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Evolution of the F-4 Phantom

MCDONNELL DOUGLAS

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EVOLUTION OF THE F-4 PHANTOM

by
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INTRODUCTION

It must be assumed for these remarks to be valid, that the program to be discussed has been successful. From the standpoint that the F-4 Phantom has been produced in a number of models (approximately 17 to date) at a peak production rate of more than 70 aircraft per month, and a cumulative total in excess of 4000 aircraft, this program must be considered highly successful. The F-4 is in service with the U.S. Navy, U.S. Marines, U.S. Air Force, United Kingdom's Royal Navy and Royal Air Force, South Korean Air Force, Imperial Iranian Air Force, Israeli Air Force, German Air Force, Royal Australian Air Force, and Japanese Self Defense Force. The Phantom also is flown by the U.S. Navy Blue Angels Flight Demonstration Team and the U.S. Air Force Thunderbird Air Demonstration Squadron. This aircraft is produced in both fighter and reconnaissance versions for carrier as well as land based operation.

THE BEGINNING

The Phantom had its beginning not by winning an aircraft competition, but rather by losing one. In 1953 McDonnell Aircraft Corporation lost a competition for a carrier-based fighter which was won by Chance Vought with the F8U. McDonnell previously had been the designer and producer of the first jet-powered, carrier-based aircraft for the U.S. Navy, namely, the Phantom I, and had produced more than 1000 carrier-based jet aircraft prior to 1953, in the form of Phantom I, Banshee -1, -2, -3, -4, and -5, and F-3H Demons. With this background, McDonnell was determined to continue design and production of carrier-based aircraft. After having been notified of the loss in the competition with the F8U, McDonnell engineers canvassed numerous Navy operations personnel, the Bureau of Aeronautics (BuAer), and the Chief of Naval Operations (CNO), and in fact, any Navy personnel willing to listen and return questionnaires to determine their desires for the next version of carrier-based aircraft. Numerous studies and layouts were made during the next year, and a full-scale mock-up of the aircraft which was believed to most nearly represent the desires of the majority of Navy operations personnel was constructed.

Invitations were sent to numerous Navy operating commands, Overhaul and Repair facilities (O&R's), BuAer and CNO, requesting that they visit McDonnell and offer their criticism or recommendations on our mock-up. Finally, in November 1954, the Bureau of Aeronautics gave McDonnell a letter of intent to design and build two aircraft similar to the mock-up display. Many of us considered this a consolation prize for having lost the F8U production contract.

Following receipt of the letter of intent for an aircraft designated as the AH-1 (Phantom II), engineering proceeded with the design of the aircraft while negotiations with the Bureau of Aeronautics were continued in an attempt to prepare a detail specification for the AH-1. This was a difficult task because there was no military requirement for the aircraft. The Navy project officer worked diligently with the CNO and other divisions of the Bureau of Aeronautics during the same period in an attempt to finalize requirements. Finally, in April 1955, two CNO officers and two Bureau of Aeronautics officers came to St. Louis and within an hour sketched on a blackboard and described the military mission desired for the Phantom. Simply stated, the mission was fleet air defense. That is, the aircraft was to be deployed from a carrier, cruise out to a radius of 250 nautical miles, stay on cap and attack an intruder when required, and return to the carrier with a total deck cycle time of 3 hours. The Navy further stated that the airplane should be armed with air-to-air missiles of the latest type instead of guns.

Until this time the AH-1 was contemplated as a single-place, twin-jet aircraft equipped with guns, radar, and the necessary fire control system. It had 11 external stations for carrying bombs, rockets or practically any armament in the Navy arsenal.

Within two weeks after receiving the mission requirements for the AH-1, the airplane design was reconfigured by removing the guns, changing the fire control system to be compatible with air-to-air missiles, and removing all external armament stations except one at the centerline which was retained for a large external fuel tank. Within two weeks the detail specification was revised and approved by both contractor and customer. At this time the Sparrow I, II, and III missiles were in the development phase, and the Phantom was configured to carry semi-submerged in the bottom of the fuselage four of these types of missiles.

It is noteworthy that this was the first semi-submerged installation of missiles in a fighter aircraft, and as will be noted later, all speed records set by the Phantom were with missiles installed.

Until then, the AH-1 was powered by two J-65 engines and was estimated to have a V_{max} of approximately 1.5 Mach. At the time the Phantom was reconfigured to the missile version, the J-79 engines were substituted for the J-65s with corresponding changes in duct area, and other features which gave the aircraft a V_{max} well in excess of Mach 2. The Phantom II became the first Mach 2-plus carrier-based aircraft for the U.S. Navy.

