chose the Mirage III and officially authorized the domestic production of 100 aircraft under a Mirage III-S designation at a programmed total cost of $203 million (1960 dollars). Of the total, $120 million were allocated to aircraft procurement, including avionics, $54 million to spares and accessories, $19 million to armament equipment, and an additional $10 million to miscellaneous equipment.

By July 1961, when the contract was signed, the Swiss had decided to buy 18 Mirage III-RS aircraft as part of the procurement package and to fit a TARAN avionics system (made by Hughes) in place of the Cyrano avionics system Dassault normally installed in the Mirage III-C. (The change was partly motivated by Swiss desires to use the Falcon missile rather than a similar but simpler French air-to-air missile. The Falcon was also a Hughes design product.)[7]

Such changes obliged the Swiss to modify the airframe of the Mirage so that it would accept the TARAN system. They also proposed—or accepted proposals for—further modifications intended to improve landing and takeoff performance. Still more alterations were incorporated in the III-S design to facilitate underground storage of the aircraft, to allow for droppable fuel tanks, and to provide for built-in engine starters.

Construction of the airframes began in a Swiss factory in 1963, as did licensed production of the Atar engines. The Dassault-built prototype Mirage III-S fighter bomber made its first flight later that year. Concurrently, the Swiss government conducted its first financial review of the program and discovered that largely because of the changes imposed on the original Dassault design, an additional $50 million would be required to fund the program. That initial disclosure of ongoing cost growth was followed by a 1964 announcement that still another $135 million would be required to finance aircraft modifications and changes in inventory requirements. An estimate of anticipated inflation effects was for the first time included in program estimates, driving them up by another $52 million. By then it was

[7] Technological transfusion may also have been a contributor to later difficulties. It seems probable that Swiss exposure to the Falcon capability of the SAAB aircraft motivated the decision to require Falcon capability in the Mirage. The Draken carried avionics licensed by Hughes, and SAAB also built a licensed version of the Falcon missile.

apparent that program costs would approach $338 million by 1968, a cost growth of 70 percent. At that point, the Swiss government also acknowledged that the various changes and modifications would delay the completion of the program by at least one year.

In October 1964, the Swiss reduced the scheduled total of production aircraft to 57 and added $47 million to the original program total (in lieu of the $135 million requested). The 57 aircraft in the program now included 18 reconnaissance versions (Mirage III-RS) and 36 fighter bomber aircraft (Mirage III-S), two dual-seat trainers (Mirage III-BS), and a Mirage III-C (to be used as a flying test bed for a various equipments). By 1965 the program costs had been reestablished at a total of $274 million for the 57 aircraft.

The sources of cost growth in the Mirage III-S program were neither obscure nor difficult to identify. One underlying cause was the inexperience of Swiss producers with the close tolerances and specialized fabrication techniques essential to building high density supersonic fighter aircraft. The last aircraft produced in quantity in Switzerland had been a growth version of the DeHavilland Vampire (laid down in 1941 as part of the effort to provide jet fighters to use against the Luftwaffe). Although the Venom did not fly until September 1949, it was, in fact, inferior in most respects to the F-84, F-86, and MiG-15 aircraft in wide use elsewhere in the world by 1950.

Between the Venom and the original Mirage III-S was a production and design gap that the Swiss had filled only to the extent of building three fighter prototype aircraft of a design subsequently deemed unsuitable for production. The attempt to make the Mirage III-S mostly of components built in Switzerland imposed great strains on the production capabilities of the small Swiss aircraft industry. The Swiss had taken into account neither the problems of producing the aircraft nor the probability that program costs might rise. Further, the requirement for the incorporation of an American radar in an aircraft that had been intended to accept a very different French avionics system introduced new difficulties and expenses. The TARAN itself had not been fully tested at the time the Swiss decided to adopt it. Integration of the Hughes electronics equipment in the Dassault airframe eventually took 18 months rather than the six originally projected. In effect, the eventual Swiss aircraft was so unlike its Mirage III-C progenitor that it was almost a new development. The major changes were introduced after production arrangements for the original III-S design had been made. (The experience of the Swiss was in sharp contrast to that of the Australians and the South Africans, who successfully manufactured the Mirage III-C very much in accordance with the drawings and specifications provided by Dassault.)

