U. S. AIR FORCE

PROJECT RAND

RESEARCH MEMORANDUM

THE CENTURY SERIES FIGHTERS: A STUDY IN RESEARCH AND DEVELOPMENT

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RM-2549

May 20, 1960

Copy No.________

This research is sponsored by the United States Air Force under contract No. AF 49(368)-700 monitored by the Directorate of Development Planning, Deputy Chief of Staff, Development, Hq USAF.

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R-117 (10-51)

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From Weapon Systems Project Offices (Source) on 1957-1958 (Date)

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SUMMARY

This is a study of the development histories of the Century Series fighters with the objective of shedding light on the effectiveness of Air Force Research and Development policies. The most striking features of these histories are the high level of uncertainty entailed in the attempt to develop aircraft that embody state-in-the-art advances and the flexibility with which aircraft subsystems, once developed, can be employed in systems for which they were not originally designed. The high level of uncertainty in development is indicated in these studies by the numerous and unforeseen technical difficulties that arise with airframe, engine, electronics, and armament and that in turn result in weapon-system delivery slippages, degradation of performance, and increases in cost. The flexibility of components is apparent by the numerous instances in which engines, fire-control systems, and armament are found useful in aircraft other than those for which they were specifically designed.

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ACKNOWLEDGMENTS

I am indebted to Rueben Kessel, formerly of RAND, whose unpublished study of the F-104 development program served as the basis for the presentation here. I am indebted also to numerous representatives of individual aircraft contractors and Weapon System Project Offices, AMC/WADC, who gave generously of their time in answering many questions about their fighter programs. In addition, a great deal of information was drawn from the data files and case histories compiled in the historical offices of the Air Materiel Command, Wright Air Development Center, and the Air Defense Command. In particular, I am very much indebted to Dr. P. M. Davis, Mr. George Alling, and Mr. Martin Miller of the Historical Division, AMC, and to Mr. R. L. Perry and Dr. D. R. McVeigh of the Historical Branch, WADC, for their generous assistance throughout the course of this study. I must bear the full responsibility, however, for any errors in fact or interpretation that remain.

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I. INTRODUCTION

During the last four years RAND has conducted a study of research and development practices for the purpose of finding methods by which the Air Force might increase the effectiveness of its R and D programs. The study has drawn on evidence from a large number of military development programs. A summary document, describing in general terms the case studies undertaken at RAND and containing suggestions for the improvement of R and D practices, is available.[1] The purpose of the present document is to give a detailed account of some of these case studies -- the histories of the Century Series fighters.

There are two striking features of development that emerge from these Century Series histories. The first is that there is a great deal of uncertainty in developing aircraft that embody significant advances in the state of the art. We find a barrage of unforeseen technical difficulties during development with airframe, engine, electronics, and armament: airframe designs that prove to have higher drag than initially calculated, engines that fail to perform as anticipated and thereby jeopardize the weapon-system programs for which they were designed, fire-control systems that slip badly in their development schedules, and air-to-air missiles that have unacceptable levels of accuracy and reliability. These difficulties, occurring either singly or in combination, result in weapon-system delivery slippages, degradation of performance, and cost increases. With respect to cost in particular, it is notable that there is not a single

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[1] Klein, B. H., W. H. Meckling, E. G. Mesthene, "Military Research and Development Policies," The RAND Corporation, Report R-333, December 4, 1958.

Century Series fighter whose actual cost has not exceeded the cost estimated early in the program. In addition to these "technological" uncertainties, there are what we shall call "environmental" uncertainties. Even though an aircraft may be developed without unforeseen technological problems arising, the program can be affected by changes in the environment within which the aircraft is conceived. For example, over-all budgetary stringency may force cancellation of the project while it is still in the development stage, or there may be a marked change in the operational role to which the aircraft is assigned. While one system may be carefully planned from its inception to fill an anticipated Air Force "need," by the time it is developed and in production the preference scale of the Air Force may have shifted to favor other systems. This shift in preference may arise because, for example, the enemy threat suddenly changes or because technological breakthroughs make alternative systems highly attractive. A strong interaction between the effects of technological and environmental uncertainty is evident from an examination of Century Series development histories.

The second striking feature in the development of the Century Series is that aircraft components, after they are developed, are very flexible in the sense that they can often be successfully used in aircraft for which they were not originally planned. While a great deal of emphasis is placed in the United States on the "weapon-system concept" under which components of the system are specialized from the very start of their development to work optimally together as a system, we find in fact that components are often useful in other, and sometimes quite different, systems. For example, the Pratt and Whitney J57 engine, originally conceived for the Boeing B-52 heavy bomber, has since been used in the North American F-100, the McDonnell F-101, and the Convair F-102 fighters; the Hughes Falcon semi-active radar-guided missile, designed for the F-102, has been found usable with the F-101B interceptor. The Hughes MG-13, a version of the MG-10 fire-control system designed for the F-102, is going into the F-101B. The Douglas MB-1 rocket is employed on the F-101B, the Lockheed F-104A, and the Convair F-106A as well as the earlier Northrop F-89.

These findings are highly pertinent to the framing of R and D policies designed to facilitate rapid improvement in military capabilities. Whether parallel R and D projects are desirable depends on the uncertainties involved. If the goal is development of a Mach 3, long-range interceptor and the particular aircraft design that will best fill this need is perfectly obvious from the start, there is little reason for parallel development programs of alternative, competing designs. On the other hand, if uncertainty prevails because of possible technological and environmental difficulties, there may be very good reason to conduct parallel development programs to the point where it is possible to choose at a high level of confidence the one design that appears best. Furthermore, whether a particular aircraft subsystem should be developed only after a need for it is found in some specific weapon system or whether it should be developed as a more or less independent program depends on the ease with which a subsystem can be tailored to a specific use once the basic technical problems have been overcome. Evidence from the Century Series suggests that the level of uncertainty surrounding military R and D programs is typically high and that subsystems once developed are remarkably flexible in their applicability to particular weapon systems.

Rather than treating the aircraft according to the strict chronological order of their development, we have followed a more meaningful arrangement. The fighters whose origin can be traced back to the interceptor competition held in 1950-51 (the F-102/F-106, F-100, and F-104) are treated first. Within this group, we begin with the F-102 because it was the earliest aircraft put under development as a result of the competition. The much later F-106 is treated simultaneously with the F-102 because the development of the F-106 is intimately tied to that of the F-102. The F-100 and F-104 cases follow in the order in which development of these aircraft began. The F-101, whose origin was outside the interceptor competition, is treated separately. The Republic F-105 and the North American F-107 fighter bombers, which were in direct competition with each other, appear together after the history of the F-101. The remaining aircraft in the Century Series -- the Republic XF-103 and the North American F-108 -- are omitted because they were cancelled before reaching flight status.

II. THE CONVAIR F-102A AND F-106A INTERCEPTORS

In the late 1940's several factors were of particular importance in shaping the concept of air defense out of which the F-102 and F-106 aircraft emerged. First, the interceptors soon to enter inventory were expected to have only marginal capability against Russian jet bombers expected to become operational in the early 1950's. Flying at near Mach 1 speeds at altitudes of around 50,000 feet, these bombers would provide elusive targets for the North American F-86D and the Northrop F-89, which were subsonic and had combat ceilings of under 50,000 feet.

Second, successful interception of such bombers involved reliance on the continued development of air-to-air missiles, rockets, and radar fire-control systems to provide all-weather capability in detecting and identifying enemy aircraft, in positioning the interceptor in the optimal flight path for the kill, and in preparing and firing weapons at the proper instant of time. In the new era of extreme speed, visual methods of aiming and conventional machine gun armament became hopelessly obsolete. At the same time, the increasing complexity of electronic equipment threatened to make impossible demands on the single pilot during the final intercept phase. Use of a second crewman, as in the F-89, to ease this burden involved weight and space penalties that made this solution only a stop-gap measure. Stress was therefore placed on making the "ultimate" fire-control system as automatic as possible.

Finally, in the late 1940's, considerable attention was directed to the desirability of designing from the outset airframe, engines, fire control, and other equipment to be operated together in an integrated weapon system. This approach stood in contrast to the more or less piecemeal fashion in which technological advances (such as the B-29, P-51, F-80) of World War II and the early postwar years had been made. Typically, under the latter approach an airframe was developed, after which the engines and supporting equipment, developed under separate programs, were requisitioned "off the shelf" to complete the system. Problems arose because components so tied together were not always compatible: an airframe might be developed for which no suitable bombing-navigation system was simultaneously available, or environmental conditions imposed by the aircraft might be outside the tolerance levels of its electronic equipment. Because it was felt that the attainment of ever higher levels of aircraft performance in the future would entail progressively more restrictive environmental conditions, more stringent space limitations, and greater difficulty in keeping component development in phase, the notion of applying the new "weapon system concept" to subsequent aircraft development became increasingly popular.

In 1949 General M. S. Fairchild, Air Force Vice Chief of Staff, and Major General G. P. Saville, Chief of the Air Defense Command, presented to Air Force Headquarters the idea of a coordinated development program of an interceptor system capable of dealing with the enemy threat during the 1954-1958 time period. This effort culminated in a directive to AMC calling for "the development of the one-man radar presentation for interceptor aircraft" and "an interceptor competition...to meet military characteristics now awaiting approval."[1]

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[1] Letter, Maj. Gen. Power, Asst. DCS/M, USAF, to Hq. AMC, 4 Feb. 1949, subj: Interceptor Program.

In May 1949, Generals Fairchild and Saville and other officials held a series of presentations in Washington before a large group of representatives from both industry and the military. Among other things, they outlined the problem of air defense and broached the subject of the weapon-system concept in which they envisaged the various components such as airframe, armament, ground and airborne radar, communications, servicing facilities, etc., as forming an integrated, complete defense network.

Since the Air Force believed that development of a fire-control system would take longer than development of the airframe, and since the airframe was planned to be tailored to the requirements of the electronic and control system, a competition for the electronic and control system was held prior to the competition for the airframe. Requests for proposals and an outline of requirements for the electronic and control system were sent to 50 firms in early 1950. By early April, 18 companies had offered proposals. Cost estimates for the development program ranged from the $1,680,000 figure of Emerson Electric to the $14,250,000 from North American. In July 1950, Hughes was named winner of the competition, and a first-year contract for $1,500,575 was subsequently negotiated for its MX-1179 electronic and control system.

In September 1950, AMC sent requests for airframe proposals to 19 aircraft companies. Requirements were written around an interceptor to be operational in the 1955-59 time period and capable of intercepting bombers having a maximum speed of Mach 1.3 and flying at altitudes up to 60,000 feet. Armament included the MX-904 (Falcon) missiles and 2.75 inch rockets; combat radius was specified at 375 nautical miles. The aircraft was to be directed automatically to the target area by the ground-based Aircraft-Warning and Control System tied directly by data link to automatic intercept-course computers and an automatic flight-control system in the aircraft. After the aircraft locked onto the target, the armament was to be aimed and fired as directed by the fire-control system. It was planned that the pilot have only a monitoring function during the intercept. That the new weapon-system concept was to govern the development of the interceptor was emphasized in an introductory statement to the request for proposals:

> The problem of interception can be solved successfully only by effecting the highest degree of integration of electronic and control equipment into the design of the airplane. To insure the success of the new interceptor, it will be mandatory for the aircraft and the electronic and control system manufacturers to coordinate extensively both developments. In this respect, the prime responsibility for the satisfactory functioning of the airplane as a weapon will rest with the aircraft manufacturer.[1]

By the end of January 1951, the deadline for replies, six firms had submitted a total of nine proposals. Republic offered three, North American two, and Chance-Vought, Convair, Douglas, and Lockheed each proposed one design.

For our purposes, only one proposal, the MX-1554 of Convair, need be discussed in detail. It called for a delta-wing, single vertical-fin configuration resembling Convair's earlier XF-92A.[2] The advantages claimed for this configuration were:[3]

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1 AMC, "Request for Proposals in Design Competition for a New Interceptor Fighter Aircraft," 1 September 1950, MCREOA-4/WRR/bmm.

2 This earlier aircraft was designed to flight-test a delta-wing platform.

3 Convair letter to AMC, 26 January 1951.

1. Low weight and high rigidity with very thin wing sections
2. Low drag at transonic and supersonic speeds
3. Adequate stability and control without addition of a horizontal tail
4. High maneuverability and freedom from buffeting with a smooth stall development and excellent spin recovery characteristics as compared with conventional swept-wing configurations

Convair specified the Wright J67, an engine presumed to be available by June 1954, for use in the ultimate version. In addition, it suggested the Westinghouse J40, programmed to be available nearly 3 years earlier, for use in early test-flight vehicles. A prototype, using the J40, was expected to fly in 1952 or early 1953. Specifications for the aircraft were:

	J40 (13,700 lb. Thrust with Afterburner)	J67 (21,100 lb. Thrust with Afterburner)
Maximum Speed (Mach)	1.88	1.93
Combat Ceiling (ft.)	56,500	60,200
Combat Radius (n. miles)	715	768
Take-off Weight (lbs.)	22,472	22,940

Convair's cost estimates for two prototype airframes were:

Phase I	$ 468,675	- Preliminary design and mock-up
Phase II	4,007,848	- Fabrication
Phase III	624,019	- Flight test for one year
Total Cost	$5,100,542	

Cost estimates for production airframes ranged from approximately $500,000 per unit for 25 to approximately $190,000 per unit for 300. Given an order for 300 units, a March 1951 go-ahead, and availability of Hughes' MX-1179 in June 1953, Convair specified initial deliveries in 1954 and a production peak of 15 per month in the spring of 1955. Armament was to consist of six MX-904 (Falcon) missiles and nineteen 2.75 inch FFAR rockets, all internally mounted.[1]

On the basis of these and other claims, Hq. USAF announced in July 1951 that Convair, Lockheed, and Republic were the winners of the competition, that each would be given a Phase I contract, and that one would be given a production contract on the basis of the results of Phase I work. It appears, therefore, that the intention of the Air Force was to keep several contractors in the program but to make only small commitments to each of them early in development in order to "purchase" information and delay the major decision concerning a production contract because of the relatively high costs involved until more knowledge was available.

However, the strategy of sponsoring competing programs was changed soon thereafter. Only a month later Lockheed was notified that it would not be given a development contract. In addition, Republic was informed two weeks later that development of its aircraft, the AP-57, would continue as a separate, long-range program because its success would rest on development of the J67 in combination with a ram-jet arrangement utilizing the afterburner -- a joint development that would take some years. Consequently, by the end of September 1951, Convair remained the only contractor upon which the Air Force could depend for development and production of an interceptor whose characteristics might have been expected to meet the requirements set forth in the competition.

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1 Convair, MX-1554 Interceptor, Logistics Information, Report No. ZP-50-10004, 29 December 1950, various pages.

While the original commitment to Convair was small in dollar terms, in in August 1951 the contractor was awarded a Phase I letter contract for $200,000[1] covering wind-tunnel work, rocket tests, and mock-ups to be completed within 9 months. The strategy of small dollar commitment by the Air Force was also soon modified because of the turn of events in the fall of 1951. During the aircraft evaluation, Hq. USAF concluded that none of the proposals would result in an operational aircraft by 1954. By the fall of 1951 it appeared that Convair's MX-1154 would not be available before 1956 because of expected delay in the delivery of the MX-1179 fire-control system and the J67 engine. An obvious candidate for an "interim" interceptor for the 1954-1956 time period was the MX-1554/J40 version that Convair had suggested as a test-flight vehicle. After the flight-test program this aircraft was to be fitted with either the MX-1179 or an "interim" electronic and control system. Cost estimates were requested in October from Convair covering development through two prototypes and production of 25 airframes in the first year, with tooling to support a build-up to 50 per month. The figures were:

Development	$ 6,683,215
Production (25)	14,281,570
Tooling	10,995,676
Total	$31,960,461

Other candidates for the interim role, the Douglas F4D, the Republic XF-91A, and the North American Sabre-45, were also considered.

The Air Force decided in favor of the MX-1554 in November 1951. The first 50 aircraft to be used for an accelerated test-flight version were

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[1] Additional expenditures were contemplated, however, under Phase I. Convair had estimated the total cost at $781,987 before the contract was signed.

designated the YF-102; the follow-on tactical version of the interim aircraft was designated the F-102. (The "ultimate" version of the aircraft was designated the F-102B in late 1952.)

ARDC and AMC assumed authority to select the most suitable power plant, fire-control system, and flight-control system that would be available at the time the interim aircraft rolled off the assembly line. Production was to be conducted under the "Cook-Craigie" plan in which Convair was given the green light to proceed with production tooling prior to first flight of the prototype. Early production was to include only a few planes per month in order to provide an inventory for an intensive flight-test program. While eliminating the bugs in the airframe, Convair could at the same time modify its tooling and presumably be in a position to move into large-scale production build-up within a relatively short time.

> ...The over-all objective of this program is designed toward getting an operationally effective weapons system into tactical use at the earliest possible date and to obtain the ultimate 1554 interceptor through normal model-improvement of the initial production aircraft.
>
> ...The early production aircraft will utilize the *same airframe* as the ultimate article; however, available production type equipment, systems, components and engine will be used in the early configuration.
>
> ...The first year's production will be at the minimum rate required to provide a sufficient number of aircraft to conduct a comprehensive test program. *Tooling and other preparations for full-scale production will be made.* Production build-up will be authorized by this Headquarters when it is determined through testing that we have a tactically suitable article.[1]

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[1] Letter from Lt. General O. R. Cook, Deputy Chief of Staff, Materiel, to AMC, 26 November 1951, "Development and Production of Convair MX-1554." Italics not in the original.