During this period there were two schools of thought as to whether Navy aircraft of this type should be single-place or two-place. So McDonnell prepared both single- and two-place configurations, identical except that the two-place version had a 150 gallon fuel cell removed from the forward fuselage to provide space for the second crewman. This fuel was replaced by expanding the external centerline tank by approximately the same volume. Both versions were shown to the Bureau of Aeronautics and CNO. The Navy selected the two-place version and advised the contractor of its choice within 36 hours. After the CNO established the mission for the AH-1 and it appeared that the program might go beyond the research and development effort, the Bureau of Aeronautics, in 1955, invited Chance Vought to build a competing aircraft for the same mission, apparently to keep McDonnell honest. Chance Vought designed and built prototypes of the F8U-3, a single-engine, single-place, missile-carrying aircraft. In 1958 the F4H-1 and the F8U-3 flew a hard-fought, side-by-side competition during the Navy Preliminary Evaluation (NPE) at Edwards AFB. The NPE pilots flew both aircraft and were able to make a direct comparison. After this competition, the Bureau of Aeronautics awarded McDonnell a limited production contract for the F-4 Phantom II in December 1958.

THE F-4 PHANTOM

During the design and development phase of the Phantom, numerous performance improvements and capabilities were added after analysis and discussions between the contractor and customer. A few examples are: the diameter of the radar dish was increased which substantially increased the target acquisition and lock-on range of the radar; the missiles were changed from rail launch to ejection launch; boundary layer control was added to the leading edge, as well as the trailing edge flaps of the wing; dual controls were added for the rear crew member as an option; the engine air flow was increased to accommodate a larger, more powerful version of the J-79, and numerous other features which will be listed later. Typical guaranteed items on the F-4 shown in

Figure 1 are weight empty, V_{max}, rate of climb, ceiling, time to accelerate and stall speed. The sum of the percentages by which the first model of the Phantom, the F-4A, exceeded its guarantees amounted to 75 percent.

System Parameters	Units	F-4A	
		Required	Demonstrated Capability
M_{max} - Maximum Power	m	2.04	2.03
M_{max} - Military Power	m	0.99	1.01
Rate of Climb at 35,000 ft Maximum Power	ft/min	12,258	17,500
Time to Climb from S.L. to 35,000 ft Maximum Power	min	1.30	1.13
Time to Accelerate from MRT V_{max} to M_{max} at 35,000 ft	min	0.81	0.59
Supersonic Combat Ceiling with Maximum Power	ft	55,430	56,900
Maximum Specific Range	nm/lb fuel	0.1107	0.1173
Combat Gross Weight	lb	36,817	36,817

FIGURE 1 CONSISTENTLY EXCEEDED PERFORMANCE GUARANTEES

Figure 2 illustrates progression of the various F-4 models. The F-4A was updated to the F-4B by a number of improvements, including a change from the J-79-2 to the J-79-8 engine with a comparable inlet duct enlargement; improved longer range radar; Sparrow III missiles, and fire control improvements. The F-4C model was designed and produced for the U.S. Air Force based upon the philosophy of minimum change from the F-4B Navy version to meet the requirements of the Tactical Air Command. The principal changes were the addition of an anti-skid system; J-79-15 engines; enlarged wheels, brakes and tires for softer runway surfaces; new radar and bombing systems; provisions for boom type air-to-air refueling in place of probe refueling; cartridge starters for engines instead of compressed air turbine impingement starting used by the Navy; more extensive dual controls, and an inertial navigation system.

A reconnaissance version for the Air Force known as the RF-4C was the next Phantom II model. It was primarily an F-4C with the reconnaissance equipment installed in a new nose. The RF-4B designed for the U.S. Marine Corps essentially was an F-4B with the RF-4C nose and reconnaissance equipment. The F-4C was followed by the F-4D for the U.S. Air Force. The F-4D had an improved radar, improved inertial navigation system, and launch provisions for the Falcon missile in place of the Sidewinders. The F-4D for the Iranian Air Force was known as the (IR)F-4D. The Air Force's latest Phantom fighter, the F-4E had an improved radar, additional internal fuel, J-79-17 engines, and an internally mounted, rapid-firing 20mm cannon and Sidewinder missiles in addition to the Sparrow missiles. The F-4E, designated (IR)F-4E also is being produced for the

Iranian Air Force, for the Israeli Air Force known as (IS)F-4E, and for Japanese Self Defense Force known as the (JA)F-4E. A reconnaissance version of the F-4E is being produced for the German Air Force designated (GY)RF-4E and for the Israeli Air Force designated as the (IS)RF-4E. Aircraft produced for foreign nations have certain classified equipment deleted.