About 25 percent of the effective cost growth in the Mirage III-S program was attributable to inflation, or more precisely to an unfavorable change in the relative values of the Swiss and French francs. The original estimated unit price for each in a lot of 100 aircraft was $2.07 million; inflation drove that price to $4.55 million, increased development and manufacturing costs added an additional $3 million to the bill for each aircraft, and the 1965 unit price was $5.6 million.[8] Some portion of the $3 million unit cost increase could be charged to production cost growth incident to reducing a 100-aircraft program to a total of 57 aircraft. Yet for each

[8] 1965 dollars, and for a smaller quantity of aircraft.

Mirage III-S, about $2 million of the total price was attributable to unanticipated engineering difficulties and to alterations in the specifications of the aircraft. This implied a cost growth factor of 1.8 (corrected for inflation). The F-111 had almost precisely the same cost growth factor, and for similar reasons.

The Swiss experience was not unique. The West German Air Force incurred a cost growth of nearly 150 percent in acquiring its large complement of F-104Gs in the middle 1960s, for instance. The sources of program cost growth were strikingly similar for the two programs—considerable changes to basic specifications and performance requirement, the incorporation of functions and subsystems not found in the parent aircraft, and production start-up problems of several kinds—but they plainly were not inherent in either the original aircraft design or the licensing process for either. (Japanese versions of the F-104 actually cost less than the Lockheed-built American models.) In both instances the evidence suggests that if the originally proposed and accepted aircraft had actually been built, significant cost growth would not have occurred.

V. OBSERVATIONS AND IMPLICATIONS

Underlying the Dassault mode of aircraft development is a fundamental commitment to austerity. Technical staffing is minimal, by American or British terms, and administrative staffing is meager. Facilities are almost Spartan, and only in the provision of test and fabrication machinery does one encounter resources as abundant as in American aircraft manufacturing.

Such habits are reflected in funding policies. Although Dassault frequently invests corporate risk capital in new programs even when the apparent customer has indicated initial disinterest,[1] the investment is characteristically expended in careful design analysis and in capability demonstration. Further, the extent of such investment is carefully limited; most Dassault prototypes are cheap because they incorporate only those non-standard and custom-built elements that are essential to the demonstration of whatever is being sought. (However, on occasion Dassault has introduced new techniques, such as chemical milling, into prototype programs as a device for investigating them inexpensively and without risking the success of production operations. Generally, such innovations have been supported by a customer.)

Dassault managers appear to believe that cost-plus contracting is dangerous for the company—an outlook that is totally foreign to American preferences. But the Dassault view has a perfectly logical and readily comprehensible basis. The company maintains that indifference to cost factors in one aspect of a program will inevitably influence working-level cost consciousness in activities in which cost is a vital factor. Thus for Dassault considerable accuracy in forecasting costs is essential. Because short-duration programs are notoriously easier to estimate and control than are extended multi-phase programs, Dassault does development sequentially and in relatively brief phases.

High risk development programs characterized by efforts to subdue uncertain technology cannot be completed quickly or costed accurately. But new technology can be adapted to new needs without great financial risk *if* the process of introduction is sufficiently cautious, or so Dassault maintains. As has been observed earlier, the company is not averse to taking relatively large technical risks, evident in Dassault's work with vertical takeoff, variable wing sweep, rocket boost, canard foreplanes, and similar variations on "standard" aircraft designs. But, as has also

[1] As with both the Mirage III-A and the Mirage IV.

been noted earlier, rarely does Dassault introduce at one time more than one basic variant on an existing model.

Thus the risk is minimized, and so is development time. That practice has another advantage. If but one or a few major innovations are demonstrated in a single prototype, the design and test effort can be concentrated on those features. Other elements of the prototype, having been thoroughly demonstrated, require little attention. The small size of Dassault design staffs can be partly explained by that trait alone. (In design and construction of the vertical-sweep Mirage G, the entire design staff worked on wing design, pivot design, sweep-effect, and wing integration tasks. Two earlier American variable sweep aircraft had incorporated such features as new engines, new duct designs, new control system concepts, new hydraulic and electrical systems, and a host of novel subsystems. In terms of design labor and initial development costs, they were enormously more expensive than the Mirage III-G.)[2]

Other attributes of the Dassault organization arise in its environment. Employment stability is both a product and a cause of company policy. Partly because of political exigencies in France, partly because of company tradition, partly because the company has avoided assignments that invoke fluctuating labor force needs, Dassault has experienced either labor force stability or modest growth for each of the 26 years of the company's postwar existence.[3] Slow growth and a stable labor force have inhibited intra-company employee mobility and have made that static situation acceptable to company employees. (Such stability is less characteristic of senior engineers and managers but the effect is seen even there.) The resulting tendency to a single-skill career is rarely encountered in the aircraft industry of the United States. One engineer has been the principal designer of every wing used on a Mirage aircraft, which does much to explain the excellence of design.