This was, of course, a major decision involving expenditure of many millions of dollars for tooling, manufacture of hardware, and flight testing, in contrast to the hundreds of thousands of dollars involved in Phase I contracts planned at the time of the aircraft competition. AMC did not immediately award a definitive contract to cover this additional work. However, in January 1952 Convair's original letter contract was increased by 1.8 million dollars to implement a production-engineering and tooling program. No large-scale production schedule was set at that time, but in early 1952 Convair was authorized to proceed with two YF-102 prototypes to be delivered in June and September 1953 and seven production-version aircraft to be delivered through January-August 1954.

There were several factors that apparently motivated the Air Force to make this major commitment early in the development of the aircraft. First, there was a growing preoccupation in the Air Force with reducing "lead-time" consumed in moving from paper-stage planning to operationally suitable aircraft. Under the development approach previously followed, typically one or two prototypes were constructed with relatively crude and inexpensive tooling, and the procurement decision postponed until after flight-test data were available. That this procedure might involve excessive time and duplication is well expressed in a May 1952 statement:

> It is not believed that an airplane produced partially by hand and partially with temporary tooling is a true representation of the final production article. As a result, much of the flight testing may have to be repeated on the first airplane fabricated with production-type tooling. Also, the fact that some parts can be satisfactorily fabricated by hand does not always mean that these same parts can be readily produced within the acceptable tolerances with production tooling. ... Should the results of the first six months flight testing be favorable and a decision made to produce the aircraft in quantity,

> the time consumed in manufacturing the first article with production tooling would be essentially the same as for producing an entirely new aircraft.[1]

In addition, a rapid production build-up on the basis of limited flight testing of non-production prototypes had in the past frequently resulted in major defects being uncovered only after a large number of production aircraft had been built. (One of the best examples here is the B-47 experience.) This alteration resulted in expensive and time-consuming retrofit programs.

A proposed solution to these problems, the Cook-Craigie plan, enjoyed increasing Air Force support in the early 1950's, and the F-102 became the first aircraft tied to this new production technique. By constructing production-engineered aircraft with production tooling at the outset and holding output to a low level for about 18 months during the test program, the manufacturer would presumably discover and remedy the major difficulties before undertaking large-scale production. Furthermore, it was hoped that time and money would be saved in moving from an experimentally designed article to one suitable for mass production.

Another factor bearing upon the Air Force decision was the presumption that development, production engineering, and tooling cost of the interim version of the interceptor would not have to be duplicated for the ultimate version, since the original plan was to construct a common airframe for both. Only the engine and possibly the fire-control system and other supporting equipment were to be different. Consequently, the Air Force had no reason to believe that costs for the over-all program would significantly increase because of the independent interim effort.

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[1] Letter from AMC to Hq. USAF, 16 May 1952, "Initial Production Rate for New Model Aircraft." Italics in the original.

A third factor, and one related to the second, was that when Convair was authorized to proceed with the interim version, the "best guess" was that the MX-1179 fire-control system would be available and that no separate interim system, which would involve additional development cost and possibly delays in the MX-1179 program, would be necessary. While ARDC and AMC had authority to select another fire-control system if necessary, it was thought that the MX-1179 would be available for the tactical aircraft, especially since the first 50 or so aircraft built during the first year were to be used only for development and test purposes. The only firm change at the time was an engine switch from the J40, originally proposed by Convair for test-flight purposes only, to the Pratt and Whitney J57. The J67 remained programmed for the ultimate version.

It is notable that the Air Force had only limited knowledge concerning the performance and cost of the interim aircraft at the time it authorized the interim program in November 1951. It had the cost estimates provided by Convair in October (tabulated on page 11); it also had Convair's estimate of performance with the J57, which included a maximum speed of Mach 1.5 and an altitude of nearly 60,000 feet. However, the aircraft laboratory at Wright Field and NACA had not yet conducted wind-tunnel tests to verify Convair's figures.

During 1952 and early 1953 several things happened to bring about a radical shift in fire-control system programming. Hughes was beset with continuing delays, and the MX-1179 was falling behind schedule. In addition, during the summer of 1952 the Air Force cancelled the F-89F interceptor program, the aircraft that had been intended to precede the interim F-102 in ADC inventory. This decision made it even more imperative that the over-all interim program remain on schedule, which in turn forced a reappraisal of the availability and capability of alternative fire-control systems. The best bet for an interim system appeared to be the Hughes E-9, originally programmed for advanced F-89 interceptors, modified for use in the YF-102. Hughes estimated that a crude system would be available for installation in an early YF-102 by July 1954 and a refined version available in production quantities two years later.

A decision regarding the E-9 presented the Air Force with a dilemma. If no interim fire-control system program were interjected, it was felt that the MX-1179 would be ready for testing by December 1954, in phase with the YF-102 test flight program, and that production quantities would be available by April 1957, about a year behind the schedule for the E-9. However, with an interim fire-control system in the picture, the MX-1179 might be delayed an additional 18 to 24 months. Moreover, the E-9 as then developed had few of the automatic features of the MX-1179. The pilot would have to fly manually to and from the target area as directed by verbal ground instructions, he would not have the benefit of automatic flight itself, and there was no provision for an autopilot -- a feature generally considered essential for long intercept flights.

In early 1953 Hq. USAF decided in favor of the E-9 and shortly thereafter approved a proposal to develop an E-9 autopilot to be available for retrofit by September 1956. In addition, the decision included initiating work on a program involving pilot-assist subsystems aimed at providing automatic flight control and automatic attack modes. Possibly because of the increasing cleavage between the interim and ultimate versions of the aircraft, the nomenclature was revised: the tactical version of the interim aircraft, the F-102, was redesignated the F-102A, while the ultimate version was designated the F-102B. In the words of ARDC in March 1953:

> Every effort should be exerted to expedite the tactical availability of the F-102A whose configuration has been determined as incorporating the E-9 Fire Control System and the J57 engine. The F-102B configuration with the MX-1179 and J67 engine will be phased in at the earliest date without affecting E-9 availability for the F-102A.

A final note concerning the E-9 is that much more than a repackaging job was involved in the initial program. About half of the equipment had to be designed specifically for the F-102A in order for the system to operate at altitudes up to 60,000 feet, the combat ceiling of the aircraft. The original E-9 had been developed for altitudes up to only 50,000 feet. Despite the objection of Hughes that this modification would result in substantial delays, the Armament Laboratory insisted (in July 1953 after the E-9 decision had been made) on the higher altitude operational capability. Because of the major changes involved, the fire-control system for the F-102A was redesignated the MG-3.

During 1952 and early 1953, major changes were also made in the airframe involving substantial weight penalties -- weight increases that were later to play a critical role in the performance of the airplane. As originally designed, the aircraft was to carry the Falcon missiles in one bay directly below the engine and the rockets in a forward bay. This arrangement was based on a missile wingspan of 20 inches. Later in the development of the Falcon, Hughes discovered that the missile would have to be enlarged and, in particular, the wingspan would have to be increased to 24 inches. A simple increase in the size of the missile bay and the resulting increase in fuselage diameter would reduce the top speed of the F-102A by about

70 knots. Therefore a complete redesign of the armament bays was necessary. The missiles were installed in two tandem bays and the rockets placed in the doors of each bay. The fuselage was lengthened 20 inches, and with resulting changes in controls, wiring, etc., the airframe weight increase came to 130 pounds; the increase in missile weight totaled 111 pounds; changes in armament (increasing the number of rockets from 19 to 24 and providing an alternative load of 96 rockets in lieu of 24 plus 6 missiles) totaled another 380 pounds.[1]

Many other weight changes were also made. Some of the major ones were:[2]

	Item	pounds
1.	Change from J67 to J57	+ 326
2.	Increase in MX-1179 requirements (less the 150 lb. reduction when MG-3 was substituted)	+ 704
3.	Increase in wing weight due to correction of arithmetical error in original wing skin calculations (416 lbs.) and increase in design temperatures due to aerodynamic heating (84 lbs.)	+ 500
4.	Increase in airframe structure to provide for increased design tail side-loads (187 lbs.), and to provide strength for government-requested weight increases (315 lbs.)	+ 502
5.	Revision of missile bay structure due to air loads and aerodynamic heating	+ 121

[1] Two types of Falcons were to be used, either together or singly: the radar-guided GAR-1 that homes on echoes from the target generated by the radar signals of the interceptor and the infrared GAR-2 that homes on the heat waves radiating from the target. The combination of 6 missiles and 24 rockets has remained the armament of the F-102A to the present day.

[2] Convair, F-102A Weight History, Report ZW-8-002, June 1953, pp. 3-14.

The J67 version had been specified at 22,940 lbs. (gross take-off weight) during the design competition, but owing to these and many other weight increases the figure had grown to 27,789 lbs. by June 1, 1953.

During this time period a schedule of production was drawn up under the letter contract signed in 1951. Early in 1952, two prototypes were scheduled for June and September 1953 deliveries, and seven more aircraft were scheduled for January through August 1954. Slippages, due largely to the engine switch later in the year, caused a revision in deliveries to October and December 1953 and April through August 1954. In September 1952, 33 more aircraft at a price of $14.5 million were added to the contract for delivery September 1954 through July 1955.

Late in 1952 the Air Force negotiated a definitive contract (cost plus fixed-fee) for nearly 100 million dollars covering production of the 42 aircraft previously committed. During negotiations Convair submitted the following cost estimates:

2 Prototypes	$11,415,957
40 Production Aircraft	40,878,965
Production Tooling	10,978,989
Reports and Data	817,840
Mock-ups	228,472
Wind-Tunnel Tests	615,804
One Static Test Article	1,036,786
	$65,972,453
6 Per Cent Fee	3,958,347
	$69,930,800

Estimated tooling cost was based on a capacity of 125 airframes per month with a two-shift, five-day, 40-hour week. This relatively high capacity was requested by the Air Force to provide a high production buildup capability after completion of development and testing. During the negotiations, Convair's figures were considered quite reasonable; it was around this figure, therefore, that negotiations were completed. The contract, AF33(600)-5942, covered the following:

2 Production Prototypes	$11,714,038
40 Production Aircraft (with tooling)	51,443,651
Spare Parts	15,181,446
Special Tools & Ground Equipment	1,156,120
Training Parts	3,160,377
Engineering Data	603,540
Mock-ups	240,282
Wind-Tunnel Tests	639,786
Static-Test Article	1,089,857
Mobile Trainer	325,000
	$85,554,105
6 Per Cent Fixed Fee	5,133,246
Allotment for Engineering Changes	8,940,726
	$99,628,077

During this same period of time there occurred a debate about the drag of the F-102A that culminated in an extensive modification of the aircraft. Early in 1952 WADC engineers disputed Convair's claim of a 57,500 foot ceiling and a 350 nautical mile combat range for the J57 version, believing that insufficient allowance had been made for "trim drag." NACA subsequently conducted an analysis of drag and came to conclusions that were disquieting: actual ceiling was estimated at 52,400 feet, combat range at 200 miles, and even the supersonic capability of the aircraft was held in doubt -- all due to an expected "unusually high transonic drag rise." NACA, furthermore, developed the "ideal body theory" and recommended that it be incorporated in the F-102 design. Very briefly, this theory, based on the work conducted in 1952 by Richard Whitcomb and R. T. Jones, indicated that in order to compensate for the drag of a delta wing at transonic and supersonic speed, the fuselage would have to be indented like a coke bottle at the juncture of fuselage and wing and elongated to conform to a minimum acceptable ratio of fuselage length to cross-section area.[1] By early 1953 wind-tunnel and rocket tests of models incorporating the indented and elongated fuselage confirmed the belief that Convair's early estimates were wrong. In August 1953 Convair accepted the "ideal body theory" and joined in recommendations to the project office concerning necessary modifications.

These modifications were fairly extensive. Besides the indentation, they involved lengthening the fuselage by seven feet and moving the wing and vertical fin rearward. In addition, a cambered leading edge to increase lift and "warped" wing tips to reduce trim drag were included in the program. The modifications amounted to a 1100 pound weight increase. Specifications called for a maximum speed of Mach 1.32 and a combat ceiling of 53,000 feet.

The configuration change complicated the program because under the Cook-Craigie plan Convair had already tooled up for production of the old configuration. Changes in tooling would involve scrapping about two-thirds of the 32,000 tools already procured. The cost of this plus the cost of undertaking extensive engineering changes Convair estimated at about 15 million dollars. Because hardware fabrication was well along for the first few articles, Hq. USAF authorized that the two prototypes to be delivered in October and December 1953 proceed on schedule, that an additional eight

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[1] The "coke-bottle" modification was intended to improve performance in the transonic region while a different modification, later proved out by Jones, was intended for aircraft flying in the Mach 1.2-2.0 regions.

of the old configuration, already far along in the works, be completed during 1954, and that beginning with the eleventh aircraft all the remaining 32 incorporate the modifications. The first ten were designated YF-102, and the new version, F-102A. (The "ultimate" version, the version proposed originally by Convair with the J67 engine and the MX-1179 fire-control system, remained the F-102B.)

The prototypes, built with production tooling, were delivered on schedule. Flight tests confirmed the fear that the plane would be subsonic. Maximum speeds attained were about Mach .98. Maximum altitude tests in April 1954 indicated a combat ceiling of under 50,000 feet.

At the beginning of 1954 it became apparent that more than the "ideal body" modification would be necessary to provide adequate performance in air defense. By itself the modification was expected to add only .1 Mach to maximum speed (with the J57 engine), while combat altitude would remain below 50,000 feet. The F-102A had simply grown too much in weight since it had been originally conceived in 1951. Take-off weight with all the preceding modifications, and many others, had risen to 29,937 pounds by early 1954, as compared to the original 22,940 pound estimate. Air Force officials felt that only an engine such as the J67, in the 20,000 pound thrust class, as compared with the J57's 15,000 pound thrust, could provide the kind of performance needed. But prospects for the availability of the J67 were growing bleaker and bleaker. In fact, there was increasing talk of substituting the J75 for the J67 in the "ultimate" version (F-102B). Rather than halt development of the interceptor pending availability of a larger engine, the decision was made to reduce drastically the weight of the airframe of the F-102A. The airframe had been designed to withstand satisfactorily the stresses that would be exerted in flight with an engine producing over 20,000 pounds thrust. But with the 15,000 pound thrust J57, it would be possible to reduce the dimensions of structural members without reducing structural integrity within a lower-stress flight environment. But this involved serious problems. First, the airframes originally planned for the F-102A and the F-102B were to be identical, thereby requiring only one set of development and tooling costs. With two distinct airframes in the program, subsequent F-102B airframe development and tooling costs would be in addition to all the costs incurred in the interim program. Furthermore, the tooling needed to produce "ideal body" F-102A's beginning in early 1955 was modified from that employed in constructing the ten YF-102's. To carry out a second program involving weight reduction, even more tools would have to be replaced or modified and substantially more engineering changes would be needed.

Nevertheless, the Air Force approved this second modification program, estimated by Convair to cost $15 million. It involved not only reducing weight by about 2400 pounds, but also modifications involving nose lengthening, canopy redesign, intake redesign, and aft wing fillets. The planned take-off gross weight of the final light weight version was 28,061 pounds, 5000 pounds above the original 23,000-pound estimate made in 1951. Rather than produce the remaining 32 aircraft under the contract with only the "ideal body" modification (as planned in late 1953), Convair was directed to proceed with <u>four</u> of these as planned and then apply the second modification program to the remaining 28. Only the last 28, therefore, were expected to enter the air defense inventory. In summary, the following is a tabulation of the models comprising the 42 aircraft:

YF-102/F-102A -- First Contract

2 - production prototypes
8 - unmodified production versions
4 - "ideal body" modification, heavy weight versions (synthetic weight reduction applied to first aircraft)
28 - both "ideal body" and weight reduction modifications
42

Convair produced the remaining eight of the first version during 1954. These were used in various phases of flight testing that did not involve supersonic flight. The first "ideal body" aircraft flew in December 1954. In order to approximate the flight characteristics of the later light weight aircraft, it underwent an arbitrary weight-reduction program in which over a ton of equipment was simply tossed overboard. Flight tests with this aircraft indicated substantial improvement in speed (Mach 1.2+) and an altitude capability superior to the YF-102's. The other three heavy weight F-102A's were delivered in early 1955. After discarding about one-half of the 28,600 tools used to manufacture the four heavy weight F-102A's and adding another 20,000 tools to the production line, Convair completed the first light weight version in June 1955. The 28 light weight aircraft, to be used as test-flight vehicles, were produced at the rate of 2 to 3 a month; the last one was delivered in March 1956.

Phase IV performance tests on the F-102A (light weight, "ideal body") were conducted at Edwards in early 1956. The evaluation, which for the most part covered testing of the airframe-engine combination, is summarized:

The high rate of climb of the F-102A, a combat ceiling of 56,000 feet, excellent maneuvering capabilities at high altitudes, and 360 nautical mile radius of action make this aircraft greatly superior to any all-weather interceptor currently in use. Maximum speed of the F-102A approaches that of the North American F-100A and is adequate for interception of current bomber aircraft.[1]

The actual cost of these 42 aircraft produced under the first contract was in considerable excess of the original allotment of $99,628,077 (p. 20). Some of the additions involved the two major modification programs; others involved new items, such as flight testing. The following is a tabulation in rough figures of the major costs up to January 1957:

(millions)	
$100	Original allocation
41	Engineering changes in excess of original $8,940,000
37	Overruns
30	Major redesign (the two modification programs)
40	Flight-test program
9	Miscellaneous
$256	

Four other contracts were awarded Convair for the F-102A and the TF-102A, a two-place trainer version. Aggregate costs for the five contracts, with amendments added through January 1957, are as follows:

	Contract	Cost Summary (millions)	F-102A	TF-102A
FY53	AF-5942	$ 256	42	
FY54	AF-23903	101	37	20
FY55	AF-29264	135	108	28
FY56	AF-31174	489	562	63
FY57	AF-33695	80	140	
TOTAL:		$1,061	889	111

[1] Air Force Flight Test Center, F-102A, Phase IV, January 1957, frontispiece.