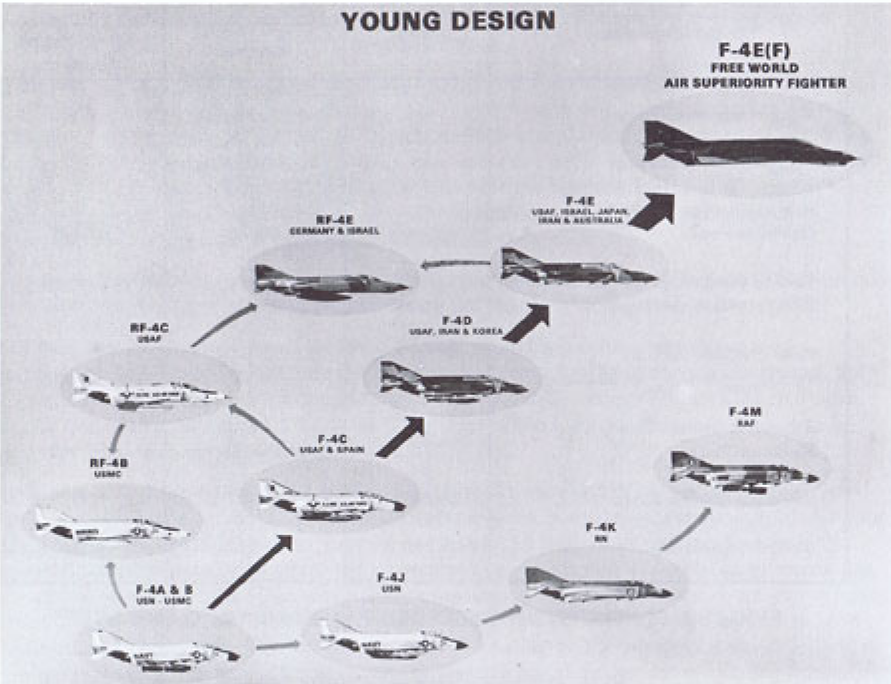

FIGURE 2 F-4 MODEL PROGRESSION

The designation F-4F was not used because of a conflict with a previous model. The F-4G is a variation of the F-4B with extensive two-way data link installed. The F-4H designation also was not used because it was used prior to the present model designation system. The F-4J is the latest U.S. Navy version of the Phantom and it differs from the F-4B principally by a general beef-up of structure and landing gear; wheels and tires increased to the size used on Air Force aircraft; a new AWG-10 missile control system; drooped ailerons and slotted stabilator to permit lower landing speeds at higher gross weights; increased internal fuel capacity; J-79-10 engines; rocket ejection seats, and extensive radar warning and electronic countermeasure equipment.

The F-4K Phantom was produced for the Royal Navy with Rolls Royce Spey engines installed; an extra extendible nose landing gear to permit catapult from carriers at lower wind speeds; combustion starters for the engines, and an extensive substitution of British-made equipment, particularly electronic systems. The F-4M was produced for the United Kingdom Royal Air Force. Principal differences from the F-4K were the removal of the extra extendible nose gear, drooped ailerons, and catapult provisions, and the addition of a new British-made inertial navigation attack system, a 20mm gun pod, a reconnaissance pod, and additional British missile provisions.

Early in production, as much as 55 percent of the airframe by weight was fabricated by other U.S. aircraft contractors as shown in Figure 3. In the case of the F-4K/M, 45 percent of the dollar value of the airframe and equipment was produced in the United Kingdom. In the case of the German (GY)RF-4E, a substantial number of subassemblies are produced in Germany. Major airframe contractors that have, or are producing F-4 assemblies are: Northrop, Republic, Beech, Rohr, Aeronca, Short Brothers, Messerschmidt, Dornier, Mitsubishi, and Kawasaki.