The conservatism of Dassault's approach to new technology is complemented by a testing policy that is quite unlike American practice of recent decades. Even a relatively minor variation on one of the basic Mirage models generally is tested in prototype; more extensive changes, as from the Mirage E series to the F models, frequently involve three successive sets of prototypes ranging from concept demonstration through pre-production. One product of such activity is a great deal of real

[2] The two aircraft were the F-111 of 1963 and the XF10F-1 of 1950, a Grumman prototype for a variable-sweep Navy fighter.

[3] Stability of the labor force is, of course, a well-known policy goal of the French government. In Dassault's case, it appears to have special implications. Dassault is at present the only major source for combat aircraft within France, and the French policy of independent deterrence requires that such a source be maintained. There is no direct evidence of a government commitment to support of Dassault's levels of company employment, but a *de facto* commitment of that sort seems to exist. As noted elsewhere, Dassault has a flexible subcontracting policy that causes sudden work overloads to be farmed out. That policy has occasionally extended to detailed design as well as to fabrication. But Dassault does not consistently farm out any single function; the decision on what is built within the company and what is purchased appears to be made on a case-by-case basis. It is not unreasonable to postulate that the French government honors an unwritten commitment to support a Dassault operation of a specified size, whatever the government's single year requirement for development or production of weapons. Production appears to continue at a relatively steady pace without much regard for inventory requirements of the French Air Force. That would suggest the possibility that French Air Force requirements for specific systems may be delayed or accelerated to take advantage of slack time or to permit a shift of emphasis to an export order. Those export orders seem to be quickly accommodated within Dassault's resources without occasioning protests from the French government about delayed delivery of aircraft ordered earlier, and without causing Dassault to expand its work force. The cost, in any case, could not be excessive. In 1970 dollars, the wages for Dassault's 11,000-12,000 employees probably did not exceed $50 or $60 million—rather less than the cost of two 747 transports or a bit more than the cost of one C-5.

knowledge about the characteristics of new or modified aircraft before production commitments are made. Moreover, owing to the limited change in going from one model to its successor (even from the III-E to the Mirage F), testing can concentrate on the uncertainties arising in a few features and their effect on total performance. Finally, the small size of design staffs and government project offices complements and reinforces the minimal demand for peripheral information. Tests, and particularly flight tests, tend to be briefer, narrower in scope, and appreciably less costly than is the usual case in the United States. Single test phases can be concerned with limited aspects of total system performance, permitting the short term, sequential contracts that are characteristic of flight test programs for new Dassault aircraft.

That Dassault can perform sequential tests without drawing out a development program to unacceptable lengths is a consequence of the Dassault process. Designs can be quickly translated into prototypes if the extent of required design effort is limited, and prototype flight tests can be highly productive if the generated data largely concern the most important new features of the prototype. Therein can be found an explanation for the rather remarkable feat of carrying the Mirage IV bomber from design concept to operational readiness in roughly two-thirds the time required for the F-111—an aircraft with similar size and performance attributes—and for about 10 percent of the cost. (The two aircraft were developed under almost identical priorities and had similar development schedules; both incurred schedule slippages of about 10 percent, but in fact the Mirage IV satisfied all of the customer's operational requirements in some three years less than did the F-111.)

The scientific underpinnings of the French aircraft industry are not inferior to those of Great Britain and are superior to those of Sweden. The French certainly profit more from national research than do the aircraft industries of Germany, Italy, Japan, or the smaller nations of Eastern Europe. France has its own centers of aeronautical research, its own metallurgical institutions, its own electronics and computer industries. They are smaller, less diversified, and poorer in terms of resources than their counterparts in the United States and the Soviet Union. But that says little; so are the comparable institutions of every other nation. And, as does every other nation (including the Soviet Union), France draws to the fullest possible extent on the research and technology generated by the United States. French avionics and computer-technology applications clearly are inferior to those of the United States (and so are those of the Soviet Union). Whether Dassault is significantly handicapped thereby may be quite another question, however. Dassault is rarely the first to apply an advance in basic technology to operational aircraft—and as rarely is the last. France has both a variable-sweep and a vertical-rise fighter in advanced development and has the evident capability to produce either, once a requirement has been validated. The United States has produced two variable-sweep fighters, the F-111 and the F-14, but has only test-bed vertical-rise aircraft, and none is a fighter prototype or equivalent. The British have no variable-sweep development but have a vertical-rise fighter, the Harrier, in production. In such gross terms it is not evident that France has suffered by not pushing research in either of those costly research areas. Notably, Russian variable-sweep and vertical-rise fighters appeared after their French counterparts.