Production of the F-102 series continued through the summer of 1958, at the rate of about 2 a day. Amendments covering additional costs were added after January 1957 to these contracts; hence the total figure above cannot be interpreted as final.

The light weight version finally developed under the first contract was acceptable to the Air Force and the subsequent contracts were for this version. The first plane of its type was delivered to George AFB for squadron use in May 1956. As of October 1958, ADC had programmed 31 squadrons, consisting of a total of 800 F-102A's, to be equipped by the end of FY 1959.

Since 1954 the fire-control system has undergone considerable change. While in 1953 only an MG-3 was programmed (as discussed on pp. 16-17), a data link developed in the MX-1179 program and an automatic flight-control system were added so that the system, now designated as the MG-10, provides increased capability. Air defense direction centers in the SAGE network can send steering instructions to the pilot through the data link, providing visual presentation on an airborne radar indicator -- a considerable improvement over voice communication. Altogether the MG-10 system provides an automatic radar search function, automatic steering signals during the intercept phase, automatic aiming, readying and firing of armament, plus such auxiliary features as automatic target identification, radar-beacon nevigations assists, and automatic instrument landing up to "flare out."

At the close of 1956, the operational capability of the F-102A weapon system was low. The Air Proving Ground Command at Eglin AFB concluded after operational suitability testing in late 1956 that many improvements were needed. To quote from the report:

The present F-102A Weapon System cannot effectively perform the assigned air defense mission. Specific factors contributing to this lack of capability are:

(1) The unreliability of the complete weapon system, including the excessive failure rate of the missile launcher mechanism, missile auxiliary components and the GAR-1/1D (radar-guided) missile.

(2) The inability to determine that combat-ready systems are available on a continuing basis due to lack of adequate test equipment for the MG-10 Fire Control System.

(3) The low hit probability of the GAR-1 radar missile when all systems are apparently operating properly.

(4) The unreliability and excessive unscheduled maintenance requirements of the AN/ARC-34 radio antenna installation in the F-102A.

(5) The inability to turn around more than 50 per cent of available aircraft to a combat-ready status during multiple interceptor employment.

(6) The unsuitability of the "snake" mode of the MG-10 radar when used for recognition approaches on unknown aircraft under conditions of low visibility.

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The unreliability of the complete F-102A Weapon System will have a tremendous effect on the combat capability of converting units. This situation is compounded by the present lack of test equipment that could reveal these failures on a continuing basis rather than at scheduled inspection periods. Added to this unreliability factor is the low kill probability of the F-102A when missiles are fired in an operational environment. The results of this test whereby only 6 passes out of 21 attempts (29 per cent) resulted in hits being registered on a QB-17, indicate a limited combat effectiveness.

This indicates that the using commands are to be faced with a low combat capability until the existing deficiencies are corrected. The low dependable operating time of certain components within the complete system does not appear to be an insurmountable problem. Test equipment to detect these malfunctions rapidly can be provided. Therefore some hope exists in realizing the potential that this weapon system possesses.[1]

In addition, in-commission rates in squadron use were very low in 1956 and 1957 largely because of a low level of reliability of the

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[1] Air Proving Ground Command, Final Report on Employment and Suitability Test of the F-102A Weapon System, January 1957, pp. 1-5.

fire-control system and a general shortage of spare parts. In mid-1957, about 30 per cent of the 300 F-102's in the ADC force were operationally ready compared to an over-all rate for all ADC aircraft of 55 per cent. By the end of 1957 the operationally ready rate had risen to about 50 per cent.

To improve the reliability of the fire-control system and, in general, to increase over-all system capability in accordance with the recommendations of the Air Proving Ground Command, a major retrofit program was instituted in late 1957 to bring all earlier F-102's up to the configuration of the 459th aircraft. The program, which involved a cost of about $43 million, was completed in late 1958.

Hughes has also sought to improve the reliability of the GAR-1 radar-guided Falcon, whose shortcomings were noted in the 1956 Eglin tests. The GAR-1D, which incorporates modifications in guidance systems and fin configuration for increased altitude capability, constitutes a significant advance. According to ADC sources, the GAR-1D is presently working well within the F-102 system. About 1100 of the approximately 2500 GAR-1's that have been built are being used for training purposes. The remaining 1400 have been put in storage.

All in all, with the retrofit program on the F-102A and with the improvement in Falcon capability, the weapon system now has an acceptable level of over-all effectiveness. The in-commission rate has continued to rise, standing at about 60 per cent for the 24 ADC squadrons existing in June 1958. Although the aircraft has not been modified to include the highly effective Douglas MB-1 nuclear rocket, which is appearing on other interceptors, ADC regards the F-102A as an important contribution to air defense.

As for the "ultimate" version of the interceptor, the version with which Convair had won the competition back in 1951, a contract was let from FY 1955 funds for 17 F-106A's (earlier designated the F-102B). Another contract for 18 F-106A's along with seven F-106B's (2-place trainers) was let from FY 1957 funds. An engine switch from the J67 to the J75 was made in 1955, but Hughes' MX-1179, now the MA-1, has remained throughout for the interceptor program.

There are numerous differences between the F-102A and the F-106. Among other things the latter has a redesigned tail, increased fuel capacity in the fuselage, armament changes (two MB-1 nuclear rockets and two Falcon missiles in lieu of six Falcons plus 24 2.75 inch rockets), and redesigned and repositioned air inlets. The MA-1 provides a superior capability over the MG-10. The total mission after take-off can be flown automatically under the guidance of SAGE, with the pilot providing only a safety and a monitoring function. In the case of the MG-10, the pilot still flies the aircraft from take-off to landing, except when on automatic attack mechanism and automatic pilot, and he has the responsibility of selecting targets and interpreting data supplied by ground stations.

Other comparisons are tabulated below:

	F-102A[1]	F-106A[2]
Maximum Speed (Mach)	1.19	1.8
Combat Ceiling (ft.)	56,000	53,000
Take-off Weight (lbs.)	27,300	33,100
Engine Thrust (with afterburner)	16,000	23,500

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[1] Specifications based on Phase IV testing completed in May 1956.

[2] Specifications based on Phase II testing completed in June 1957.

The total cost forecast on 15 April 1958 for completion of the 42 F-106's on the first contract is as follows:

17 each F-106A - Airframe and Tooling	$ 7,800,000
18 each F-106A - Airframe	32,226,162
7 each F-106B - Airframe and Tooling	34,450,000
Training, Spare Parts, and Data	11,797,217
Mobile Training Units	1,908,000
Delivery Stretch-out	4,643,000
Contract Overrun	22,305,140
Engineering Changes	37,598,130
	$223,727,649

First flight of the F-106A took place in December 1957; Phase II testing was completed in June 1957. In Phase II the aircraft failed to meet Convair's specifications. In the words of the test report:

> The F-106A performance is lower than that predicted by the contractor. The airplane is capable of approximately 1.8 Mach number in level flight at 36,000 feet under standard day conditions as compared to a predicted Mach 2 capability. The maximum power combat ceiling is 53,000 feet, 2,400 feet lower than predicted, but an altitude of 60,000 feet was reached briefly from a zoom climb initiated from 1.7 Mach number at 40,000 feet. The steady state maneuvering capability at supersonic speeds is thrust limited to load factors less than 2.5 g above 30,000 feet. The general stability and handling characteristics throughout the speed range tested are good. The longitudinal and directional control is good but the lateral control is too sensitive around neutral. The prototype cockpit is unsatisfactory and will require redesign. The ejection seat is inadequate for bail-out at supersonic speeds. Except for the lack of performance the prototype airplane tested as the potential of being an excellent Air Defense Command interceptor. Satisfactory demonstration of stalls, spin recovery, inertial coupling, and dead-stick landings, as well as an operational fire-control system, are required before the aircraft is delivered to operational units.[1]

A modified F-106A, incorporating a new engine inlet-duct configuration, a different engine dash number, and modified wing camber, was later subjected to another Phase II test at Edwards. First squadron deliveries

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[1] Air Force Flight Test Center, F-106A Phase II Flight Evaluation, October 1957, frontispiece.

were made in the summer of 1959.

In mid-1957 ADC had planned a total build-up of 40 squadrons (over 1000 aircraft) of F-106's. During the budget crisis in the fall of 1957, the procurement of the aircraft was cut back to 26 squadrons, and during that time serious thought was given to cancelling the program entirely. In June 1958 the program was again cut to 16 squadrons, and as of October 1958 it was down to 15 squadrons, consisting in total of 285 F-106A's and 56 F-102B's.

There were several reasons for the cutback in programming. The budgetary constraint forced ADC to re-examine all of its programs. The F-106 program, because it involved particularly large sums of money, bore the brunt of the retrenchment. The aircraft had also been subject to numerous delays during development (it went into service in 1959, a date originally considered in the competition to be the <u>last</u> year of first-line use for the interceptor for which the competition had been conducted), and other weapon systems which were not in the picture in earlier years have been substituted to some degree for the F-106.[1] One such system is the BOMARC missile. Another is the McDonnell F-101B interceptor, an outgrowth of the F-101A, which was never planned to serve in an interceptor role but was originally conceived as a SAC escort fighter. Because of the relative promise of the F-101B, it was given in 1957 a development priority higher than that of the F-106A. While squadron planning for the F-106 was cut to 15 squadrons and 341 aircraft, in October 1959, the F-101B planning included

[1] In February 1957 the F-106 was set back six months largely because of engine and fire-control system difficulties. At the same time strong consideration was given to dropping the program or converting it to a 2-place long-range interceptor.

at the same time 19 squadrons and 494 aircraft. The F-101B and F-106A are closely competitive -- the latter has a higher maximum speed and greater altitude capability, but the former has a longer combat radius.[1] The MA-1 fire-control system of the F-106 is probably superior to the MG-13 of the F-101B, but the MG-13 is more fully developed. ADC has anticipated less trouble with the MG-13 in early squadron use because it represents mainly a repackaging of the F-102's MG-10. Finally, the F-101B is, all in all, a less expensive system.

CONCLUSIONS

What can we learn from the history of development of the F-102/106 interceptors? Since this particular case history embraces the first use of both the new weapon-system concept and the Cook-Craigie production method, it ought to tell us something about the fruits of Air Force programming within the weapon-system/Cook-Craigie framework.

First, on the basis of this experience, it seems clear that the initial plan to integrate specific components, yet to be developed, into a final complete weapon system does not in any way guarantee that the final product will, in fact, contain these components as envisaged. The greatest difficulty, pointed up in the F-102/106 case, is that development of the components may very quickly get out of phase. Convair presumed in early 1951 that the J67 would be available by June 1954; that the J40 could be flight-tested by August 1951; and that the MX-1179 would be available by June 1953. Under these conditions the development of an integrated weapon system to be

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[1] The F-101B has a maximum speed (at 35,000 ft.) of about Mach 1.7, a combat ceiling of 50,000 ft., and a combat radius of about 600 n. mi., compared respectively with the F-106A figures of Mach 1.8+, 53,000 ft., and 350 n. mi.

operational within the specified time appeared plausible. But both the J67 and J40 very soon thereafter were beset with delays. Because of the time-phase problem in late 1951, the whole idea of the "integrated" weapon system had to be scrapped for the interim F-102 program; AMC and ARDC were given the responsibility for picking the "best available" subsystems for the F-102 airframe. As it turned out, they had to pick both a new engine and fire-control system. As for the F-106A, the lag in development of the MX-1179 has been met by a commensurate lag in airframe development.

A second difficulty of the new weapon-system approach is that when components are planned from the start to operate together, they are designed to operate within the environment expected to be imposed by the other components (indeed, this is the rationale for the whole concept). The expected environment, in turn, is determined by the expected performance, weight, physical dimensions, etc., of these components. In the case of the F-102/106, these expected parameters underwent radical changes that generated interactions adversely affecting cost, performance, and production schedules of the system. For example, the increase in the size of the Falcon missile forced redesign (fortunately at an early state of development) of the fuselage. Progressive increases in the weight of the missiles and the fire-control system contributed unplanned weight increases in the system not only directly but also indirectly because of the added airframe structure, fuel load, etc., required. The airframe was stressed for an engine in the 20,000-pound thrust class but ended up with one in the 15,000-pound class. The result was a system with unacceptable performance -- a problem that was solved only by separating development of the interim airframe from that of the ultimate version.

In the case of the F-102 the interjection of the Cook-Craigie plan involved early tooling and production engineering that contributed to inflexibility. In particular, the weight reduction program, for the purpose of making the airframe compatible with the J57 engine, entailed tooling-up for a third time. Moreover, with the previous version in the pipeline ("ideal body" but heavy weight version), the modification could not be effected until four aircraft of the previous version had been completed.

Another salient feature of the F-102/106 development is that cost figures were revised upward, performance figures were revised downward, and production dates were moved farther and farther into the future. In short, the final payoff of the design competition was far different from what had been planned at the time the F-102/106 program was initiated. In the original proposal Convair gave a cost estimate of $5,100,542 for two prototypes and about $400,000 per unit for 40 production airframes, or a total of about $21 million. By late 1951, estimates for development through two prototypes and production of only 25 aircraft had risen to $32 million. It was at least partly on the basis of this cost estimate that the Air Force made the decision to implement the interim program. Late in 1952 Convair quoted a price of about $66 million for production of 42 aircraft. The final development, tooling, and manufacturing cost, obtained by adding to the $66 million the cost of overruns, modifications, and engineering changes is about $183 million, a ninefold increase over the original estimate. These figures, of course, are for the interim version (F-102), which had lower flight performance than was specified in the original proposal.

The degradation in performance estimates can best be shown in a tabulation. The estimates that the AMC evaluation board made during the original competition are also included.

	Maximum Speed (Mach)	Combat Ceiling (ft.)	Combat Radius (n. miles)	Take-off Weight (lbs.)
Convair Proposal (J67)	1.93	60,200	768	22,940
AMC Estimate	1.83	58,000	-	-
First Model-102A (J57)	.98	40,000-47,000	-	-
Operational Model-102A (J57)	1.17	56,000	365	27,500
Early F-106A (J75)	1.8	53,000	-	33,100

Time to Climb from Sea Level
(Minutes)

Convair Proposal	to 45,000 ft.	2.02
AMC Estimate	to 45,000 ft.	2.14
Operational Model F-102A	to 50,000 ft.	7.10
Early F-106A	to 45,000 ft.	3.0

As for production schedules and slippages therein, it is again convenient to present the evidence in tabular form:

Delivery Schedule - F-102

	First Prototype	First Prod. Aircraft (Operational version)	Last One of 42
Convair Proposal (Jan 51)	Dec 52	Dec 54	-
Letter Contract (Feb 52)	June 53	Jan 54	-
Letter Contract (Aug 52)	Oct 53	Apr 54	July 55
Definitive Contract (Dec 52)	Oct 53	Apr 54	July 55
Actual	Oct 53	June 55	March 56

All in all there was a 10-month slippage for the prototype, a 6-month slippage for an operational aircraft, and a 9-month slippage in the completion of the first contract for just the interim version. The aircraft that essentially met the specifications set forth in the 1950 competition, the F-106A, did not fly until December 1957 -- 5 years after the date originally proposed by Convair in the aircraft competition held in 1950.

Finally, it is notable that while the Convair design was carefully planned from the start to provide an all-weather interceptor, the F-106A being the final payoff in this effort, another aircraft has become highly competitive with the F-106A. This is the F-101B -- an aircraft that was not in the picture at the time of the aircraft competition in 1950-51, and an aircraft that was envisaged at the beginning of its development not as an all-weather interceptor but rather as a SAC escort fighter.

III. THE NORTH AMERICAN F-100 SERIES

North American competed unsuccessfully in the interceptor competition held in 1950-51. When Convair and Republic were declared the winners and given the go-ahead to develop their proposals (out of which grew the F-102/106 series and the now cancelled F-103), North American at its own expense continued development of its "Sabre-45" proposal, an advanced version of the F-86.

The company spent about a year working on design studies and conducting wind-tunnel tests before receiving an Air Force contract for what was to become the F-100. Because of the desire of the Air Force for a new air superiority fighter to combat the MIG-15 encountered in Korea, against which existing USAF aircraft exhibited certain deficiencies, a procurement decision was made in November 1951 covering two prototypes and engineering, tooling, and long lead-time materials for implementation of the North American proposal. Thirty million dollars were committed to the program, but only $12 million were allocated in this initial phase. As a result of its earlier work, North American was able to provide a mock-up for inspection at the time of the Air Force decision to proceed with the F-100.

Negotiations leading to a letter contract were conducted during the rest of 1951. During that time North American succeeded in getting retroactive coverage to January 1951 for development work that had been financed out of company funds.

In addition, a clause was inserted calling for the implementation of a production program (94 aircraft were mentioned), including the purchase of long lead-time items, spare parts, tooling, etc., in preparation for "large scale" production.[1] The letter contract, AF33(600)-6545, was signed in January 1952. Delivery of the two prototypes was scheduled for December 1953 and January 1954.

Amendments made soon thereafter radically increased the size of the program. Amendment No. 1, dated February 1952, called for 23 F-100A aircraft to be delivered from December 1953 through July 1954. Delivery of the prototypes was advanced six months, to June and July 1953. Amendment No. 4, dated 11 March 1952, authorized fabrication of tooling (jigs, dies, and fixtures) to support a production rate of 25 aircraft a month and capable of a peak rate of 175 a month. Amendment No. 7, dated 26 August 1952, specified 250 additional vehicles to be delivered during the period August 1954 to July 1955.