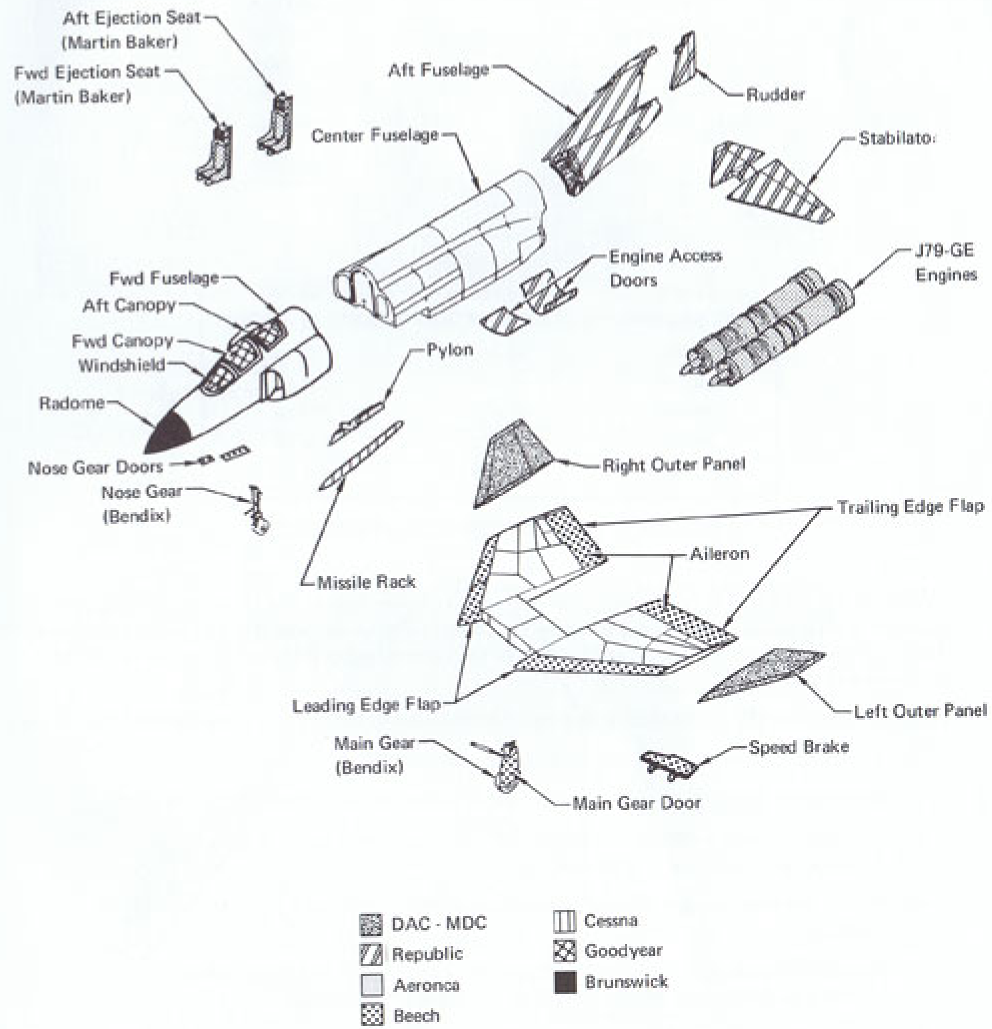

FIGURE 3 SUBCONTRACTOR INTEGRATION

The F-4 Phantom established numerous flight records (Figure 4), and it should be particularly noted that these records were set by the standard combat aircraft configuration with standard armament carried.

15/25 Kilometer Straightaway	1606 mph
3 Kilometer Low Altitude	902 mph
100 Kilometer Closed Course	1390 mph
500 Kilometer Closed Course	1216 mph
Los Angeles to New York	170 minutes
Sustained Altitude (Level Flight)	66,443 feet
Altitude	Over 100,000 feet

TIME TO CLIMB

METERS	FEET	SECONDS
3,000	9,842	34.52
6,000	19,685	48.78
9,000	29,527	61.62
12,000	39,370	77.15
15,000	49,212	114.54
20,000	65,617	178.50
25,000	82,021	230.44
30,000	98,425	371.43

FIGURE 4 F-4 PHANTOM FLIGHT RECORDS

Although not shown in these records, it is interesting to note that an F-4 aircraft with pre-compressor cooling installed attained a speed of 2.62 Mach number and was still accelerating during a trial. The speed run was discontinued for fear of the consequences if the water supply would be exhausted at that speed.

Some attributes of the F-4 aircraft which have contributed to its long life as a successful fighter are:

1. First Mach 2-plus aircraft suitable for carrier operations.
2. More speed, altitude, and time-to-climb records than any other aircraft in the world.
3. A reputation as the best fighter in the Free World, a title it has now held for over a dozen years.
4. Proven performance by maintaining air superiority in Southeast Asia and Middle East conflicts.
5. Proven outstanding performance and versatility as a fighter, fighter-bomber, and reconnaissance aircraft during more than 4 million hours of flight.
6. Proven service in the air arms of eight nations.
7. Demonstrated outstanding performance with the Blue Angels and Thunderbirds during the past two years.

8. Unique design features:

A) First engine inlet duct movable ramp system used for Mach 2-plus performance (Figure 5).

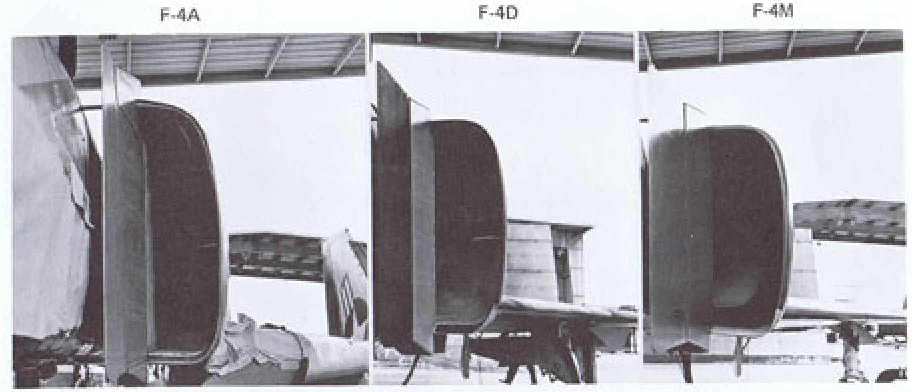

FIGURE 5 ENGINE DUCT VARIABLE RAMP SYSTEM

B) First use of bellmouth to control engine inlet and secondary airflow through aerodynamic nozzle.

C) First use of boundary layer control on both leading edge and trailing edge flaps on an operational fighter to reduce stall speed and improve lateral control at low speeds (Figure 6).