Dassault relies on French aeronautical research and test institutions for support in airframe development and for the troublesome tasks of integrating engines and external stores with airframes. Dassault's perceived requirements for advances in aerodynamics, engines, hydraulics, avionics, and computer subsystems influence the menu of research in other French research institutions. Dassault rarely attempts advanced research in its own right, and rarely attempts to incorporate in current designs the newest products of research in specialized areas. Instead, Dassault selects from a menu of available subsystems and technologies, depending chiefly on specialized suppliers for such additional development as may be required to accommodate the subsystems to its needs. The emphasis, always, is on proven (or nearly proven) components, on minimizing risk, and on assurance of cost. Other firms may be forced to such risk avoidance by sparse resources; in Dassault's case, the choice is deliberate. It is a cornerstone of company policy.

Dassault's ability to operate austerely and to respond quickly is unquestionably enhanced by the willingness of the French Air Force and the Air Ministry to limit the elegance of requirements documents, specifications, and the trans-development reporting process. Of course, it would be preposterous to attempt to impose on Dassault the sorts of data and reporting requirements common to U.S. aircraft development. Dassault entirely lacks the staff to cope with such demands, and even if it could satisfy them neither the Air Force nor the Ministry could find the people to review the product. No one at Dassault bemoans that shortage.

A similar data relationship extends to contracts between Dassault and its suppliers and subcontractors. The Dassault practice of having airframe elements subcontractors design and construct their own production tools and jigs is illustrative. It conforms to the Dassault policy of avoiding involvement in functions and activities not essential to the main business of developing aircraft. Notably, however, when *design* work is subcontracted, Dassault exercises careful supervision of the process—but by way of engineering participants rather than through data specification or elaborate documentation.

One of the more commonly heard explanations of Dassault's continuing success in developing and delivering advanced aircraft is that the company is a chosen instrument of the French government and that it does not have competition. In part that is a valid observation. Not for a decade at least has any other French aeronautical firm attempted to develop the kinds of aircraft Dassault specializes in. But it is also true that Dassault reached its present domestic position of monopoly serving monopsony by competing fiercely with other French firms, none of which continued in that line of work. And Dassault did so without much encouragement from the Air Ministry, then totally committed to encouraging growth in the nationalized sector of the French aircraft industry. Dassault's absorption of Breguet after 1967 disposed of the last native competitor,[4] but by that time Breguet was surviving on the largesse of the French government and the reluctance of Dassault to become involved in multi-national programs that usually went nowhere.

In other ways, Dassault still has competition. The Mirage series has been sold abroad in direct technical and cost competition with various American, British, Swedish, and Italian aircraft. The Falcon-20 executive jet has been sold successfully in the United States and England in the presence of fierce domestic competitors. It is not evident that the quality of French fighters would appreciably improve by the establishment of another French fighter developer; none of the companies that

[4] Sud Aviation and Nord Aviation have occasionally proposed fighters for French Air Force use, but none has proceeded even to a prototype stage in the past 10 years.

earlier disputed with Dassault for French Air Force contracts appears to have been at all competitive in price, schedules, or performance. Dassault's corporate position is undoubtedly more secure than that of similar American companies. Dassault has excellent relations with the French government. But again, Sweden, Italy, the Netherlands, and Japan support non-competing "chosen instrument" aircraft companies, England is nearly to that point, and in none of those countries has an aircraft company with Dassault's record and reputation emerged. In such terms, the questions of competition and government favor seem largely irrelevant.

Some of the advantages of the company may indeed arise from its favored position in France, or even from its being a French company (though that "advantage" does not appear to be translatable into comparable achievement when computers, electronics, missiles, engines, and several other high-technology specializations are at issue). The argument that Dassault progresses by exploiting advances made elsewhere in aeronautics applies with equal weight to all of the world's aeronautical industry. (The wing box in Grumman's F-14 fighter owes more to Dassault's Mirage G-8 than to the F-111, for instance.) The contention that Dassault aircraft are somehow technically inferior to others is probably true when much more costly American fighters, the F-4, for example, are brought into the comparison. Otherwise it is largely incorrect.