The definitive fixed-price incentive contract covering these and other items was signed in December 1952. Some of the major items were:

Item	Estimated Cost
2 prototypes	$ 13,579,950
23 aircraft at 1,530,825	35,208,975
250 aircraft at 299,426	74,856,500
Static-Test article	1,530,825
Flight Test	4,074,781
Spare parts	29,480,598
Spare parts	500,000
Engineering Changes (alloted)	1,728,549
Other (Wind-Tunnel models, manuals, etc.)	11,262,364
TOTAL	$172,222,562

The prototype and production versions were to be identical except for the engine (the former had the XJ57-7; the latter, the J57-7), the afterburner nozzle, and the aft fairing of the fuselage underbody.

[1] WADC, Historical Branch, Office of Information Services, Historical Resume, The F-100 Program, Initial Stages, p. 3.

Specifications of 18 May 1952 described a plane with a wing span of 36.58 feet, a length of 45.19 feet, and a gross take-off weight (clean) of 24,989 lbs. GFAE included an AN/APX-6 Radar Set, an A-4 gunsight, an AN/APG-30 Gunlaying Radar, and four 20 mm Type T-160 guns supplied with 1100 rounds of ammunition. Maximum speed was estimated at Mach 1.31, service ceiling at 55,700 feet, and combat radius at 505 n. mi.[1]

A major reason for the large commitment to North American prior to completion of a prototype was the feeling that the program did not entail a major advance in the state of the arts.

> The selection of the 'Sabre 45' for production had been predicted on two principal circumstances: '...the confidence that our people have in the ability of North American to produce good equipment, and ...the fact that this airplane design does not represent major unknown areas of development.' The Air Materiel Command considered the airplane to be no more than '...a moderate advancement from the proven F-86 design.' Early production availability of a high performance air superiority fighter was the major consideration in the decision to buy the 'Sabre 45' on an 'off the shelf' basis, 'without benefit of the usual experimental program.'[2]

On the other hand, there was some reason for believing that major unknown elements did exist in the program. In July 1952, North American commented that:

> ...the structure of the F-100A airplane incorporates a number of features not yet widely used in the field of aircraft design. The wing, for example, is of heavy skin construction, up to 1-1/4 inches thick at the root, utilizing stringers machined integrally with the skin. The landing gear support ribs and root ribs are one-piece forgings. A further example is illustrated by the fuselage structure, which incorporates such features as tapered skins, forged frames at critical locations, stressed panels of metallic honeycomb, and a rear fuselage constructed almost entirely of titanium.
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1 North American Aviation, Inc., Report NA-51-594A, May 1952, various pages.
2 WADC, Historical Resume, p. 4.

> Not only was the wing new in both design and structure, but the fuselage, air intake, tail assembly, armament installation provisions, and a number of other prominent elements departed significantly from previous practices of design and construction. The J-57 engine, produced by a firm which, like North American, had a high reputation for engineering excellence, was nonetheless in an early stage of development when it was scheduled for use in the F-100. It was further complicated by the addition of an afterburner, a feature never tested in conjunction with that particular engine.[1]

Finally, in February 1954, North American commented:

> Recognizing that this airplane is a completely new development and is the first combat aircraft capable of sustained flight and combat maneuverability at supersonic speeds, we have expected that *major development would be required.*[2]

Considerable apprehension was expressed in the Air Force concerning the conduct of the program. The first production model was due only six months after delivery of the first prototype -- a time plan that would allow few changes in the aircraft as dictated by test-flight evaluations. In fact, the test-flight program as originally conceived was such that *all* of the F-100's on contract would be delivered before flight testing could be completed. (The program was subsequently modified to include 36 aircraft in flight-test inventory to permit a more rapid completion of flight evaluation; nevertheless, the evaluation was to be completed only after a substantial number of aircraft had been produced.) Moreover, the prototype itself was to be a production-engineered aircraft constructed with hard production tooling -- any major changes found necessary during flight test could be time consuming and costly to incorporate on the production line

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[1] *Ibid*, pp. 5-6.

[2] Ibid., p. 17. Italics not in the original.

because of the large tooling program planned by the time of first flight. In September 1952 (after the additional 250 aircraft had been programmed) Major General Albert Boyd stated that because several features of the F-100 would prove troublesome, a rapid production build-up should be delayed until evaluation of the first 25 aircraft had been completed. In the same week, Colonel V. R. Haugen, Chief of the Weapon Systems Division, warned that "... the early and rapid acceleration of this airplane into full production will cause considerable difficulty in reducing it to a practical, reliable weapon suitable for operational employment ... the schedule allows no opportunity for an orderly test program to uncover any unsatisfactory features which may well exist, before the production line is operating at full capacity."[1] In November 1952, General Partridge said, "I can only foresee that as now programmed, we are headed for another rash of groundings, retrofittings ... and all the things that have plagued us recently in the B-47, F-94C, and F-89 programs."[2] Nevertheless, the delivery schedule was not revised in any substantial way from that established in 1952.

The first YF-100A flew in May 1953, about 16 months after the initial implementation decision. Phase II flight evaluation was completed four months later:

> The test results indicate that the craft is superior in performance to any production fighter in the USAF. The most serious defects of the aircraft are the inadequate visibility over the nose during take-off and landing, the poor low-speed handling characteristics, and the negative to neutral static longitudinal stability experienced in level flight from approximately .8 Mach to maximum level flight speed.[3]

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[1] <u>Ibid.</u>, pp. 8-10.

[2] <u>Ibid.</u>

[3] Air Force Flight Test Center, <u>Phase II Flight Test of the North American YF-100A Airplane</u>, p. ii.

Flight testing continued into 1954 while North American proceeded with large-scale production. A follow-on letter contract for 230 aircraft in the C version was let in February 1954, and a definitive contract for 564 F-100C's was signed in June. The first squadron delivery of the F-100A took place in September 1954.

During this period, stability problems, in particular, plagued the program. Late in the test-flight series in November 1954, a fatal crash due to inertial coupling led to the grounding of the approximately 100 vehicles that had been produced during the 18-month span subsequent to first flight. To cope with these problems North American instituted a retrofit program on completed aircraft (consisting mainly of installing a larger vertical fin and adding a 12-inch extension to each wing tip) and incorporated modifications into the production line. The retrofit program was completed by August 1955. The first wing of F-100A's was operationally equipped in June 1955, four and a half years after the development program had been started. Supplemental agreement 43, signed in June 1955, provided for a cost increase on the contract of about $7 million, which presumably covered the cost of the retrofit and modification program.

In mid-1955, two years after first flight, the F-100A underwent its operational suitability tests at Eglin Air Force Base. Even at this late date many problems were noted. For example:

> Deficiencies in the engine limit the kill probability of the F-100A. These include compressor stalls with throttle manipulation and afterburner failure to ignite on many initial selections.[1]
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> . . . .

[1] Air Proving Ground Command, Final Report on Operation Suitability Test of the F-100A Aircraft, September 1955, p. 6.

The F-100A is severely restricted from optimum combat performance because of compressor stalls. Experience has demonstrated that compressor stalls may occur at any combination of altitude, power setting and flight condition ... Once compressor stall commences, the pilot has little or no choice except to break off any attack and regain control of the engine by all means at his disposal.[1]

. . . .

In combat it will be difficult to tell if explosive projectiles are hitting the aircraft or compressor stalls are occurring.[2]

. . . .

Serious limitations presently exist in the F-100A weapon system hindering its ability to deliver ordnance on an aerial target.[3]

. . . .

The results of an evaluation involving 29 sorties indicate that pilots flying the F-100A aircraft, as presently equipped with the MA-3 fire control system are not capable of firing satisfactory air-to-air gunnery scores. The exact cause of this limitation is unknown at this time, since on some passes with good tracking and with the pipper on the targets no hits were obtained. In addition, all pilots attempting air-to-air gunnery in the F-100A stated that smooth tracking was very difficult and that reticle vibration during gunfire was excessive.[4]

. . . .

When guns are fired at altitudes above 40,000 feet, an inverter failure indication sometimes occurs during the time of gunfire [this renders the gunsight and radar, as well as other equipment, inoperative]. Of even more significance, at altitudes above 50,000 feet a delay of up to five seconds often occurs between triggering and gunfire. The cause of these discrepancies has not been determined.[5]

These deficiencies have been alleviated in subsequent development of the aircraft. A series of engine modifications and an intake duct redesign have reduced the frequency of compressor stalling so that the operational

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[1] Ibid., p. 12.
[2] Ibid., p. 35.
[3] Ibid., p. 6.
[4] Ibid., p. 12.
[5] Ibid., p. 13.

capability of the aircraft is not now seriously compromised. The MA-3 fire-control system, consisting of the AN/APG-30 radar and A-4 gunsight, has never been modified satisfactorily for the aircraft. These components, which were developed during the time of the F-86, cannot make adequate correction in the steering and target data presented to the pilot because of the flight characteristics of the aircraft, namely, a general lack of stability as a gun platform and a tendency to porpoise at certain speeds and altitudes. However, pilots well accustomed to the characteristics of the weapon system have been able to achieve satisfactory target-practice scores by calling on their own judgment to aid in the operation of the fire-control system. For example, if they find that at given speeds and altitudes the system provides erroneous information regarding the amount of target lead, they can learn to make more or less proper allowance for it.

In the spring of 1955, 70 aircraft of the 250 that had been ordered under Amendment 7 were transferred to another contract covering production of the C version. The initial contract, the only one under which the F-100A was procured, therefore covered the two prototypes and 203 production vehicles. The last aircraft on the initial contract was delivered in the summer of 1955.

During the time these aircraft were produced there were many other changes and amendments to the contract that generated both cost increases and decreases. For example, a reduction totaling about $8 million was occasioned by a decrease in spare parts procurement. Small cost increases occurred because of numerous minor modifications, procurement of 500 wing tanks ($740,000), and a second mobile training unit ($495,000).

A firm (reset) target price for the 206 airframes (two prototypes, 203 production version aircraft, and one static test article) was established in March 1955 for a total of nearly $136 million. This figure is comparable to a $103 million figure calculated according to the terms of the original definitive contract.[1] In March 1957 a final renegotiation took place on this contract. The final price of the 206 aircraft came to about $134 million. With the renegotiated prices for the rest of the items covered in the contract, the over-all total (including fee) was about $186 million.

Besides the 205 F-100A's, over 2000 F-100's in the C, D, and F versions have been ordered by the Air Force. Over 1000 were delivered by the end of 1956, with little slippage from original schedules. The C, D, and F differ from the A primarily in modifications for larger external stores in fighter-bomber roles, and alteration in subsystems. The F-100D, for example, can carry either 42 FFAR (2.75 inch) rockets in six underwing clusters for a primary mission as a fighter bomber or four Sidewinder missiles as a day fighter, in addition to the four 20 mm guns.[2] It is also designed to carry a maximum external bomb load of 4500 pounds. Other features include a P-2 strike camera, in-flight refueling, and two 450-gallon external tanks. The F-100F is a tandem-seat version of the D with two guns instead of four. It serves as a proficiency and transitional trainer while retaining a tactical capability. The empty weight and gross take-off weight of the C and D versions exceed that of the A by about 2000 pounds and 4000 pounds respectively.

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[1] This is the total for two prototypes estimated at $13,579,960; 23 aircraft at $35,208,975; 180 aircraft ($299,426 each) at $53,896,680; and one static test article at $299,426.

[2] The addition of the Sidewinder missile to the F-100D system gives the aircraft a satisfactory capability as an interceptor within certain environments. See APGC, Final Report on Employment Suitability Test of F-100D/GAR-8 Weapon System, 29 Nov. 1[illegible]

ANALYSIS AND CONCLUSIONS

Several points brought out in the F-100 history merit attention. First, it is notable that the aircraft, though originally designed as an air-superiority fighter, has apparently proved quite versatile in being adaptable to a fighter-bomber role. This adaptation required some redesign of the airframe, alterations in equipment, and an addition of up to 4000 pounds in gross take-off weight. Yet North American was able to add various combinations of off-the-shelf items to the basic airframe and roll out a weapon system that the Air Force bought in large numbers. Although only about 200 aircraft were procured in the version originally planned, and although there were a number of difficulties with this particular version, ten times that number were procured in the subsequent versions. This turn of events illustrates two points: (1) components are often adaptable to weapon systems for which they are not originally designed, and (2) the preference scale of the Air Force may change through time (the effect of environmental uncertainty). Even if the Air Force gets the system it originally ordered more or less as planned (that is, even if the effects of technological uncertainty are of relatively small magnitude), it may find another system preferable. While the whole F-100 program was begun on the premise that an advanced air superiority fighter was needed, the Air Force, apparently finding a few years later that a fighter-bomber was more badly needed, procured the two at a ratio of 10 to 1 in favor of the fighter-bomber.

Second, while great caution is necessary in comparing one weapon system with another (there are features that are simply not comparable), it is notable that the development time of the F-100 program has been less than that of any other Century Series program. Even allowing for the year spent by North American on its own, the first wing was operationally equipped four and one-half years after initiation of the program. Time spent from USAF implementation to first squadron delivery for other Century Series aircraft has in no case been less than five years.

Third, the cost of development through the initial contract was relatively low. While $186 million was spent for development through 205 F-100A's, well over $200 million has been spent for the first 115 F-101's, over $200 million for 42 F-102A's, about $200 million for 15 F-105A/B's, and over $200 million for 42 F-106A's and B's. Only the F-104A, for which the first 228 articles may run to about $220 million, appears to be equally inexpensive.[1]

Finally, development of the F-100 has been accomplished in a fairly straightforward manner: Aside from the inertial coupling problem, the airframe has shown no serious aerodynamic deficiencies and there have been no significant delivery slippages. The design proposed in 1951 was developed without major change. The F-100 is the only one of the Century Series in which the engine originally selected appeared on the finished plane. Cost overruns have been modest in comparison with those found in some of the other Century aircraft; and major performance parameters of the finished product are not far different, except for range and ceiling, from those predicted by North American at the time the definitive contract was signed.

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[1] All cost figures are exclusive of GFAE and most flight testing.

	Specification 18 May 1956 F-100A	Specification 1 May 1952 F-100A
High Speed at 35,000 ft. (kts.)		
Augmented Thrust	742	752
Military Thrust	567	561
Average Speed During Combat Mission (kts.)	512	561
Combat Radius (1305 gal. fuel)	402 n.mi.	505 n.mi.
Service Ceiling (ft.)		
Augmented Thrust	51,800	55,700
Military Thrust	45,100	47,100
Take-off Gross Weight (clean)	24,917 lbs.	24,989 lbs.

How can the relatively short lead time, low cost, and reasonably straightforward character of the program be explained? While no complete answer is possible, there appear to be three factors of particular relevance. First, the design was based roughly on the configuration of the F-86, an aircraft that was well proven and by any reasonable standard quite successful. At the low supersonic speed required, and for the tactical roles planned for the F-100, the basic design simply did not exhibit major deficiencies. There were no unexpected transonic drag rises, pitch-up problems or unexpected weight increases, characteristic of certain other programs, that might have degraded performance. In short, there was a wide range of configurations -- delta wing, straight wing, swept wing, single-engine, twin-engine, nose air intake, side air intake, etc. -- from which to choose in designing an airplane with the general capability of the F-100, and some would in all probability have been better than others. North American, with its favorable

F-86 experience, simply picked one that worked out reasonably well.

Second, the airplane was based on off-the-shelf procurement of proven major components. The electronics (including the radars) and gunsight had been developed earlier and had already seen operational use. This procedure facilitated the aircraft program in two ways: (1) no major problems arose concerning availability of these components when needed on the production line; (2) the principal area of uncertainty was confined to the airframe-engine combination. Such is not the case when all major components are designed at the paper stage to work together as a weapon system before they are tested in hardware form -- a situation in which unforeseen problems occurring in the development of any one component can have a serious effect on the development of the whole system. It should be pointed out, however, that despite the fact that the subsystems did not involve any major development problems, nevertheless problems did arise in getting them to work properly after the airplane had been put into operational use. As for the engine, it is true that the J57 was still in development at the time North American selected it. However, it had passed it 50-hour test in August 1951, three months prior to Air Force implementation of North American's proposal, and it had already powered the B-52 prototype, which made its first flight in April 1951. While this selection did not preclude compressor stall and afterburner deficiencies, nevertheless North American got an engine that in general met specifications, was relatively reliable in operation, and was available more or less on schedule.

Third, and perhaps most important, it is notable that the Air Force had a better basis for committing itself in the F-100 program, in terms of quantity of information available to it, than it did in other Century Series developments. It had the benefit of the information gained by North American during the year the company worked alone -- a year that evidently was productive insofar as the mock-up inspection was held at about the time the Air Force gave the initial go-ahead. In other Century programs, mock-up inspection was held some time after initial commitment: the time gap amounted to a year for both the YF-102 and YF-105A, nine months for the F-101, three months for the F-107A, and one month for the XF-104. The importance of this observation lies not in the fact that mock-up itself is of primary importance, but in the fact that typically many of the changes and modifications occurring in aircraft programs are made on the basis of wind-tunnel tests, rocket tests, and paper calculations performed prior to mock-up. By the time mock-up is completed, the specifications of the aircraft provide a more reliable basis for Air Force commitment than those drawn up earlier. In general, the longer a development program continues, the progressively more reliable is the basis for predicting its "success." In the case of the F-100 the Air Force placed its initial "bet" somewhat later in development than it did in other cases.