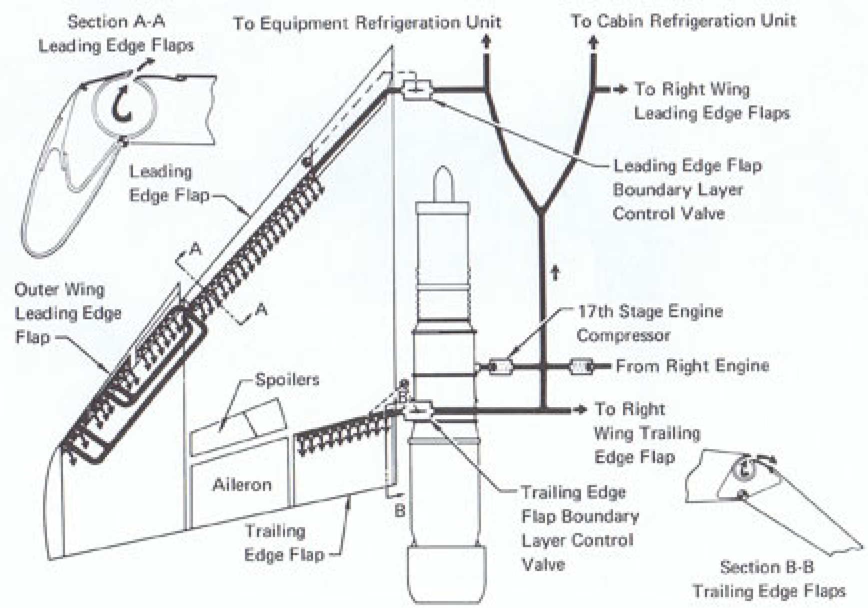

FIGURE 6 BOUNDARY LAYER CONTROL ON LEADING AND TRAILING EDGE FLAPS

D) Longest range radar installed in any fighter-type aircraft.

E) Greatest speed range (V_{max}/V_{stall}) of any operational fighter built to date.

F) First use of drooped ailerons and slotted stabilizer to reduce landing speed on a fighter aircraft (Figure 7).

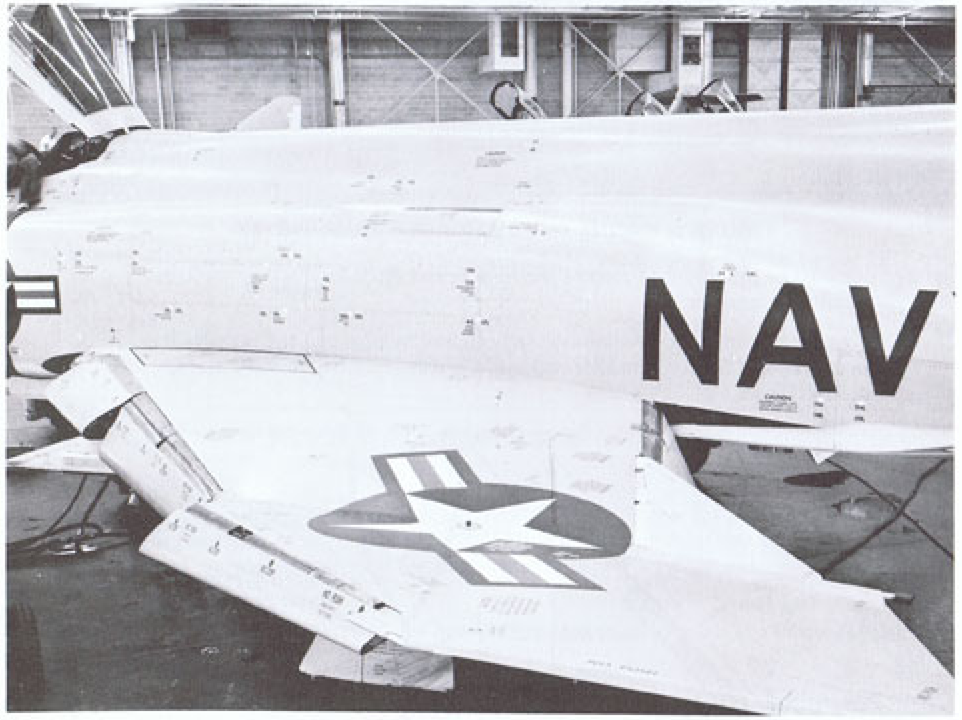

FIGURE 7 F-4 DROOPED AILERONS AND SLOTTED STABILATOR

G) First use of an extra extendible nose strut to reduce wind-over-deck required for catapult (F-4K) (Figure 8).

H) First operational fighter carrying semi-submerged Sparrow III missiles with low drag, in addition to Sidewinders and 20mm rapid fire guns (Figure 9).