Nevertheless, some of the external factors that contributed to Dassault's striking successes in the 1950s and 1960s may not be so effective in the 1970s. Notwithstanding the singular corporate achievements of Dassault, it cannot be gainsaid that the company has been favored by the coincidence of several outside circumstances. The foremost has probably been the dearth of effective competition for the Mirage, in its various models. The MiG-21 and the basic Mirage III weigh about the same, have comparable payload and range factors, and perform in the same flight regime. The MiG has somewhat better maneuverability, but the Mirage has much better ground attack capability. Mirages were priced at about $3.5 million in the 1972 world market. The only other low priced competitor to the MiG-21 available through most of the 1960s was the F-5A, which was handicapped by inferior speed and a fire control system that left something to be desired, but which was cheaper than the Mirage, even when the Mirage III could be purchased for half of its 1972 price.

By the 1970s, however, several low cost, light, multipurpose fighters with reasonably high air-to-air potential had begun to emerge. The Viggen has previously been mentioned; its price and performance made it generally competitive with the Mirage, but it was only nominally a competitor for sales because the Swedes had refused to sell the Viggen to anybody likely to use it (that is, to anybody who had a pressing need for a high performance fighter, which meant almost anybody outside Scandinavia except the Dutch, the Belgians, the Swiss, and the Austrians). The J-35 Draken, though considerably older, was also cheaper, and was probably capable of coping with MiG-21s at medium and low altitudes. But Swedish politics also limited its availability to a few countries. No such inhibitions restrained Northrop, which could offer the F-5E (Tiger II) for near term delivery and was anxious to entertain orders for the P-530 (Cobra) in any of several potential model variants. Lockheed had an improved F-104 on the market (the CL-1200 Lancer), though it lacked customers and sponsors, having failed to win either the international fighter or the lightweight fighter competitions of the early 1970s. The Lancer nevertheless offered some potentially attractive cost advantages to prospective buyers, largely because the basic

F-104 had been built in Germany, Italy, and Japan in the 1960s and starting production of a modernized version might be less difficult—and less costly—thereby. Northrop's F-17 (basically a P-530) and Convair's F-18 entries in the USAF's lightweight fighter competition also represented potential competition, both being comparable to advanced versions of Mirage in weight, range, and overall air-to-air performance.

Devaluation of the dollar in 1972-1973 had the effect of making several of the new breed of American fighters roughly competitive with the Mirage. (Dassault lost several promising Mercure orders to Boeing and McDonnell-Douglas early in 1973 largely because devaluation made the 737 and DC-9 little more costly to buy than the newer Mercure.) The Mirage F-1 promised still better performance than any of the earlier Mirage III variants could provide, but at a cost about 20 percent above that of the earlier aircraft (about $4.2 million instead of the $3.5 million cost of export Mirage IIIs). And when unit cost passed the $4 million mark, the Mirage family became squarely competitive with such aircraft as the CL-1200, P-530, F-18, Viggen, the proposed lightweight F-4, and even the Mirage III variant with J79 engines generally believed to be in an advanced stage of development in Israel. Aircraft in the class of the F-14, F-15, and MRCA were likely to cost $15 to $20 million and clearly were not competitive. The F-1 was in early production; most of the others were at best in advanced development, and several were no more than prototypes. But that might not have been enough to overcome the other attractions of the newer American aircraft, if those attractions could be demonstrated quickly enough.

Dassault's cautious efforts to avoid actions that might call down the bureaucratic wrath of the French government became more difficult after 1970 and promised real trouble by 1973. The addition of Breguet to the Dassault corporate structure had apparently represented at least a modest concession to French government desires to avoid folding that company into the generally less successful combination of nationalized aircraft firms known as Aerospatiale.[5] Reorganization of Aerospatiale into four divisions, one specializing in aircraft only, occurred in mid-1973. As a result, the entire French aircraft industry (excepting helicopters) became a two-part enterprise, Dassault-Breguet representing the last remnant of private enterprise, and the aircraft element of what earlier had been Sud and Nord Aviation constituting the remainder. The principal projects of the new organization were the Concorde and parts for the Jaguar, neither having very attractive export potential, suggesting desperation as one of the moving forces in the reorganization. Apart from the F-1, which was being delivered to the French Air Force in 1973, and the Anglo-French Jaguar being built by the Breguet division of Dassault, only one fighter aircraft was firmly on the French requirements list for the early 1980s. That was a partly defined advanced interceptor tentatively scheduled to be developed by Dassault along the lines of the Mirage G-8, though probably not with a variable-sweep wing. If the Concorde did not sell abroad, the French government would be confronted by a situation in which the only identified major military aircraft development program for the 1980s was consigned to Dassault, with about 12,500 employees, while the Sud-Nord amalgam, with perhaps 40,000 employees, had no major work.