IV. THE LOCKHEED F-104 SERIES

The F-104 series is related to the design Lockheed entered in the competition of 1950-51 out of which grew the Convair F-102/106. After the screening in mid-1951, only two companies -- Convair and Republic -- were left in the running. This came as a surprise and a serious loss to Lockheed since at one point in the evaluation the firm had received a letter from the Air Force stating that Lockheed's proposal, the L-205, would be placed under development. With this turn of events Lockheed had fears for its long-run future in the fighter field. Its last fighter development prior to the L-205 proposal was the XF-90, which had been a failure partly because it was designed around the Westinghouse J46 engine, which did not perform as expected. Because of the failure of the XF-90, and because of the lack of a contract enabling Lockheed to keep its hand in the fighter field, Lockheed foresaw a danger that it would be unable to compete with other companies for fighter business in the future.

In order to remain in the fighter field, Lockheed continued work on the L-205 and renewed its efforts to win a contract. A subsequent version growing out of this work, the L-224, won support in some circles of the Air Force in early 1952, but the model was judged by WADC to be not enough better than the Sabre 45 (the F-100) to justify its development.

Lockheed returned to the drawing board and in May 1952 presented WADC with another proposal, design L-227. This proposal, at one time on the verge of acceptance, was rejected in June. The cause for rejection marked the emergence of a new concept that was to affect the type of aircraft Lockheed subsequently developed. In mid-1952, military circles were concerned about the possibility of future wars resembling the Korean War. Attention was focused, therefore, on exploring the implications of peripheral wars for the kinds of military hardware required. For a tactical fighter it was suggested that a cheap, mass-produced light-weight plane be developed. Proponents of this approach argued that it was profitable to trade quality for quantity, and that we had gone too far in insisting that our planes be equipped with a number of "luxury items." This position was supported by the testimony of many ex-Korean combat pilots, who asserted that much of the equipment on their planes was of little value. This light-weight concept stood in direct contrast to all Lockheed's earlier proposals, which had called for gross weights in the 26,000-pound class.

The new proposal was far from unopposed. Another faction in the Air Force, contending that such a development policy would lead to inferior equipment and a second-best Air Force, strongly urged development of aircraft such as the L-227. The light-weight fighter proponents were strong enough at the time to block the contract with Lockheed for the L-227 but not strong enough to initiate development of a light-weight fighter. As a result, neither a heavy- nor a light-weight fighter contract was let in mid-1952.

The rejection of the L-227 by the Air Force touched off a lengthy debate over the relative merits of light- and heavy-weight fighters. Within the Air Force the strongest supporters of light-weight fighters were those in TAC responsible for maintaining theater air superiority. Most strongly opposed were those in Air Defense, who insisted that they would not be interested in a fighter of less than all-weather capability, which in turn would require a heavy-weight design. Within Lockheed, the emergence of the light-weight concept was viewed as a threat to its heavy-weight proposals.

Consequently, Lockheed stepped actively into the debate on behalf of the heavy-weight design. This action was in contrast to that of certain other companies, Northrop, North American, and Republic in particular, who submitted specific light-weight proposals to the Air Force.

During the course of the debate certain developments in technology affected the relative merits of the two positions. The most important were in the field of engines, where it appeared that better thrust-to-weight ratios, lower specific fuel consumption, and better ratios of thrust to frontal area would shortly be available. These factors implied that a reduction in aircraft weight was possible with no reduction in over-all capability. Some of these advances had already been embodied in the British Sapphire engine, the predecessor of the Wright J65. Although the various models of the J65 weighed about the same as most models of the J35 and J47 (the engine in the B-47), the J65 provided a considerable increase in thrust. Specifically, the J65 had 7800 pounds static thrust dry and 11,000 pounds thrust with afterburner, as compared respectively with 5400 and 7500 for the J47-17. The specific fuel consumption of the J65 was .93 dry at sea level and 2.0 with afterburner, compared respectively with 1.12 and 2.3 for the J47. Furthermore, it appeared that even more substantial gains would be achieved with the General Electric J79 engine, which was at that time in the paper stage. Developments also in radar and armament made weight reductions feasible without loss of capability. In particular, development of rapid-fire cannon made it possible to reduce gun weight without reducing fire power.

For these reasons, the light-weight proponents successfully argued that it was possible to build a first-class air-superiority fighter much lighter than the F-86F and the F-100. Early in 1953, then, the Air Force was ready to let a contract for such an aircraft.

Although Lockheed had been a very active proponent of the losing side of the debate, it was quick to adjust to the turn of events. Lockheed took only about three weeks to come up with a proposal, the L-246 for a 15,000 pound airplane -- hardly more than one-half the weight of the previous proposal. Contract negotiations between Lockheed and the Air Force proceeded in early 1953 and a letter contract, AF33(600)23362 ,was approved by the Air Force in March of that year. It covered the procurement of two prototype XF-104's (the redesignation of the L-246), mock-ups, spare parts to support 100 hours of flying, and rocket and wind-tunnel models, all for an estimated price of less than $4 million. The plane was to be equipped with a J65 engine having a maximum thrust with afterburner of 12,000 lbs. Armament was to consist of two 30 mm. cannon, 320 rounds of ammunition, and an APG-34 ranging radar. Empty weight and maximum take-off weight were specified as 10,720 and 18,570 lbs. respectively. For the basic mission (take-off weight 16,145 lbs.), maximum speed was given as 1.82 Mach (1048 knots at 35,000 feet), sea-level rate of climb as 49,200 feet per minute, a combat ceiling of 52,900 feet, and a combat radius of 375 nautical miles.

The definitive contract, signed in November 1953, covered the same items but at an increased estimated price of about $7 million. Of this amount, the two prototypes themselves were estimated at about $4 million. Both vehicles were to be delivered in March 1955. A subsequent change in orders increased the cost coverage to include items such as modification of afterburners, development of the MA-10 fire-control system, and substitution of the T-171 gun for the two 30 mm cannon.[1]

Construction of the two prototypes began in March 1953 and first flight took place only 11 months later, a month ahead of schedule. Total cost of the two planes, including development of the MA-10 and some flight testing, amounted to about $13 million.

Lockheed's performance in constructing the XF-104 was affected by a number of factors. One was the fact that Lockheed felt that its F-104 would be crucial in determining whether or not it stayed in the fighter business. Consequently, it took the project very seriously. A second factor was that whether by accident or intention Lockheed was given a relatively free hand in development. The GOR for the system, issued almost simultaneously with the contract, imposed few constraints on Lockheed; it had little to say in detail, being couched for the most part in generalities. A third factor of enormous value to Lockheed and of great importance to the success of the development program was the extensive use of wind tunnels. Lockheed was able to rely upon NACA facilities to resolve uncertainties associated with the F-104. Fortunately for Lockheed, the NACA was particularly interested in a number of problems that were of concern to Lockheed in developing the F-104. By comparison with most aircraft under development, the F-104 was therefore able to command an unusual amount of wind-tunnel time for proving its aerodynamics. A fourth factor contributing to Lockheed's success in development was the availability of information, particularly wind-tunnel data, gathered in the course of the Douglas X-3 program. Although the X-3 program (initiated in 1943 and terminated in 1951) was generally thought a failure, largely because it was designed

[1] The MA-10 consists of a simple, light-weight conical-scan search radar and an infra-red/optical sighting system.

around the J-46 engine, which never lived up to expectations, the experience gained had a carry-over value for the F-104 program. Finally, the vehicles were virtually handmade, few tools being designed specifically for the purpose of constructing it. Later when Lockheed did in fact tool for production, it took as long as a year and half to construct some of the tools required. Thus, if the first two test aircraft had awaited production tooling, they would have been available only much later than they were.

As a result of the relative freedom in design, the strong economic pressures to develop a saleable product, the extensive use of wind-tunnel facilities, a research and exploratory program concerning problems of supersonic flight, and the absence of early tooling, Lockheed's performance was in some respects unique. In addition to building an aircraft in less than a year, a record unequalled by any other Century Series aircraft, Lockheed also developed an afterburner for the engine. When the J65 was delivered in the fall of 1953 for use in the XF-104, it was a relatively proven engine, having passed its 150-hour test in its non-afterburning version. An afterburning version was being readied by Wright for the Navy, but not on a schedule suitable for use in the XF-104 prototypes. Because the success of the F-104 program was at stake, Lockheed itself undertook the development of the afterburner and succeeded in making available a J65 afterburner version for the early XF-104 flight-test program.

The XF-104 made its first flight in February 1954 and completed Phase II testing 13 months later. The second XF-104 vehicle, which was to be used for the T-171 gun-firing program, crashed on its thirtieth flight in April 1955 because of the disintegration of the gun. According to the

Phase II evaluation:

> The capabilities of the XF-104 as a supersonic air superiority fighter exceed those of any other known turbo-jet powered aircraft. The handling characteristics of the aircraft throughout the speed range with the yaw and roll dampers operating are very satisfactory. The preciseness, ease of operation, and general feel of the power control system is outstanding. The possibility of longitudinal control problems exists. Care must be exercised in production quality control of the system components. The proper operation of yaw and roll dampers is essential to operation of the XF-104 as a tactical weapon. Take-off can be safely accomplished but the aircraft is not suitable for any tactical purposes in this configuration. The unpowered rudder does not furnish directional control at high indicated air speeds or Mach numbers. The capabilities of the XF-104 as a subsonic air superiority fighter are exceeded by USAF fighters currently operational. The major deficiency of the XF-104 is the lack of thrust [of the J65 engine] both at military and maximum power to fully utilize the tactical capabilities of the aerodynamic configuration. The lack of thrust is manifested in the relatively low service ceiling, the small load factor attainable at high speed without loss of speed or altitude, and the time required to accelerate to speeds above 1.3 Mach number. The handling characteristics with the tip tanks installed are acceptable within the limits tested. The present flight limitations render the tanks unsuitable for tactical usage. The aircraft should be placed in production as soon as an engine is available with sufficient thrust to give supersonic combat capabilities without the use of afterburner.[1]

The aircraft and the engine had failed to meet the specifications that had been written in 1953 at the time the letter contract was signed. The comparison is shown in the following tabulation:

	Actual (Phase II flight test)	Specification 24 March 1953
Engine Thrust (lbs.)		
Maximum	10,300	12,000
Military	7,800	8,300
Basic Weight (lbs.)	11,800	11,406
Sea Level Rate of Climb (ft./min.)	32,000	49,200
Combat Ceiling (ft.)	48,650	52,900
Maximum Speed (Mach)	1.59	1.82

[1] Air Force Flight Test Center, XF-104, Phase II, May 1955.

In mid-1954 the Air Force was undecided about the program. The old heavy-weight proponents were in favor of dropping the project. A second group, concerned with the possibility that the United States might soon become involved in a war in Indochina, contended that the F-104 should be procured immediately with the J65. A third group, whose views eventually prevailed, suggested adding more equipment to the F-104 and improving its performance by switching to a more powerful engine. These suggestions were supported by the fear that with the J65 engine the F-104 would have inadequate altitude capability in air defense. Enemy bombers, it was argued, would very likely attack from an altitude in excess of 50,000 feet and would, therefore, be invulnerable to attack by the F-104.

In view of the relatively low thrust of the J65 engine, an official decision was made in mid-1954 to switch to the J79 in the production version. At the estimated 14,350 lb. maximum thrust, the airplane was expected to attain Mach 2, have a rate of climb of 20,000 ft./min. at 35,000 feet, and have a combat altitude of 60,000 feet. It is notable that the J79 version had been proposed as an alternate as early as March 1953, the month in which the first letter contract was signed. The necessity for the engine switch, demonstrated in XF-104 Phase II flight tests, apparently came as no shock to Lockheed: there is reason to believe that Lockheed had presumed all along that the J79 would be used in the production version of the F-104 and had taken this into account in the preliminary design. Furthermore, Wright's lack of interest in designing, to Lockheed's specifications, an afterburner for the Wright engine suggests that Wright may have realized that there was little reason to expect a production contract to support the F-104 program.

There was considerable risk associated with substituting the J79 for the J65. In mid-1954 a 50-hour test had not been completed on the J79 while the J65 had already passed its 150-hour test. Furthermore, General Electric was having trouble with the early versions of the engine. Yet it was felt that the expected increase in performance was sufficiently great to warrant taking the risk.

An implementation program involving obligations for production planning and tooling was begun in mid-1954. In the fall of 1954 Lockheed signed a $39 million contract for seventeen F-104A airframes. Deliveries were run from January to October 1956.

As a result of the switch to the J79, the F-104 fuselage was lengthened by five feet and increased in diameter. From the point of view of production, the J79 version was virtually a new airplane. If Lockheed had tooled for production of the J65 version, a switch to the J79 would have meant scrapping nearly all these tools.

The first F-104A made its first flight in February 1956, two years after the first XF-104 flight. The early flight-test program of the F-104A suffered considerable delay, at least partly because of a great deal of mechanical difficulty with the J79 engine. While the F-104A made its first flight in mid-February 1956, it did not make its second flight until a month later. It attained a progressively higher top speed in subsequent tests, attaining 1.95 Mach late in April. By the first week in June, just prior to the delivery of the second F-104A, the plane had made 16 flights.

Phase II flight testing was completed six months after first flight. An abstract of the Phase II evaluation follows:

> The performance of the F-104A is superior to the performance of other Century Series fighters currently in production. Low internal fuel capacity severely limits the combat radius of action. This factor, together with the large variations of performance with temperature change, the high speed and high altitude capabilities, all combine to complicate optimum utilization of the aircraft. Successful integration of the F-104A into the SAGE system is essential if its maximum potential as an interceptor is to be realized. The fine handling characteristics in the normal flight region are offset by an uncontrollable pitch-up at high angles of attack which increases in severity during accelerated maneuvers. Spin recovery has not been demonstrated. Characteristics preceding pitch-up are similar to those experienced in the F-101 but result in more violent maneuvers. It is expected that little or no natural warning will occur at supersonic speeds and that the high load factors encountered in a supersonic pitch-up may lead to loss of both aircraft and pilot.[1]

This evaluation disclosed deficiencies in the aircraft somewhat different from those found by the test on the XF-104 model. While the two principal deficiencies of the F-104A were lack of range and pitch-up, neither was mentioned in the earlier evaluation. For the most part the problems of the XF-104 appeared to be due to the too small engine.

However, a good deal was learned from the XF-104 experience that was applicable to the F-104A program. Lockheed officials have said that although much of the detail engineering planning that went into the XF-104 -- the drafting and blueprinting -- was not transferable in a body to the F-104A program, Lockheed did learn from the XF-104 a considerable amount about general manufacturing problems, about how to handle the metals going into the aircraft, and about particular tooling problems. For example, the fuselage of the aircraft is built around a central keel that is the main structural weight-bearing member. Since this feature appeared in the XF-104, Lockheed gained early experience with it and found the experience applicable

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[1] Air Force Flight Test Center, F-104A Phase II Flight Evaluation, December 1956, frontispiece.

to the F-104A program. Furthermore, test flying the XF-104 disclosed certain deficiencies that could be corrected; hence it was possible to accelerate to some extent the test-flight program for the F-104A. This carry-over from the XF-104 may explain to some extent the seven-month difference between the time taken to carry the XF-104 through Phase II flight testing and that taken by the F-104A.

Early wind-tunnel tests had shown that there might be a pitch-up problem, although it did not appear in the earlier Phase II evaluation. That it showed up strongly in the production-version aircraft was due largely to the fact that the combination of the higher-thrust engine and the peculiarities of the modified airframe gave the aircraft some of the characteristics of a ballistic missile. When pitch-up occurred, the wing blanketed the air flow to the empennage and the pilot lost virtually all control of the aircraft, and because of its extreme speed and inertia the aircraft followed a ballistic flight trajectory. A pitch damper was installed in the XF model to take care of any pitch-up tendency and no major problem arose by the end of Phase II flight testing. However, for the F-104A the pitch-up problem was serious from the standpoint of flight safety. It was not until early 1957 that development of a satisfactory pitch control was completed for the F-104A.

A flutter problem arose in later test flying. This again was a problem that Lockheed had feared but that did not arise until 1957. This problem was finally solved by covering the vertical fin with steel instead of aluminum. Testing for spin was conducted late in the test-flight program; fortunately, no serious spin-recovery problems have arisen.

Difficulties with the T-171 gun have complicated the F-104A program. Besides the earlier trouble with gun disintegration, which caused the crash of the second XF-104, there have been two other major problems: the extremely high volume of muzzle gases that cause compressor stall, and the discharge of cartridges and links. In earlier firings it was feared that the cartridges and links, discharged somewhat ahead of the air intake, might be ingested by the air intakes when the plane flew under certain g-loads and attitudes. One solution to this problem was to design a storage space in the fuselage for spent cartridges. The links are still discharged through external openings, but farther behind the intakes than before. Problems with the gun contributed to delays in the operational use of the aircraft by TAC.

Difficulties with the gun were partially responsible for the decision to replace it in ADC interceptors with two Sidewinder infra-red missiles.[1] While the F-104 was originally designed to serve TAC, ADC later decided to procure four squadrons, but for various reasons did not favor use of the gun. Besides the mechanical difficulties with the gun, ADC felt that guided-missile armament was superior in air defense and that provision for guns on the F-104A would require a return to the ground-support provisions that ADC had long since abandoned in its general change-over to missile and rocket armament for all other interceptors.

Because the aircraft was designed around a very simple and light-weight radar-ranging fire-control system, it has a less adequate detection and lock-on range than other ADC interceptors. Its detection range of less

[1] Removing the gun is apparently not a firm decision, however. Some ADC units have maintained provision for the gun and the F-104A's recently sent to Formosa were so equipped.

than 20 miles can be compared with the F-102A fire-control system range of about 30 miles. Its lock-on range is about half that of the F-102A.