FIGURE 8 EXTRA-EXTENDIBLE NOSE STRUT

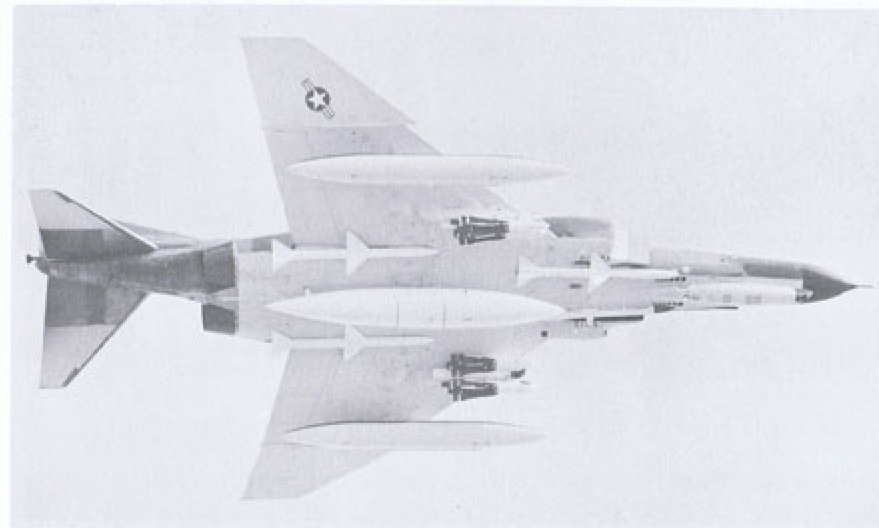

FIGURE 9 SEMI-SUBMERGED SPARROW III MISSILES

I) First inertial navigation system installed in a fighter-type aircraft to effect automatic air-to-ground weapon release.

J) First two-way data link installed in a fighter aircraft.

K) Controllable for safe return to base with hydraulic and control systems and power plant completely shot out on either side of aircraft (retrofitted) (Figure 10).

FIGURE 10 DAMAGED F-4'S RETURN TO BASE

L) Internal fuselage fuel is useable with all electrical and utility power lost.

M) Demonstrated safe carrier arrested landings with one engine lost (Figure 11).

N) First aircraft with the highly successful channel seal for internal wing fuel.

O) M61 rapid-fire 20mm gun is operable throughout complete flight envelope of aircraft without stalling engines (Figure 12).

FIGURE 11 CARRIER LANDING WITH ONE ENGINE LOST

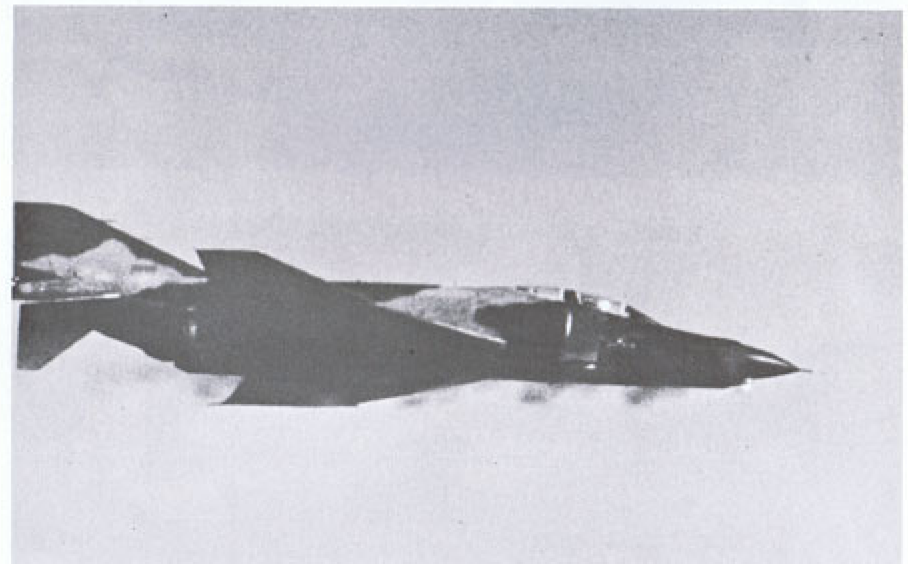

FIGURE 12 M61 20MM GUN OPERABLE WITHOUT ENGINE STALL

P) First aircraft with braided compact wire bundles, saving substantial weight and space (Figure 13).