[5] Société Nationale des Industries Aeronautiques et Spatiales, formed in 1970 by a merger of Sud, Nord, and various ballistic missile firms.

The consequences of assigning an advanced interceptor project to Sud-Nord would be to make Dassault's continued profitability largely contingent on export of a new generation of Mirage fighters and on sales of the Mercure. Dassault had beaten back the principal European and American competitors to the 1960s Mirages on price-performance grounds. But the competition in the 1970s would probably be more troublesome to Dassault, particularly if any among the new breed of lightweight American fighters entered production. The notion that Israel might export an advanced J79-Mirage, embodying the best combination of American and French technology available to the developing states, could not be disregarded either. There was the further complication of potentially effective competition from Great Britain and Sweden: an advanced Harrier and an export Viggen. SAAB and the Swedish government faced problems similar to those plaguing Dassault and the French government; without export orders, the continuance of a domestic fighter aircraft enterprise was unlikely because in neither case could national budgets adequately support either new developments or extended production. Hawker, in England, was in similar straits; BAC was the British agent for the unpromising Jaguar development,[6] and the MRCA had, by 1973, attracted little interest from prospective foreign purchasers. Thus Hawker's success in selling the Harrier or a new lightweight fighter in competition with Dassault offerings would gravely influence the future of the British military aircraft industry.

Finally, it is not impossible that Dassault could become the victim of its own success. Advocacy of the Dassault approach to development and production began in the early 1960s in the United States and must be credited with considerable influence in the 1970 decision to develop lightweight fighters, using existing technology, for possible adoption by the USAF and USN late in the decade. Northrop's P-530 Cobra was admittedly developed along Dassault-favored lines, and as a competitor for the Mirage (although Northrop had less to change in the way of design strategy than most other fighter producers). Hawker and SAAB-Scania acknowledge the influence of Dassault experience in the final development of the Harrier and Viggen. Lockheed, in the CL-1200 proposal, applied a blend of the "skunk works" approach and Dassault doctrine, though with little initial success in terms of sales. The Israeli J79-Mirage, if it appears, will surely reflect the Dassault approach to development. The irony is unlikely to escape Dassault's notice.

One other Dassault attribute requires consideration in any evaluation of its achievement. To some unmeasurable extent the company and its many products are expressions of the personality of its founder, owner, and principal manager. There usually is one outstanding individual in any uniquely capable aircraft development organization: Sir Sydney Camm, "Kelly" Johnson, Heinkel, Ilyushin. Usually they become legends in their own time. Marcel Dassault is one with them. Sometimes their capability lingers after them; often it does not.

In many respects, the uniqueness of Dassault appears to be explainable mostly in terms of the company's people, principles, policies, and practices. Many of them not transferable to other companies or countries; but some are, or might be. The difficulty of effective transfer of Dassault processes to the United States is that here the institutions are hostile to the basic premises that Dassault honors and operates

[6] Although Dassault-Breguet was the French participant in Jaguar production, it seems unlikely that Dassault would urge Jaguar on any prospective purchaser of the competing Mirage-5, whatever BAC's preferences.

under. Adoption of some of the forms of the Dassault process could well change American aircraft, and the industry that makes them, for the better. At the least the aircraft and the process would be less expensive, and that is of some interest. But unless fundamental institutional changes accompany the adoption of new forms and procedures, they are unlikely to have the effect that is sought; defense departments and large corporations skillfully and bitterly resist changes that threaten established positions, habits, and prerogatives. Still, there remains in the Dassault way of aircraft development enough of interest to others to encourage hope that among the better parts some can be transferred, and may be.