While the range deficiency of the F-104 threatened to be a serious handicap, this problem has become less pressing. Largely because the J79 has progressively improved in specific fuel consumption, the F-104A now has about the same combat radius in some profiles as does the F-102A. While there was some talk in 1957 at ADC of substituting an additional fuel tank for the space previously taken by the gun, the idea was dropped because the radius of the F-104 is now great enough so that the costs of adding such a tank, are not justified.

Engine reliability has continued to be low and has handicaped the F-104 system to a greater extent than any other factor. The accident rate of the F-104 has been high (three crashes occurred within one week during 1957) and several groundings have been ordered because of such things as flameouts, bearing failures, compressor stall, and vibration. While over-all improvement has been achieved in engine reliability, operational use of the aircraft is still limited.

In addition to the $13 million spent for the two XF-104's, the first 17 F-104 aircraft, completed by early 1957, cost about $62 million. The next 209 F-104A's (later cut back to 170) had a firm target price of about $125 million.[1]

The generally high capability of the F-104 system as a light-weight low-cost fighter accounts in part for Lockheed's recent success in the stiff competition among US, English, French, and Scandinavian manufacturers to

[1] All costs are exclusive of GFAE.

sell light-weight, low-cost fighters to NATO and SEATO governments. The West German Air Force is negotiating with Lockheed for manufacture of the aircraft under license in Germany. Negotiations are also being conducted with Canada, Japan, and The Netherlands for procurement of the aircraft.

CONCLUSIONS

The F-104 history illustrates, first, that research and development in one program can have a great carry-over value to another. Lockheed's success in building and flying a prototype less than a year after go-ahead would very probably not have been possible without the knowledge derived from the Douglas X-3 program. Although the value of this experimental effort in the F-104 effort could hardly have been anticipated when Air Force money was advanced to finance the program, nevertheless the value to the Air Force of the X-3 program extended far beyond the immediate results achieved with the X-3.

The F-104 history also illustrates the effects of uncertainty. Unforeseen difficulties with the J79 engine and T-171 gun are examples of the troubles that can beset a program when reliance is placed on components that are only in early development at the time the aircraft program is initiated. Although the aircraft was first envisaged as an air superiority fighter, it has gone into ADC inventory as an interceptor, and in the tactical version it has a nuclear bomb capability. Although it was originally designed to have only gun armament, the Sidewinder missile (which was developed on a completely independent basis) has been successfully added. Although the aircraft was originally designed for considerably less than Mach 2-performance, the engine switch has provided maximum speeds and rates of climb and ceilings (zoom climb) that have broken speed and altitude records for operational-type USAF aircraft.

A notable feature of the F-104 program is the manner in which it was conducted. The initial commitment to Lockheed covered construction of two experimental prototypes that were virtually handmade. Proceeding in this manner had two advantages. First, Lockheed was able to get the aircraft flying more quickly than would have been possible if production tooling had been used. Furthermore, the absence of tooling greatly facilitated the switch from the J65 to the J79. Had extensive tooling been built for the early version, converting to the J79 would have entailed costly rebuilding of nearly all the tools. By proceeding in this way the merits of light-weight fighter design were quickly and (relatively) inexpensively tested in an early flight program, and modifications found necessary on the basis of testing were added to the production version at modest expense. Although the initial financial commitment to Lockheed was small (with the early emphasis placed on early experimental flight test rather than on production of an operational weapon system), the total time of five years between the start of the program in 1953 and the first squadron deliveries in 1958 is a record exceeded in the Century Series by only the F-100A.

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V. THE McDONNELL F-101 VOODOO SERIES

A. THE XF-88

An adequate treatment of the F-101 development requires going back to the F-88, a close predecessor developed by McDonnell soon after the close of World War II. When the war ended, the Engineering Division at Wright Field reverted to a prewar method of getting new fighter designs -- the industry-wide, preliminary design competition. In August 1945, the Division submitted to industry preliminary penetration fighter characteristics for the new generation of jet-propelled aircraft. Thirteen companies responded with a total of 20 design proposals. The Engineering Division evaluated the McDonnell Model 36 as the best of the group. It was particularly impressed with the swept-back wing, V-tail, high critical Mach number, and the growth potential of the design.

> Of all the penetration designs submitted, the Engineering Division believed that the Model 36 would fight best at altitude and only the Vultee design would fight better at sea level. The Voodoo's low wing loading and relatively short span provided good maneuverability. The pilot's seat well in front of the wing gave good all-around vision. Housing all fuel in two large tanks in the fuselage had three advantages: (1) the simple fuel system; (2) a simple wing structure; and (3) a fuselage so large that varying kinds of tactical equipment could replace some of the fuel. The design would be reasonably easy to service and repair. The inboard engine placement meant good single-engine performance.[1]

In May 1946, McDonnell received a Phase I development contract covering work through mock-up of the XP-88. Mock-up inspection was held in August 1946. After agreement was reached concerning certain revisions of design, a definitive contract was negotiated covering Phase I and II, including designing, constructing, and flight testing two experimental airplanes.

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[1] Ethel M. DeHaven, The Voodoo Story 1945-1957, Historical Division, AMC, W-P AFB, 1957, p. 18.

The first XP-88 was to be ready for flight testing in April 1948; the second, two months later.

The delivery date for the first aircraft was subsequently slipped six months because of design changes and revisions in the flight-test program. McDonnell engineers had to abandon the V-tail in favor of the more complex and expensive conventional tail, and they had to reshape the engine air-intake openings in the wing leading edge to conform to the 35-degree wing sweepback. McDonnell had originally planned to conduct flight testing at St. Louis, but the Air Force subsequently decided, in the interests of safety, to test new aircraft at Edwards. Besides the increase in the cost of the over-all program, several months were necessary to disassemble the aircraft in St. Louis, truck it to Edwards, and then reassemble it. The plane was completed and ready for engineering inspection at St. Louis in June 1948; its first flight took place in September 1948. The airframe changes themselves were responsible for about three months of the six-month total slippage.

In the meantime there was one particularly important change made in the second aircraft that affected its delivery date. A decision was made in early 1948, after a lengthy feasibility study, to incorporate afterburners in the design of the second plane, which was redesignated the XF-88A. This gave rise to a serious problem. Since the engines were located in the bottom of the fuselage, proper ground and aft fuselage-exhaust clearances dictated that the afterburners be no longer than 52 inches. However, the afterburners, being developed by engine manufacturers, were much longer than that. Consequently, McDonnell was authorized to develop its own afterburner, the costs of which were included in the original XF-88 contract. The original delivery date for this airplane was June 1948. It was not until March 1949, nine months later, that the plane was actually ready for shipment to Edwards.

The first aircraft, the XF-88, completed Phase I flight testing in March 1949, six months after its first flight in September 1948. Its Phase II test program was completed a month later. The plane achieved a maximum speed of .92 Mach in a shallow dive. At the conclusion of Phase I testing, the contractor reported that the XF-88's "excellent high Mach number characteristics" was an outstanding feature uncovered in the tests. "No buffeting, roughness, or stability and control difficulties were encountered in the subsonic range and none were indicated for supersonic flight."[1] However, the air-inlet design restructed air flow on take-off resulting in a poor take-off performance. The contractor planned to overcome this deficiency by redesigning air-inlet doors and the engine nozzle area. The afterburner on the second model was expected to produce further improvements in performance.

McDonnell had hoped to continue into Phase III testing but learned in mid-1949 that the Air Force had not yet decided to procure the F-88. In fact, the decision was made to procure only after completion of a competitive evaluation of the McDonnell XF-88, the Lockheed XF-90, and the North American XF-93, though these other aircraft were far behind the F-88 in development and would not fly until 1950. Hence the evaluation testing

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[1] Ibid., pp. 42-43.

was delayed until mid-1950. After completion of Phase II on the XF-88, the contractor continued with additional Phase I testing until October 1949. By that time, 13 months after first flight, the plane had accumulated 84 hours of flight testing. The XF-88 was then flown back to St. Louis to be used in the Propeller Laboratory's supersonic propeller project.

The XF-88A, the second aircraft, made its first flight in April 1949, the same month that the XF-88 Phase II was completed. However, in November 1949, after the XF-88A had completed about 30 hours of flight, it was damaged in a hasty crosswind landing. The XF-88 did not return to Edwards until April 1950, after improvements and repairs were made.

The competing XF-90 made its first flight in June 1949, nine months after the XF-88 first flight. It completed Phase II in June 1950, just prior to the Air Force competitive evaluation. The XF-93 made its initial flight in January 1950 and completed Phase II in June 1950. Three million dollars of FY50 funds had originally been appropriated for the flight testing in the competition and for implementing the winner's production program. However, in May 1950, this sum was cut to $1 million to be used only for evaluation.

Flight testing in the competition was conducted from 23 June to 8 July. The evaluation board's appraisal was ready by 15 August. In the Phase II flight testing, in the limited tactical-suitability tests, and in the evaluation board's ratings, the XF-88A came out best.

> The AMC pilots found that the XF-88A gave the best performance in take-off, climb, cruise, maximum level flight speed and landing maneuvers. The APGC team believed it had "superior handling characteristics at high altitude from a speed, zoom, formation, acceleration, and deceleration, and over-all maneuverability standpoint." The APGC pilots agreed that it was

> the best "flying machine" and of the three, most closely approached their impressions of the manner in which a fighter should perform. "They agreed that it possesses superior high speed handling characteristics between Mach numbers of 0.9 and 1.1" and that it was the only one of the three that could be operated tactically from 6500-foot runways under nearly standard conditions.[1]

However, the Air Proving Ground Command Team did state that none of the aircraft tested was superior in over-all combat capability to the F-84E and the F-86. This team also stated that at least 100 hours flight time would be necessary for adequate appraisal of the XF-88A.

It is notable that one of the three aircraft, the XF-93, was rated well below the other two entries. APGC pilots concluded that it could not be successfully operated without afterburner at altitudes above 25,000 feet, that the maximum altitude even with the afterburner was only 32,000 feet, and that the afterburner consumed too much fuel at low altitudes. In addition, the XF-93 evaluation flights revealed that air speed deteriorated rapidly during maneuvers, even at maximum thrust, that above Mach 0.7 tracking was difficult because of snaking, and that wing-tip stalls and mild stick force reversals were encountered during normal pull-outs from gunnery and bombing runs. Finally, it was found that with landing gear and flaps down and with speed brakes extended, the aircraft could not maintain level flight.

Actually, the XF-93 had originally been considered for large-scale production -- in May 1948 North American had been authorized to fabricate 120 aircraft at a negotiated price of $53.5 million. This order was cut to only two aircraft in early 1949. The actual cost for these two aircraft

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1 *Ibid.*, pp. 50-51.

was $11.5 million, including spare parts, special tools and ground-handling equipment, technical data, engineering tests, and termination charges. In contrast, the over-all cost of the XF-88 program was about $6.5 million and that of the XF-90 was about $5.1 million. The cost of the XF-93 program was relatively high because North American had already begun a production-engineering and production-tooling program by the time the order was received to cancel all but two aircraft.

Because of a stringent budget ceiling for aircraft procurement, the F-88A, even though declared the winner, was not procured in quantity. The decision was made instead to improve the F-89, F-94, and F-86. After the outbreak of the Korean War, the emphasis was on getting quick improvement in performance by modifying existing service aircraft rather than on waiting for the delivery of new models.

B. THE F-101

After the Korean conflict started, SAC ordered 600 B-47's, the kind of bomber the Voodoo was originally designed to escort. SAC requested McDonnell, in competition with other companies, to prepare F-88 data to meet the new escort requirement. From the aircraft in the competition (Lockheed's F-90, McDonnell's F-88, Republic's F-91 and F-84F, Northrop's improved F-89, and North American's F-93), the evaluators selected the F-88 in March 1951 as the best.

By October 1951, Hq. USAF directed AMC to use some FY52 funds to get the F-88 into production. As in the case of the F-102 program, the "Cooke-Craigie" plan was applied to the development of the Voodoo. Under this development plan there were to be no additional experimental prototypes;

the initial production rate was to be sufficient to provide a test-flight inventory for a comprehensive testing program. While these aircraft were being produced, however, tooling and other preparations for full-scale production were to be made. After a tactically suitable aircraft emerged during the flight-test program, and after necessary modifications were made in tooling and production facilities as a result of test flights, the production rate was to be increased to the programmed maximum. The planes produced for test were then to be reworked into the final configuration.

McDonnell signed a letter contract in January 1952, authorizing it to proceed with tooling preparations for a peak rate of 25 aircraft per month. As in the case of the F-102 this relatively high rate reflected the "mobilization base" plan, though no specific number of aircraft were ordered at the time.

Meanwhile McDonnell made many revisions in the F-88 specifications, including the J57 engine in lieu of the J46. By February 1952, the plane, redesignated the F-101A, was larger and much heavier than the XF-88A.

	XF-88A	F-101A
Specification Dates	8-1-50	3-24-52
Engines	J-34	J-57
Wing Area (sq. ft.)	350	350
Wing Span (ft.)	39.7	39.7
Length (ft.)	54.2	65.8
Height (ft.)	17.3	18.4
Weight, Empty (lbs.)	18,557	37,570

The wing was to be identical with that of the F-88A. Other similarities were the hydraulic-power irreversible flight-control system, the fuselage engine installation, location of air-inlet ducts and guns, and the McDonnell short afterburner.

The weight increase posed a serious problem. To provide an airframe with a high strength-to-weight ratio, McDonnell, in March 1952, proposed building 33 airplanes about 14 per cent under the over-all 7.33 g strength parameter. By means of subsequent testing it could determine which structural members needed strengthening to meet the 7.33 g requirement. The next 30 planes could then be modified to 7.33 g, and the 54th and subsequent aircraft could be produced with full-strength airframes. In this way McDonnell felt that it could get a higher strength-to-weight ratio than would be possible if the plane were designed originally for 7.33 g; in the latter case the design would inevitably carry some "dead weight" that would not be isolated and removed. USAF accepted this proposal.

Though receiving tooling authorization in January 1952 McDonnell did not plunge into a full-scale production program. It engaged in very much the conventional Phase I for a new model during 1952, that is, design and development through mock-up. It was only after mock-up inspections in the second half of 1952, and the incorporation of numerous changes, that a model specification was prepared for the first plane to be produced under the contract. For example, two T-171 guns had originally been specified, but four T-160's were substituted in May 1952. There was great controversy within the USAF concerning the electronic equipment to be carried, partly because the Voodoo was rapidly becoming an "all-purpose" fighter. Separate control systems were needed for the guns and bombs. The Low Altitude Bombing System and M-1 Toss Bombing Computer were to be used for the latter purpose; the MA-7, consisting of GE's K-19 sighting system, a McDonnell drift meter and Hughes E-4 radar for the former. McDonnell was given the responsibility for developing these components into an acceptable fire-control system and installing it as contractor-furnished equipment.

Six months after the letter contract was signed, USAF finally decided to procure 29 (later 31)[1] aircraft on the definitive contract. This fixed price incentive contract for FY53 procurement was signed in December 1952. It included the following:

	Target or Billing Price (millions)
29 F-101A airplanes including FCS	$ 76.5
Spare parts	8.2
FCS test equipment	1.2
Spare parts for FCS	2.1
Static-test article	2.2
Flight-test program	1.6
Engineering-change allotment	5.9
Miscellaneous	3.2
	$100.9

The first airplane was to be delivered by the end of August 1954, and the last by the end of August 1955.

In January 1953, AMC negotiated a letter contract for FY54 procurement. A procurement directive for 86 (later 84) aircraft was made in September 1953, and the definitive contract was signed in March 1954.

But in the meantime McDonnell was running into the first of many difficulties. It had just been decided to produce the first 29 at a rate of two or three a month (with deliveries from August 1954 to September 1955) when the necessity for a major modification became apparent. In late 1953 it was evident that McDonnell had underestimated aerodynamic drag. McDonnell proposed to enlarge the wing area by a 5 per cent increase in

[1] Two YRF-101A's were added in June 1954 at a firm target price of $5.4 million.

chord, to install integral wing tanks (now possible with the larger wing), and to install the -13 engine. Additional wing changes, a new air inlet, and other improvements were planned for the twelfth and following aircraft. The wing modification was made in early 1954 and the first plane was delivered on schedule. While the cost of the modification program is not available, the cumulative cost for the 31 airplanes (including fire-control system but not flight testing) amounted by late 1956 to about $117 million, a rather low figure in comparison with other Century Series fighters. On a per pound basis this cost exceeds only that of the North American F-100A.

In March 1954, just after the definitive FY54 contract for 84 planes had been signed, the USAF adopted a new policy of "fly before you buy." New models were not to be committed to production until their development and testing had been completed. On 16 April the project office directed McDonnell "to cease all expenditures on the 84 FY54 airplanes, to place no further subcontracts or materials orders, and to notify any subcontractors to stop ordering materials and subcontracting."[1] The stop order was to be effective until about March 1955, when Phase II flight testing was expected to be completed.

The first plane was completed in August 1954 and flew in September. On its first flight of 37 minutes it went up to 35,000 feet, attained .95 Mach at military power in level flight and 1.07 Mach in a mild decent. "The pilot reported no unusual difficulties and claimed it had good lateral and longitudinal control."[2] In late 1954 and early 1955, Air Force pilots made

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1 DeHaven, The Voodoo Story, p. 137.

2 Ibid., p. 168.

11 flights. The Flight Test Center concluded that the plane was basically excellent with a "very high potential."[1] However, the plane did have deficiencies in cockpit arrangements, control characteristics, and maneuverability; most serious of all, it had a compressor-stall problem.