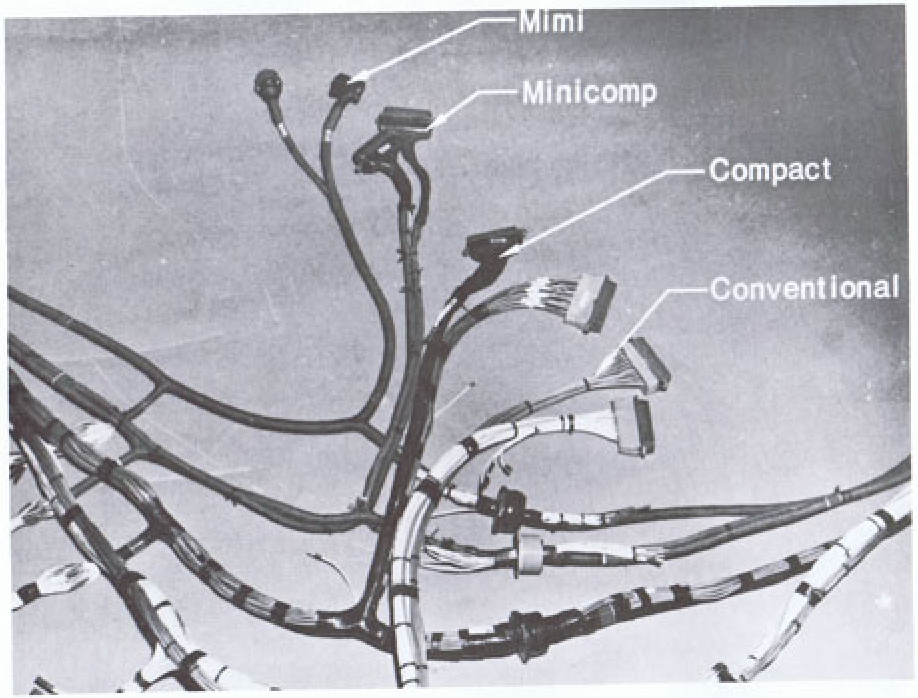

FIGURE 13 BRAIDED COMPACT WIRE BUNDLES

Q) Substantial growth both in useful load capability and permissible landing gross weight during its evolution.

R) A number of F-4s already have exceeded the original design life.

S) F-4s have delivered almost every type of bomb, rocket and missile in the Navy and USAF arsenals (Figure 14).

T) Boron composite rudders have been flown in quantity on F-4s in operational use (Figure 15).

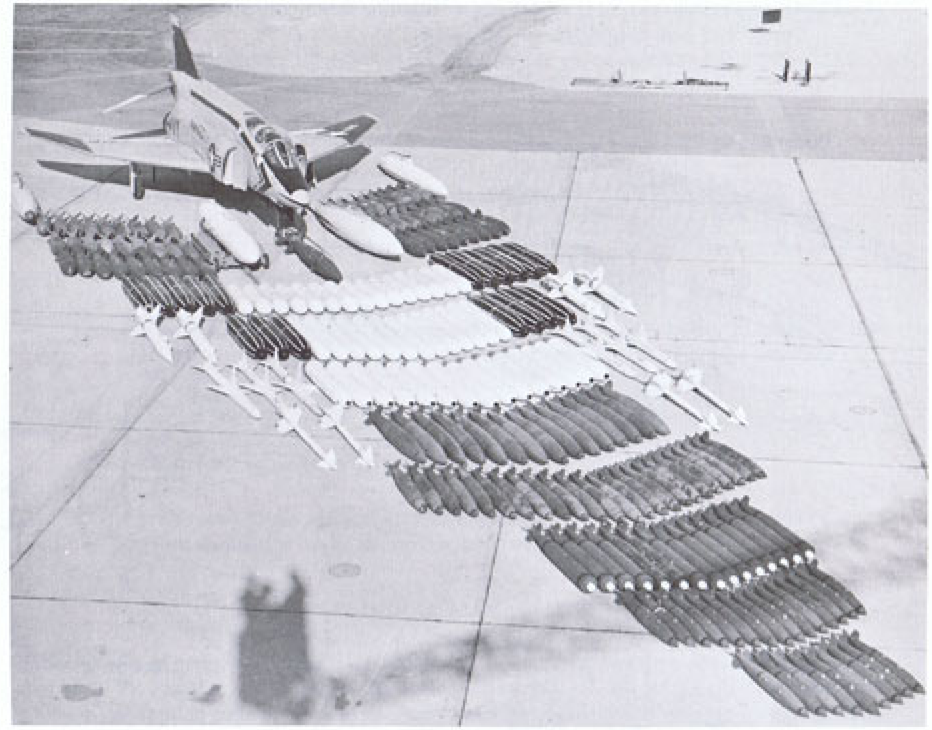

FIGURE 14 F-4 WEAPON INVENTORY

FIGURE 15 BORON COMPOSITE RUDDER

U) First aircraft making extensive use of titanium in primary structural members subject to high temperatures (Figure 16).