The most important, and perhaps the most difficult to imitate, of the attributes that characterized Dassault's aircraft development is that embodied in the principle of evolutionary development. It requires a continuity of design effort, a steady transference of basic design elements from earlier to later aircraft, and self-enforced constraints on the incorporation of high risk technology in new aircraft merely because the technology is new or abstractly attractive. None is characteristic of recent U.S. development practice. Dassault's way of proceeding from the standard Mirage III to such variants as the vertical-rise Mirage III-V and the various variable-sweep G models demonstrates that radically different design concepts can be incorporated in successively improved versions of basic aircraft designs without incurring high risks of program failure. The progression from the early Mirage III to the vastly more capable Mirage F-1 illustrates that significant performance improvements can be incorporated without going to totally new designs. An even more interesting illustration of what can be done to improve cost effectiveness while providing "better" performance is the progression from the Mirage III-C to the several Mirage-5 export models, each having generally higher performance than the III-C but costing somewhat less. Each of those advances arose in the continued application of the principle of evolutionary development, a principle not often seen in the United States in the past 15 to 20 years, the most notable exception being the McDonnell-Douglas F-4.[7]

If the United States were to decide to try the effects of an evolutionary development policy, the Department of Defense would have to begin by supporting the continued development of a basic aircraft with appreciable growth potential. A possible starting point would be the several recurrent proposals from American aircraft developers to provide a relatively low-cost fighter aircraft based on a design now flying or one with relatively slight development risk. Among the candidates are the proposed lightweight F-4 (new wing and engines), the "improved" F-104 (Lockheed's CL-1200 Lancer entry in what became the lightweight fighter competition), the "low cost" versions of the F-14 and F-15 offered for consideration late in 1972, the Northrop (F-17) and GD/Convair (F-16) entries in the lightweight fighter flyoff competition, Northrop's P-530 Cobra design, and LTV's "improved" lightweight F-8. The simplest approach would undoubtedly be to develop the winning aircraft in the 1973 lightweight fighter competition in the fashion of a Dassault aircraft (although

[7] Both the F-104 and the F-5 were successively "improved" and each appeared in several versions, but neither was used in any major role by the United States Air Force. And in both instances, proposals for substantial changes that could have led to considerably higher performance tactical aircraft were rejected by that service. The transition from the F-8 to the A-7 can not be represented as either evolutionary or low cost. Although the B-52 does reflect evolutionary development trends, it is a very different case because of size and cost considerations.

for the United States there might be advantages to having two competing fighter aircraft designs concurrently in development).

In any event, having selected promising candidates, the Department of Defense would have to proceed by a route very different from that of recent years. At the onset, for instance, the developer—and the customer—would have to understand that developed subsystems were to be purchased from suppliers rather than contracted for as system-unique entities to be developed in the course of a total program. Adapting existing subsystems to growth aircraft is one of the bases of the Dassault approach; like other elements of that approach, it has rarely been used in the development of major American aircraft since the 1950s.[8]

An American version of the Dassault approach could be realized only if the research and development echelons of the Department of Defense were largely excluded from participation in most of the requirements generation process. That is, the basic system performance requirement could not be stated in terms that would require the incorporation of attractive but unproven subsystems, each nominally capable of enhancing some aspect of aircraft performance. In France, the nearest counterpart of the Air Force Systems Command does not write requirements or specifications; it validates the technical feasibility of those proposed by the operating command and the potential developer, who work together. That practice does much to explain Dassault's success in meeting schedule, cost, and performance goals defined in the program requirements. Dassault draws on suppliers who in effect guarantee the performance of whatever they provide. In the United States, that sort of performance warranty is rare. Instead, development contracts embody promises *to develop* system-unique subsystems, and the implied penalties for failure to deliver are rarely enforced.

The argument that unique or high capability subsystems are essential to whatever aircraft is being developed is traditional in the United States although, in point of fact, "successful" American fighter aircraft of the 1950s seldom entered service equipped with the several major subsystems originally specified for them. In the end, whatever the original expectation, many of the specified subsystems were replaced by others, generally obtained from suppliers who had completed or nearly completed their development. Engines, fire control systems, armament systems, and navigation systems were particularly subject to that sequence of events.[9] In the 1960s, substitutability was often impossible, either because the originally specified system was so unusual that no substitute was available, or more commonly because the total system was so completely integrated that it could not take substitutes without unacceptable schedule delays. The Dassault approach, building around adaptable