Headquarters USAF, rescinded the FY54 production stop order in November 1954, apparently because it felt the airplane had demonstrated its worth. ARDC did not consider these eleven flights as sufficient evidence for rescinding the order and argued against it. Compressor stall was encountered in November 1954, several months after first flight. Because of this problem the airplane could not cruise above 30,000 feet; hence it could not continue into some of the exploration testing that had been programmed.

New "12-and-up" ducts, so named because they were to appear on the twelfth and succeeding airplanes, alleviated the problem. They were installed on the second test vehicle, which made its first flight in December 1954. Together with engine modifications, accessory changes and other revisions, frequency of stalling was reduced, but it was not until April 1956 that acceptable stall boundaries were agreed upon by McDonnell and ARDC. The cost for inlet-duct development, modification of the test airplanes, and installation of new ducts in the next 84 came to about $4 million.

Phase II flight testing was completed in late May 1955, seven months after first flight. An abstract of the evaluation follows:

> The F-101A is potentially a good milti-purpose fighter. It is unacceptable for service use at the present time because of comparatively poor high altitude performance, restricted maneuverability due to engine compressor stalls under accelerated flight maneuvers, and lateral control sensitivity. The rate

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1 *Ibid.*, p. 173.

> of climb, level flight speed, and ability to accelerate in level flight are good but the 49,200-foot service ceiling is poor in comparison with USAF fighter aircraft in operational use. The range capabilities with the present bleed-valve schedule are 15 per cent less than predicted values.[1]

Even though the plane did not contain all the improvements that were to be made under the "drag-reduction" program, it attained a maximum speed of 1.44 Mach at 35,000 feet.

In January 1955, two months after the decision to rescind the "fly-before-you-buy" stop order, price negotiations were resumed under the FY54 contract for 84 aircraft. By the summer of 1955, the negotiators had a good idea of what the first 31 were going to cost (all of the 31 were shop-completed by October 1955) and settled for an initial firm target price of about $103 million and a contract billing price, including items for which no target cost was agreed upon, of about $120 million.

No FY55 contract was negotiated with McDonnell, but in March 1955, a letter contract for FY56 procurement was signed. It called for preproduction work on the two-place IF-101A (later the F-101B) interceptor, including procurement of long-leadtime materials. An amendment three months later authorized the contractor to proceed with preproduction engineering, tooling design, and procurement of materials for 245 F-101A's, 77 RF-101A's, and 28 F-101B's. In August the numbers were revised to 145, 77, and 97 respectively.

Thus by the middle of 1955, soon after Phase II flight testing had been completed, USAF had committed itself to a total of 443 aircraft: 31 under FY54, 84 under FY55, and 319 under FY56.

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[1] Air Force Flight Test Center, <u>F-101A Phase II - Flight Evaluation</u>, September 1955.

The F-101B was in the cards as early as 1953. By late 1953, ADC was not at all confident that the F-102A would turn out as had been expected (this was at the time the first YF-102 flew and was found to be subsonic). For about eight months after that, McDonnell proposed interceptor versions, both as a backup and as a successor to the F-102A. The F-101A development plan indicated that the airplane could be modified on the production line into an interceptor, and this seemed to ADC to be the most attractive possibility of the several that had been offered by contractors for a backup to the F-102A. In August 1954, McDonnell was authorized to modify the F-101A mock-up into an interceptor mounting only rockets. This version was to have the F-102 cockpit and fire-control system (the MG-3). In late 1954 WADC established the single-place IF-101A, equipped with both rockets and Falcon missiles and the MG-3, as the initial F-101 interceptor. At the same time, McDonnell proposed a 2-place version, and in early 1955 a procurement authorization was made in favor of the 2-place version. Armament was to include 88 two-inch rockets, and either six Falcons or two atomic "Ding Dong" (later "Genie") missiles. In April 1955, the IF-101B was given a high priority status. Later in 1955 the more advanced Hughes MG-13 FCS was programmed, giving the aircraft, redesignated the F-101B, much the same all-weather interceptor capability as (if not more than) the F-102A, which ended up with the MG-10 fire-control system. There were more alterations after the F-101B mock-up inspection held in September 1955. Most important were the substitution of the J57 for the J67 engine and the adoption of a rotary-type armament rack. As mentioned above, the first letter contract for the F-101B was signed in early 1955. First flight was in March 1957.

In early flight tests, maximum speed of the aircraft was 1.7 Mach (compared with 1.25 Mach and 1.8 Mach for the F-102 and F-106, respectively), combat radius 661 n. mi. (compared with 350 n. mi. for the F-102/106), and combat ceiling 49,800 ft. (compared with about 53,000 ft. for the F-102/106).

Returning now to the F-101A story, we find that numerous production difficulties arose in 1955 during the early test flights. By the end of March 1955, McDonnell was six airplanes behind schedule. Much of the difficulty was due to subcontractors' failure to deliver on schedule. Martin was not able to deliver wings in sufficient quantities until March 1955. There were quality-control difficulties and tooling problems in TEMCO's fuselage program. Beech had trouble delivering windshields of acceptable quality. Landing gear difficulties, due to design and production problems, plagued Bendix's subcontracting program.

McDonnell's policy of initially designing understrength aircraft also generated trouble. Static testing of structural members had started in November 1954, two months after first flight. The static-test plane was almost totally destroyed, however, in February 1955 because of the understrength character of the airframe. A second plane was drawn from the flight-test program for static testing, but it was not until April 1955, some seven months after first flight, that the Project Office notified McDonnell of the first series of changes to be made in the 31 airplanes to bring them up to even the 6.33 g understrength specification. In September 1955, McDonnell asserted that the 7.33 g airplane would not be available until about the 116th airplane (compared with the original proposal to start with the 54th). To modify all 6.33 g airplanes then flying and to disrupt production lines and scrap parts and subassemblies to bring all F-101's up to the 7.33 g requirement was expected to entail a 10-month slippage and a cost of about $25 million. The Air Force agreed to accept the first 115 understrength aircraft, since they would nevertheless be suitable for numerous operational roles. All subsequent full strength airplanes were redesignated F-101C's.

Despite all these problems McDonnell was able to shop-complete the 31st airplane in October 1955, only a month behind schedule. However, with all the engineering changes and other modifications that had to be subsequently made, the acceptance rate was rather low. By the end of October, 10 planes were yet to be accepted. The last was not accepted until April 1956.

In addition, difficulties of probably even more serious nature arose out of information disclosed during flight testing. Aerial gunfiring began in May 1955, the same month in which Phase II testing was completed. Both gun-gas explosion and gunfire-induced compressor-stall problems were encountered. To solve the first of these problems a gun-gas purging system was devised and found satisfactory later in 1955. In September 1955, a year after first flight, severe pitch-up appeared for the first time. The spin program was started in March 1956, 18 months after first flight, and before the end of the month a plane had spun into the ground.

The pitch-up problem came as a surprise to McDonnell. In moving from the F-88 to the 101, McDonnell raised the horizontal stabilizer in order to combat any pitch-up that might occur. Wind-tunnel tests indicated that for angles of attack <u>thought to be usable</u> by the F-101, no serious pitch-up would occur. But McDonnell was wrong in one respect: the F-101 was found to be usable at higher angles of attack than had been anticipated, and it was at these higher angles of attack, untested in the wind tunnel, that severe pitch-up was experienced. The spin recovery problem came equally as a surprise. Wind-tunnel tests had indicated that the airplane would have very good spin-recovery characteristics. It was only after finding that the problem actually existed that McDonnell, by doctoring up a model, was able to duplicate (more or less) the condition in the wind tunnel.

Because of these problems, the operating commands in May 1956 agreed that the F-101A was not ready for multiple reproduction for the combat wings. While the commands could live for awhile with the understrength airplanes, cruise drag and buffeting problems, and a chronically loose canopy, they could not accept planes with pitch-up difficulties, poor spin recovery, and gunfire-induced compressor stalling. Consequently, McDonnell was ordered to restrict hiring of new employees to only those necessary to maintain the number then at work and not build up a force to meet contract schedules. Under the order, production was to be held at eight aircraft a month and no more aircraft were to be accepted until remedies had been found for these major deficiencies. As a result, McDonnell ran a modification program for six months and incorporated over 300 engineering change proposals and 2000 routine change orders in the aircraft then in production status.

A solution to the pitch-up problem, a pitch-up control system, consisting of a control stick pusher and warning device, was tested and found reasonably satisfactory in November 1956. The gun-firing compressor stall became less severe with the installation of new gas-exhaust ducts directing the gas away from the compressors. A continuing series of modifications and tests have by now all but eliminated the stall, and the operational capability of the aircraft is little compromised.

AMC and ARCD decided in November 1956, six months after the stop order, to let production proceed for combat inventory. The 41st F-101A was the prototype of the first lot of 6.33 g airplanes to be delivered to SAC. The first squadron delivery was made in May 1957, over five years after the first F-101 letter contract was signed and about 15 months behind schedule.

As to follow-on procurement decisions, the definitive FY56 contract was written (apparently despite the stop order) in the middle of 1956. Contractor's cost estimate for the 309 airplanes was $388 million. Negotiations proceeded on FY57 after mid-1956, and a target cost of $138.9 million was negotiated for 206 F-101B's. In addition, there were two separate contracts signed during the development period covering flight tests that have amounted to a cost of about $60 million.

Over $800 million has been committed for 630 aircraft through FY57:[1]

	No. Aircraft		millions
FY53	29 2	F-101A) RF-101A)	$117
FY54	56 28	F-101A) RF-101A)	120
FY56	145 77 97	F-101A/C) RF-101A) F-101B)	388
FY57	206	F-101B	156 (excluding fee)
			$781
		Flight test	60
			$841

[1] The F-101B contracts do not include the fire-control system as contractor-furnished equipment. These costs, except possibly those for FY53, are not final. All costs are exclusive of GFAE.

C. ANALYSIS AND CONCLUSIONS

The F-101 history indicates how unpredictable aircraft development can be. While the F-101A was originally conceived as an escort fighter for SAC, it has since grown into a fighter-bomber version, a reconnaissance version, and probably most significantly of all, an all-weather interceptor version to serve as the belated backup for the F-102/106, an aircraft development that had been carefully planned years earlier as an integrated weapon system for the express purpose of filling the all-weather interception role.

Moreover, the story shows that the weapon may itself undergo many changes during development because of unforeseen difficulties. While McDonnell had planned that only 33 airplanes be permanently understrength, the actual number turned out to be over a hundred. There were several engine and armament changes during the program as well as numerous design changes, such as those stemming from the Jones-Whitcomb discoveries.

Although the three competing aircraft, the XF-90, YF-93, and XF-88, were designed with the same general operational objectives in mind, the XF-88 turned out to be superior (at least on the basis of early flight test), especially to the XF-93A, an airplane that had at one point been programmed for large-scale production. The total cost for development of all three models came to about $23 million, which, relative to the costs of large procurement contracts, appears to have been quite a small price to pay for determining the relative capabilities of these competing aircraft.

The development cost of the F-101 through the first contract appears to be quite reasonable compared to that of other Century Series Aircraft.[1]

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[1] See Table 2, page 98.

Several reasons can be offered for the moderate cost of the F-101. First, McDonnell learned a considerable amount from its experience with the earlier F-88. The wing platform, location of engines, and over-all configuration of the two aircraft are roughly the same. It is impossible, of course, to quantify the value of the earlier experience to the F-101 program, but it is known, for example, that the work on short afterburners for the F-88, the advantages and disadvantages of the side-by-side arrangement of the engines determined in the F-88 configuration, and aerodynamic characteristics of the wing were transferable more or less directly to the 101 program. Second, it was very probably wise for McDonnell, after receiving the initial F-101A contract, to proceed through extensive wind-tunnel testing and mock-up before considering the design as final. Had the company proceeded with production engineering and tooling for an airplane that was considered only a mildly modified version of the XF-88, the many changes that were deemed necessary during 1953, 1954, and 1955 would have certainly been more costly than they were and the program might well have slipped more badly than it did. Third, the program ran into relatively little difficulty with major subsystems. The K-19 gunsight and Hughes E-4 radar of the F-101A were, for the most part, "off-the-shelf" items. The J57 engine, which was selected early in the F-101 program, was well developed and had been in operational use for over a year by the time the F-101A made its first flight. Consequently, few delays and modifications involving large sums of money occurred because of development difficulties with these components.

The time required from implementation to first squadron delivery was 15 months longer than originally planned and exceeded that taken in several other Century Series programs (5-1/2 years versus 4-1/2 years for the F-100A, and about 5 years for the F-102A and the F-104A). The slippage was largely due to the fact that serious deficiencies disrupted delivery and acceptance schedules -- deficiencies which in some cases were disclosed only late in the flight-test program and which required considerable time to correct. In this respect, the XF-88 program was apparently of little assistance to the development of the F-101. None of the most serious problems of the F-101 -- compressor stall, pitch-up, spin recovery, or gun-firing characteristics -- was experienced in the XF-88. In fact, the good reputation of this earlier aircraft rested upon its excellent handling qualities.

VI. THE REPUBLIC F-105A/B FIGHTER-BOMBER

Rather than carry the F-84F fighter-bomber through a series of major modifications to enhance its capability, Republic submitted to the Air Force in March 1952 a new aircraft proposal, the AP-63, that incorporated in one block a list of modifications and new items found desirable on the basis of experience with the F-84F. The most significant features of the aircraft were an estimated 1.3 Mach maximum speed at 35,000 feet (the F-84F was subsonic), a lengthened fuselage to provide an internal bomb bay, and wing-root air inlets in lieu of the nose inlet of the F-84F to allow room for growth in electronic equipment. The fighter-bomber version was to be equipped with the J71 engine, four T-130 guns (.60 cal) and 24 five-inch rockets. A reconnaissance version (RF) was also proposed. Republic estimated that with a go-ahead on 1 May 1952, delivery could begin July 1954, and accelerate to 26 aircraft per month by June 1955. Under a 1000-plane program consisting of 500 F's and 500 RF's, Republic estimated the total direct manufacturing cost of the RF's at $156 million, given a peak rate of 100 a month.

A letter contract, AF33-(600)22512, was awarded in September 1952 to implement a large procurement program. Republic was authorized to engage in pre-production engineering, tooling design and fabrication, and material procurement sufficient to meet a schedule starting with one airplane in January 1955 and building up to 40 a month by June 1956, for a cumulative total of 199 units. Four million dollars were initially obligated in the program.

Several notable events took place later in 1952 and in 1953. Toward the end of 1952, the J57 engine was substituted for the J71. The substitution was made in part because of slippage in the J71 development program and in part because of the high promise of the J57 program. The J71 had originally been scheduled to complete its 50-hour test in January 1952, while the actual date of completion was November 1952. There arose expectation of even greater slippage in passing the 150-hour test (a test which was not completed until June 1954). The J57 passed its 50-hour test in August 1951, seven months before Republic submitted its AP-63 proposal. It was apparent by the end of 1952 that the J57 would be a highly successful engine. In fact, by that time the engine was planned for the F-100, F-101, and F-102 aircraft among the Century Series, as well as for the F-105.

In March 1953, six months after the letter contract was signed, the program was reduced from 199 units to 37 units, to be delivered from April 1955 to July 1956, at a peak rate of only three a month. In June an additional $10 million was obligated under the contract. In September Republic estimated the cost plus fee of the 37 units plus mock-ups, wind-tunnel models, etc. (but excluding spares) at $59.2 million. In the following month a mock-up inspection was held. At about the same time one T-171 gun was substituted for the four T-160's, and the MA-8 fire-control system, consisting of a K-19 gunsight and an AN/APG-31 radar-ranging system, was approved.

In February 1954, USAF advised Republic that only 15 aircraft would be procured on a "that's it" basis. First delivery was planned for November 1955 (a nine-month slippage from the original schedule) with a peak rate of only two a month. On this basis Republic gave a cost-plus-fee estimate in March of $51 million including a static-test aircraft, wind-tunnel models and mock-ups. (Note that this estimate is less than 20 per cent below the $59.2 estimate for 37 aircraft given six months earlier.) Republic stated that this estimate was based on only limited tooling that would preclude full interchangeability of parts.

The definitive contract was signed in March for the 15 aircraft (J57 engine), static-test article, mock-ups, and spares at a total of about $53 million, of which $45 million was the estimated cost of the 15 airframes. Delivery was to run from November 1955 to November 1956.

Later in 1954 the possibility of substituting the larger J75 for the J57 in order to provide a substantial increase in performance came increasingly to the fore. In August, Republic was authorized to equip four of the 15 with the J75. The first J75 version was to be completed by April 1956. But just a month later USAF issued a stop order under which only three planes were to be procured, one of which was to be the J75 version. All production planning and materials procurement were to be restricted to this number. A month later the order was revised to six aircraft, four of which were to be J75 versions. In the same month (October) Republic gave an informal cost estimate for the six of $41 million, not far from the amount for 15 that had appeared on the definitive contract seven months earlier.

In November 1954, the next month, major configuration changes were confirmed which included the J75 engine, new ailerons, "waisted" fuselage designed in accordance with the area progression rule, bluff shape store, new radar (E-34 Radar-Ranging System in lieu of the AN/ApG-31), new vertical fin and bomb ejection cylinder -- all at a total additional cost of $36 million. The YF-105A was to continue development with the J57 engine and the straight fuselage; the F-105B was to be identical with it except for the J75 engine, a new engine ram injector, and the waisted fuselage.[1] The major reason for continuing the A version through two of the six vehicles was that the aircraft were already well along in production and to complete them would allow some flight testing at an earlier date than would have been the case had the two aircraft been modified to the new configuration.

The program was increased to 15 aircraft soon thereafter (2 A's, 10 B's, and 3 RF's). The three RF's (J75 powered) were subsequently cancelled in the reconnaissance version and converted to JF's to be used as flying testbeds for components of the B's.