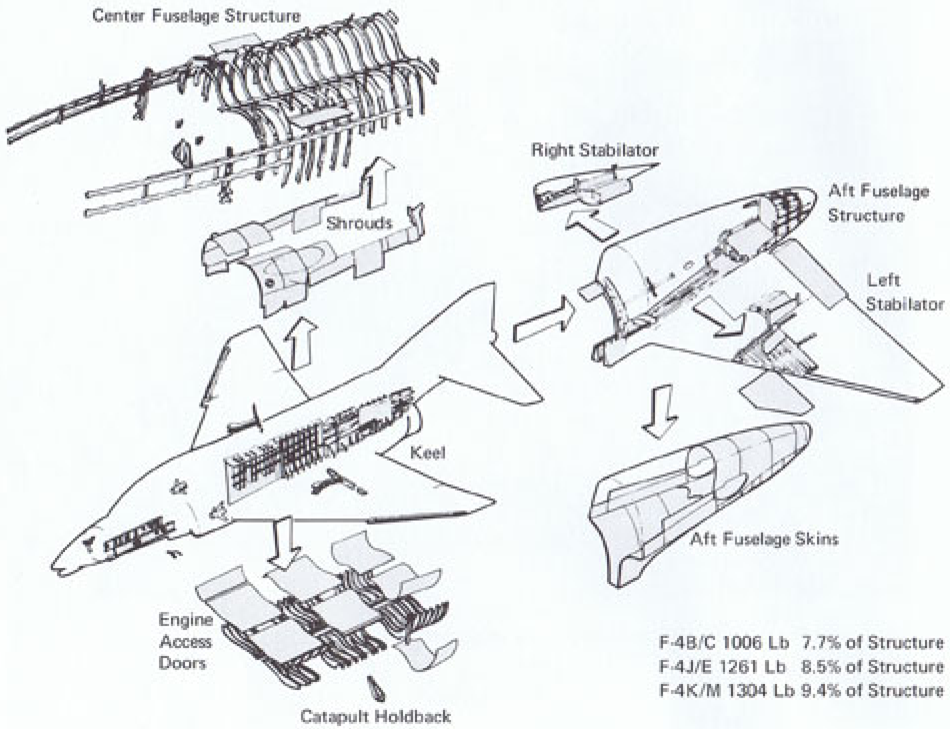

FIGURE 16 EXTENSIVE USE OF TITANIUM IN F-4 STRUCTURES

V) First and only carrier-based aircraft capable of fully automatic landings.

W) First and only fighter aircraft with pulse doppler radar having look-down and shoot-down capability.

X) A fire control system offering multiple and versatile air-to-ground and air-to-air weapon delivery including:

1) Head-on, long-range air intercept
2) Medium-to-short-range rear hemisphere attack capability
3) Sparrows, Sidewinders, and guns
4) Conventional weapons
5) Nuclear weapons

Y) First fighter-bomber in Southeast Asia with a full complement of penetration aids.

Z) First multi-service fighter-bomber adaptable to requirements of U.S. Navy, U.S. Marines, U.S. Air Force, and foreign military services.

AA) First aircraft to make extensive use of chem-milling for structural parts.

BB) F-4 has one of the best safety records of any operational fighter.

CC) First carrier-based aircraft having higher performance than contemporary land-based aircraft.

DD) F-4J is the highest density operational aircraft at takeoff weight (full internal fuel and basic armament) of any aircraft produced in this country (34.13 lb/ft^3).

EE) F-4B/J is the first fighter with full 360° nose gear steering.

FF) First aircraft to make extensive use of integrated structure.

GG) First aircraft to use integral hydraulic passages in landing gear torque links to prevent damage of brake lines from arresting cables.

PROGRAM MANAGEMENT

Various types of contracts from firm fixed price to numerous incentive contracts have been applied to the Phantom procurement for various fiscal years. Some of the customer/contractor philosophies applied to the Phantom program which probably contributed to its extended life are as follows: (Let me preface my remarks by saying that these are the opinions and impressions of an engineer, and do not necessarily reflect the policies of McDonnell Aircraft Company.)

1. Bonuses and penalties, if large enough, can have an adverse effect. They cause conservatism on guaranteed items and compromise overall aircraft performance. Flexibility and desirable trade-offs are eliminated.
2. Development of an aircraft is a big bundle of compromises. The possibility of meeting all specification items precisely is extremely remote.
3. Frequently a contractor is confused by customer requirements which are specified by numerous non-compromising activities with no indication of desirable trade-offs when such are necessary.
4. What does the customer really want and need? Both contractor and customer need flexibility for negotiation at least once each fiscal year during development of an aircraft so that desirable trade-offs may be made at the numerous cross-roads in the development phase.
5. The best aircraft for the mission at the time the aircraft goes into production should be a paramount objective of both the customer and the contractor regardless of the details in the initial specifications.
6. The customer should not ask for everything or he will get nothing worthwhile – he must provide for flexibility and trade-offs.

7. Patent, latent, and design defects. After an aircraft has passed the principal intent of all tests agreed upon by customer and contractor and spelled out in the contract, patent or obvious defects for a limited period (6 to 12 months) should be the responsibility of the contractor. Likewise, latent defects up to the legal time limit should be the responsibility of the contractor. However, the correction process should be negotiated to place the minimum burden on both the customer and contractor. Design defects caused by unexpected unknowns, even though the development and test program was analysed by the contractor to his best knowledge of the state-of-the-art and concurred in by the customer, should then become an item for negotiation of added contract cost.

8. A contract which specifies precisely what the customer wants and exactly how to prove compliance is simplest for the contractor. However, such a contract again eliminates the flexibility and trade-offs so necessary in the development of the best aircraft for a timely mission.

9. The greatest incentive to motivate a contractor is a follow-on production contract. Contractor earnings come from production and not from designing aircraft. A good contractor wants to sell a lot of good aircraft which will be highly useful to his customer. Or, in other words, what is good for the customer is good for the contractor.

The writer, who has been associated with the Phantom program from its conception 17 years ago, believes that the program was a success primarily because of the mutual understanding which existed between the contractor's project engineer and program manager and the customer's project officer and program manager. Fortunately, the Phantom was developed before the day of the heavy emphasis on the "ilities" and the complex decision-making processes.

In summary, let me state "COHENS LAW":

> "The more time you spend in reporting on what you are doing, the less time you have to do anything.
> Stability is achieved when you spend all your time doing nothing but reporting on the nothing you are doing."