[8] An interesting departure from the normal was the abortive development of a *Charger* prototype, a proposed alternative to and competitor with what ultimately became the OV-10. Although nothing came of the company-funded prototype program—for reasons not necessarily related to the quality of either the program or the aircraft—the approach adopted by Convair (San Diego) emulated some aspects of Dassault practice. One of the more noteworthy was Convair's decision to build the prototype around more or less standard subsystems provided from the existing stocks of major suppliers. The only major exceptions were the landing gear, which had to outperform anything available from stock, and the engines, which nevertheless were representative of early production articles. Details of the *Charger* program are contained in R. L. Perry, *A Prototype Strategy for Aircraft Development*, RM-5597-1-PR, The Rand Corporation, July 1972.

[9] See, for instance, B. H. Klein *et al*. *The Role of Prototypes in Development*, RM-3467-1-PR, The Rand Corporation, April 1971.

subsystems that can be obtained without much dependence on new development, generally precludes such outcomes.

Such elements of Dassault's approach to aircraft development, and others earlier mentioned, are not incompatible with the basics of U.S. aircraft development practices even if they have not been much used for the past decade or two. Contracting solely for development, for example, rather than for development-cum-production, was common for a decade after 1945 and has recently been applied, in concept, to the A-9/A-10 competition and the development of a prototype lightweight fighter (F-16/F-17). It is one of two basic ways of obtaining turbojet engines and avionics equipment in the United States. There are no legal constraints on applying it to aircraft development, only institutional constraints.

American aircraft developers are unlikely to oppose the concept of austere, sequential development. The aerospace industry has voiced deference to that principle regularly over the past decade—at Defense Science Board conferences, in testimony before Congress, in submissions to the Blue Ribbon Committee of 1969-1970, and in contributions to the Congressional Commission on Government Procurement in 1971-1972. But application may run counter to the commercial instincts and habits of senior managers, most of whom have reached institutional maturity in an environment of "total program" emphasis. The instincts of senior military managers constitute another obstacle to implementation of a Dassault-like development policy. As Klein and others have remarked, the military tendency toward risk aversion is nowhere so pronounced as in specifying requirements that strain the limits of feasible technology.[10] Therein lies a major difficulty.

It is not apparent that merely directing adoption of a new approach will achieve the desired effect. The 1969-1972 experience of Deputy Secretary of Defense David Packard in attempting to reduce the scope and complexity of reporting in the system acquisition process adequately illustrates the problem. The effort had little lasting effect. However, it seems possible that giving a military program manager authority commensurate with that recently entrusted to the F-15 program director, for instance, while concurrently limiting both the scope of the program and its manning, might serve the purpose. The French Air Force has no establishment equivalent to the Air Force Systems Command; none seems to be needed for programs of the sort entrusted to Dassault. Although it might violate several accepted principles of organization to exempt major development programs from the institutional controls implicit in the conventional American system acquisition process, that too has been tried successfully in the past and there is no obvious reason why it should not succeed in the future.[11]

In essence, then, those aspects of Dassault achievement that represent transferable practices and procedures are chiefly in government organization, definition of requirements and system specification, and program control. It is unlikely that the present weapon system acquisition policy of the United States could be expeditiously altered *in toto* to incorporate those policies and procedures. But it does seem feasible to single out one part of the system acquisition process, perhaps programs concerned with the development and production of tactical fighters (and air superiority fighters) as a start, and to exempt that part from the usual institutional constraints.

[10] See B. H. Klein, W. H. Meckling, and E. G. Mesthene, *Military Research and Development Policies*. R-333, The Rand Corporation, December 1958.

[11] The several "skunk works" program are too well known to require discussion here.

That exemption would necessarily have to extend to (a) specification of program goals, (b) contractual practices, (c) reporting and review requirements, (d) program management authority, and (e) an explicit policy of making cost-performance tradeoffs.

The benefits could well be substantial. The costs of installing such an exempt system could not be great, and the costs of operating it would surely be a small fraction of present institutional costs.

Whether a company or companies with the considerable attractions of Dassault would emerge in the United States once such policies were adopted is not a relevant issue. Every major company in the United States that has developed fighter aircraft since 1945 has at one time or another performed with the elegance and effectiveness of Dassault at its best. Those have been sporadic performances, of course, impelled in each instance by exceptional circumstances. But the capability is there, or can be recreated. The obstacles, such as they are, lie mostly outside the contractor structure. It is in the government institutions that change must first be invoked.