In mid-1955, negotiations were conducted regarding a follow-on FY56 program. Republic quoted a total figure of $50 million for an additional order of 23 B's and 13 RF's. (Its estimate for the original 15 was already $101 million as of May 1955.) In July, however, USAF advised that it would not sign a follow-on contract until after the YF-105A flew.

The first YF-105A was completed in September, two months later, in the experimental shop. Its first flight was in October. At that time USAF stated that it favored a competition between the F-105 and F-107 and would not release funds for a follow-on FY56 contract. In November the FY56 program was officially cancelled.

Because of Republic's desire for procurement of long lead-time items to serve possible later follow-on contracts, it made an internal decision to procure on a "bare commitment basis" a maximum of $7 million worth of

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[1] A larger vertical tail was subsequently added to the B version.

items up to 1 January 1956.

Phase II tests were completed 30 April 1956, six months after the first flight. An abstract of the evaluation follows:

> The F-105 airplane has a good potential as a fighter-bomber. The maximum speed of 1.19 Mach number and absolute ceiling of 47,500 feet of the F-105A will be increased with the larger engine and redesigned fuselage of the F-105B. The airplane has poor damping in pitch and yaw at transonic and supersonic speeds as well as an objectionable transonic longitudinal trim change. The control systems have several deficiencies. Inertial coupling problems in roll are very evident in this airplane. However, the increased area of the vertical stabilizer on the F-105B is expected to reduce these effects. Cockpit deficiencies ... contribute to reduced efficiency of aircraft operation.
>
> Considerable development is required to make the aircraft suitable for operational use.[1]

The second YF-105A was completed in December 1955, three months after the first, also in the experimental shop. This second aircraft, which first flew three months later, exhibited a gain in speed over the first because of a shorter tail cone, new duct splitter, and modified duct inlet lips.

A labor strike starting in February 1956 probably delayed the over-all program. However, personnel were switched to keep the first B going. It was completed in April 1956, also in the experimental shop, and made its first flight in May. The strike ended in June.

During the early part of the same year Republic finally succeeded in getting a follow-on contract for FY57, several months after the FY56 program was cancelled. It received $10 million for implementation of a production order of 65 B's and 17 RF's to be delivered starting 1-1/2 years later, at

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[1] Air Force Flight Test Center, <u>YF-105A Phase II Tests</u>, July 1956.

a maximum rate of 15 per month. The 17 RF's were cancelled in July 1956. In August 1956, about six months later, Republic received an additional $23 million for the follow-on program. A subsequent FY58 program involved 20 F-105D's (a version more or less identical with the F-105B except that it included a North American search and ranging radar and a profiloscope) and eight F-105E's, which are two-place transitional trainers.

There were numerous delays in the flight-test program of the first F-105B. During its first flight on 26 May 1956, the nose gear stuck in the retracted position, and the resulting minor damage in the wheels-up landing caused an estimated delay in completion of Phase II by about 1-1/2 months. Another problem -- excessive heat radiation from a high temperature bleed line -- caused an additional delay in Phase II evaluation. The plane did not make its second flight until August, three months after the first. This flight was also terminated because of malfunction. There was another three-month delay before it flew for the third time in November. During this flight, however, it attained 1.7 Mach.

The second F-105B was completed in November of the same year, this time in the production shop, six months after completion of the first. At about the same time, negotiations between Republic and USAF concerning follow-on procurement were terminated because (1) Republic did not have specifications acceptable to USAF and (2) USAF wanted to wait until completion of Phase II flight comparison of the F-105B and the F-107A.

The Phase II evaluation of the F-105B, consisting of 18 flights taking 13-3/4 hours over a two-month period, was completed in March 1957, some nine months after first flight. (By comparison, F-107A Phase II was completed in February 1957, six months after first flight. Phase II consumed 2-1/2 months during which time there were 32 flights totaling 19-3/4 hours.) Part of the reason for delay in Phase II completion arose from malfunction and structural failure. In January 1957, F-105B #1 was damaged because an air splitter came loose; F-105B #2 was damaged when it lost a right wheel during a landing. In February F-105B #2 was damaged in a belly landing through malfunction of gear retraction mechanism. This one malfunction in itself was estimated to result in a four-to-six-week's delay in the test program. An abstract of the evaluation follows:

> The performance of the F-105B is superior to any fighter-bomber presently in service; however, the aircraft has a large number of deficiencies. Although a maximum speed of 1.95 Mach number can be attained, poor acceleration characteristics provide little tactical utility from speeds above 1.8 Mach number. The specific range of the aircraft is approximately 20 per cent less at 35,000 feet than estimated by the contractor. Both the longitudinal and lateral control systems are unsatisfactory. Structural failures which occurred during the test program ... must be investigated and action taken to prevent future occurrence. A major redesign will be required to correct cockpit deficiencies. Fixes for these and other unsatisfactory areas must be developed and incorporated before the aircraft can be considered acceptable for tactical use.[1]

The third F-105B was completed in April 1957, five months after completion of F-105B #2. By April 1958 all 15 had been shop completed and the last few were in the process of instrumentation prior to acceptance. Squadron deliveries began in the fall of 1958.

No new serious difficulties have been encountered subsequent to completion of Phase II. Because of extensive wind-tunnel testing to determine the proper position of the horizontal tail (very low on the fuselage), no

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[1] Air Force Flight Test Center, F-105B Phase II Flight Evaluation, June, 1957.

pitch-up problem has developed; nor has there been any evidence of inertial coupling. The plane has undergone some cold-weather testing with good results. Bomb separation characteristics are also good. The lateral control difficulty arising in Phase II has been met satisfactorily. The T-171 gun has given rise to a gun-gas problem, which, however, does not appear serious. Mechanical problems have plagued the T-171 development program and delayed operational use of the gun in the F-104A. Republic solved some of these difficulties by developing a dual feed system; by feeding ammunition into the gun from each side, the rate of feed on a side is reduced to one-half of the gun-firing rate. In addition, Republic has proposed a linkless feed to eliminate problems associated with storing or jettisoning spent links.

ANALYSIS AND CONCLUSIONS

Three aspects of the F-105 development history merit particular attention. First, the aircraft went through a striking metamorphosis from the time it was originally proposed until the B version flew. This is best delineated by a comparison in Table 1 of specifications of the aircraft for which in 1952 the Air Force authorized large scale production (before reversing itself), and specifications drawn up in 1955 for the B version.

In addition, as was previously mentioned, an engine change was made from the J71 to the J57, then to the J75 (the J67 was also considered) during development. The four T-160 guns were eliminated in favor of one T-171 gun; and the E-34 Radar-Ranging System was substituted for the AN/APG-31.

As in the case of other aircraft programs studied at RAND, the F-105 history suggests that the end product of a development program may vary considerably from that envisaged at the beginning of the program. In most

Table 1

COMPARISON OF SPECIFICATIONS

Specification Date	F-105A January 1952	F-105B March 1955
Wing		
Area ($ft.^2$)	366	385
Span (ft.)	36.7	34.9
Incidence (root)	1°30'	0°
(tip)	1°30'	0°
Cathedral	5°	3°30'
Sweepback (25% cord)	45°	45°
Length (ft.)	52.3	61.3
Height (ft.)	17.7	17.5
Tread (ft.)	12.7	17.3
Take-off gross weight (lbs.)	37,000	42,162
Engine	J71 (14,000# max. thrust)	J75 (23,500# max. thrust)
Performance		
Maximum speed at 35,000 ft. (kts.)	800	1,126
Combat speed (kts.)	660	755
Combat radius (n.mi.)	471	801
Take-off ground run at sea level (ft.)	5,590	3,500

general terms this variation arises because of the impact of events taking place during development that cannot be fully appraised, or in some cases foreseen at all at the time of initiation. In the case of the F-105, the J71 was initially selected, but difficulties in development of the engine brought a quick switch to the J57. However, in December 1952, three months after implementation of the F-105 program and at about the same time that the J57 was substituted for the J71, Pratt and Whitney were given a contract to develop the J75 -- a program which was quite successful. In view of the promise of the J75 in 1954, two years after initiation of the F-105 program, it was specified for the F-105. The change in engine is largely responsible for the substantial increase in performance evident in Table 1. Another influence on the F-105 program was the work at NACA in 1952 involving the area progression rule theory that led to the waisted or indented fuselage shape of the F-105B (and also, among the Century Series, of the Convair F-102/106 aircraft). The decision to incorporate the waisted fuselage in the F-105B was made late in 1954 -- about two years after initiation of the program.[1] Finally, the difficulty of predicting at the outset the characteristics of the finished product is shown by the fact that the range of the aircraft was found to be 20 per cent less during Phase II flight testing than had been predicted by Republic.

Two other notable aspects of the F-105 program involve the high development cost and long development time relative to other Century Series aircraft. Considering the costs that are attributable to the first contract

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[1] According to conversations with Republic officials, there is some feeling that the area progression rule modification has contributed little to the performance of the F-105B. They feel that such a modification is most useful in low supersonic ranges (around 1.2 Mach) but that it buys little in the higher Mach regime of the F-105B.

in each of these programs, we have the comparisons shown in column 4 of Table 2.

It is true, of course, that for several reasons the figures in some of the programs are somewhat more "final" than they are in others. In the F-100 and F-107 cases, for example, the figures are final, renegotiated prices. The F-106 figure is a forecast made in March 1958 of the over-all cost of the contract. The F-102, F-101, and F-104 figures are the totals accumulated under the respective contracts by a date subsequent to the time of completion of aircraft covered by these contracts but possibly prior to the completion of other end items such as spare parts, handbooks, engineering data, etc. The F-105 figure is a forecast made 1 May 1958 for the over-all cost of the contract. Furthermore, in some programs the figures include cost items that are treated as GFAE, and hence excluded in other programs. Most significant here is the fact that the F-105, F-101, and F-104 contracts include development of fire-control systems while the others do not. In the case of the F-105 the development of the MA-8 system amounted to about $9 million. But even if it were possible to adjust the figures to take all these considerations into account, the F-105 still would have to be judged a relatively expensive development program.

If the F-105 represented a greater advance in state of the art, in terms of design, production techniques or general complexity as a weapon system than the other aircraft, it would be reasonable to expect these larger cost and time figures. But the F-105 does <u>not</u> appear to represent a greater advance or to involve greater complexity than the other aircraft. Construction techniques are not out of the ordinary; types and forms of construction materials used do not unduly push the state of the art

Table 2

DEVELOPMENT COST OF CENTURY SERIES FIGHTERS

	Development Cost		
Program	No. Aircraft	Airframe Unit Weight (lbs.)	Cost (Millions)
(1)	(2)	(3)	(4)
F-105	15	13,650	203
F-100	203	11,855	186
F-101	31	12,700	117
F-102	42	12,148	217
F-104	19	7,000	75
F-106	42	15,600	224
F-107	3-9	14,150	85

Note: Costs are exclusive of GFAE and most flight testing. F-104 cost includes that under first two contracts. Number of F-107 aircraft involved three completed aircraft and components for six others.

(although the aircraft may use a higher proportion of large forgings than the others), and the airplane is no greater "jump" from its predecessor, the F-84F, than are the other aircraft from their own predecessors. Furthermore, there is no evidence that Republic had abnormal difficulty with component development. The J57 and J75 engines were notably successful programs in terms of reliability of product and maintenance of delivery schedules. All the other aircraft listed except the F-104 are equipped with either the J57 or the J75, and there is nothing to indicate that Republic suffered a relative disadvantage in also using these engines. Development of the MA-8 fire-control system basically involved repackaging of more or less "off-the-shelf" components. Development of the fire-control and flight-control systems account for a total of $15 million, or less than 8 per cent of the $203 million figure in Table 2. An 8 per cent figure for these two major subsystems together with other evidence from the general history of the aircraft does not indicate that subsystems were a major source of trouble.

Several facets of the F-105 history may explain the high cost and time involved, although the evidence is spotty. The stop-and-go nature of the program -- the cut from 199 aircraft to 37, the cut from 37 to 15, the stop order to 3, the increase from 3 to 6, and the reauthorization to 15 -- undoubtedly added to the cost, particularly because of contract cancellation or renegotiation costs with both Republic and subcontractors. Unfortunately, the quantitative effect of this is not known. USAF correspondence does disclose criticism of the program on the grounds that there was serious lack of direction on the part of the Air Force and that the program was subject to continuing changes that took months to confirm.[1] If true, this could certainly account for some of the cost.

Finally, it is the practice of military contractors to prorate overhead to all contracts held at a given time roughly in accordance with the relative size of each. During development of the F-105 and after the F-84F phase-out, Republic held only a few small contracts. Contractors in some of the other Century Series programs held other large contracts while developing their own aircraft. The cost figures of Table 2 may reflect, therefore, a higher proportion of overhead charged to the F-105 program than was charged to the other programs.

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[1] Correspondence file, Historical Division, Mobile Air Material Area, Brookley AFB, Mobile, Alabama.

VII. THE NORTH AMERICAN F-107A FIGHTER-BOMBER

A version of the F-100 -- the F-100B fighter-bomber -- was proposed by North American to USAF in August 1953. Specifications called for a 1.7 Mach maximum speed, and a 29,749-pound take-off weight with the J57 engine. The configuration was approved in March 1954, and a letter contract, committing $6 million to implementation of a 33-plane program, was signed in June 1954. But during the same month the aircraft was already undergoing substantial redesign, which included a modified fuselage and a thinner wing. A mock-up inspection was held three months later.

The first amendment to the letter contract, appearing in December 1954, added $1.5 million to the implementation. The second, signed soon thereafter, gave retroactive coverage of $1.1 million to October 1953 to cover North American's early expenditures on the program.

In early 1955, just after the development plan was completed, a second major redesign program was instituted. This included provision for special semi-submerged stores, the T-171 gun, and an air duct above the cockpit. The J57, J67, and J75 were all included as alternative engines in the program. In April 1955, in view of the vague resemblance to the original F-100B version, the designation was changed to the F-107, and another $1.5 million was added to the letter contract. In July 1955, thirteen months before first flight, the program was cut to nine aircraft from the original thirty-three and $21 million was added. In August, North American gave a cost estimate of $57 million for the nine.

The definitive fixed price-incentive contract, signed in January 1956, included the following:

9 aircraft at $6.25 million	$56,250,000
Spare Parts	3,500,000
Special Tools	340,000
Static-Test Article	4,500,000
Test-Flight Program	12,958,471
Engineering Changes	1,617,000

The delivery schedule specified one aircraft a month from September 1956 to June 1957. In June 1956, only three months before first flight, the program was cut to three aircraft.

The first aircraft, equipped with the J75, flew in September and accumulated twenty hours of Phase I flight testing within 80 days. The second plane flew in November. Phase II was conducted from 3 December 1956 to 15 February 1957, and required 32 flights and 19-3/4 hours to complete. Phase II evaluation is summarized as follows:

> ...the airplane was flown to a maximum Mach number of 2.0 at 35,000 feet. The maximum indicated speed obtained was 720 knots IAS at 21,000 feet. Climb performance is good at low altitude but drops rapidly above 40,000 feet due to an unexplained power loss. The combat ceiling is 47,500 feet, although it is possible to reach higher altitudes by zooming from maximum speed at 35,000 feet...
>
> Level flight and climb performance at military power (no afterburner) is not impressive. At this power setting the performance is subsonic and the ceiling is 40,000 feet. The cruise performance at normal cruising speed and altitude is 35 per cent less than had been predicted by the contractor. Test results indicate that this deficiency is a result of high drag.[1]

The F-107A was closely competitive in role and performance with the Republic F-105B; procurement of the latter was, in fact, delayed for the express purpose of conducting a comparative flight-test evaluation. The

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[1] Air Force Flight Test Center, F-107A Phase II Flight Evaluation, June 1957.

final decision is not clear. However, according to one source, the F-105B was selected because allegedly it was ahead of the F-107A in development.

In February 1957 firm target prices were set for the three units at about $19 million each or a total price of $57 million. A renegotiated price of $85 million was later arrived at for the three units, the static-test plane, and the other items in the contract. According to representatives of North American, the components for the other six aircraft were nearly all completed by the time the program was cut to three units.

CONCLUSIONS

Like the other programs, the F-107 exhibits the effects of a high level of uncertainty. The aircraft went through two redesigns, the T-171 gun was added, and the J75 was substituted for the J57. The program began with plans for 33 units but ended with a procurement of three. Again, these changes occurred because of unforeseen events that affected the relative promise of various alternatives (such as the fact that when 33 aircraft were ordered it was impossible to foresee the effect of the F-105 on the program, or the fact that when the J57 version was initiated it was impossible to foresee that the J75, which then existed only on paper, would appear as a superior alternative for use in the F-107).

A notable feature of the F-107 program is that since initial procurement was large relative to the number of units finally delivered, the cost of the program was high. An interesting cost comparison may be made with the North American X-15 program. Here procurement was held from the start to only three units, and the cost of airframe development and procurement was estimated in 1958 at about $67 million -- about $18 million below the

$85 million cost of the F-107. Despite the fact that fabrication of the X-15 involved a great deal of research into such things as metallurgy, aerodynamic heating effects, and stability and control in a vacuum, and despite the fact that it is constructed largely of expensive Inconel X (a nickel alloy) the three units involve less than was spent on the F-107 which, by comparison, exerted little pressure on the state of the arts. This difference in cost suggests that an initial procurement plan involving only a small number of test vehicles can be accomplished at a low cost relative to the kinds of costs involved in initiating a program under a large procurement plan and subsequently cutting back to the smaller ones.

SUBJECT INDEX

FLIGHT TESTING

SPECIFICATIONS

TIME REQUIRED FOR DEVELOPMENT