DOGFIGHTER SUPREME

THE TOMCAT

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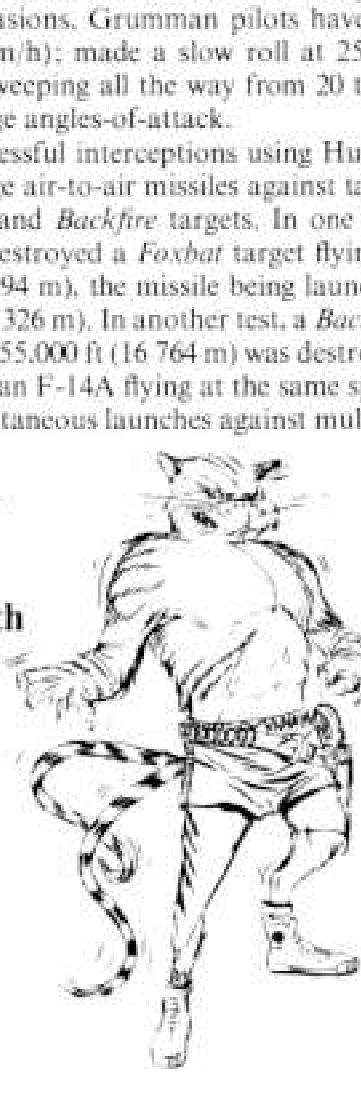
The Grumman F-14A Tomcat, fast approaching full operational status with the US Navy, is gaining recognition as one of the West's most potent fighters. David W H Godfrey, P Eng, C Eng, AFRAeS, AFAIAA, describes the Tomcat's concept and characteristics.



THERE ARE two views as to what constitutes the most effective configuration for a high-speed, high-altitude air superiority fighter — an aircraft capable of executing high-energy, high-*g* manœuvres to obtain a "kill" position for missile launching or gun firing, or a lightly loaded aircraft with a look-down, shoot-down weapon system depending on the manœuvrability of its missiles. When the special limitations of shipboard operation are added to the strictures of designing for air superiority, an optimum solution is the adoption of variable-sweepback wings for the highly-manœuvrable type of aircraft. Such a design is the Grumman F-14 Tomcat now being delivered to the US Navy.

Recent flight testing of the Tomcat has given clear evidence of the efficacy of its design concept whether in dogfighting with an F-4J or in missile attacks on target drones. An F-14A matched against an F-4J fitted with wing slats for improved manœuvrability outperformed the latter in every respect during eight dogfight encounters, pulling more than 7 *g* in initial turn breaks. This was all the more impressive since the Tomcat's slats and manœuvring flaps were locked out of action and Mach-programmed sweep for the wings was used with no pilot over-ride. At angles-of-attack up to 48 degrees, the F-14A retained excellent stability and control at speeds down to 160 kt (297 km/h), enabling it to force the F-4J to overtake and thus place itself in a target position. On the other hand, when the F-14A was ahead, it accelerated out of gun range almost instantly and out of the missile-launch zone within a few seconds, yet could manœuvre in behind the F-4J and track it in several seconds.

With the wings swept fully aft at 68 degrees, the Tomcat's nose may be pulled up until the angle-of-attack reaches 90 degrees, or it may be depressed until a negative angle of 45 degrees is reached. The aircraft has an inherent tendency to remain in controlled flight at very low airspeeds because of the strength of the lifting vortex over the curved fuselage top. Even at extreme angles, there is no perceptible buffeting, yawing, or wing rocking, and the aircraft is apparently unstallable and inherently spin-resistant. As demonstrated at the Paris Air Show last year, the F-14A has extreme agility. It was flown there down to 105 kt (195 km/h) while retaining full lateral control; pulled 6·5 *g* turns at 400 kt (741 km/h) with 40 degrees of sweepback (on other occasions, Grumman pilots have exceeded 8 *g* at 360 kt, 667 km/h); made a slow roll at 250 kt (463 km/h) with the wings sweeping all the way from 20 to 68 degrees, and flew at very large angles-of-attack.

The F-14A has made successful interceptions using Hughes AIM-54A Phoenix long-range air-to-air missiles against target drones representing *Foxbat* and *Backfire* targets. In one test, the F-14A/Phoenix system destroyed a *Foxbat* target flying at Mach 2·2 and 82,000 ft (24 994 m), the missile being launched at Mach 1·3 and 47,000 ft (14 326 m). In another test, a *Backfire* target flying at Mach 1·5 and 55,000 ft (16 764 m) was destroyed by a Phoenix launched from an F-14A flying at the same speed at 45,000 ft (13 716 m). Simultaneous launches against multiple targets have been highly successful, and the Phoenix has also been effective in look-down attacks against low-flying drones representing ship-launched cruise missiles.

Naval Needs

Evolution of a radically new aircraft configuration is a rare experience that some companies never have, successful though they may be in producing perfectly competent aircraft. Indeed, the more radical the shape or the features, the more risk is there of failure, for which few prizes are given. Sometimes, an idea is ahead of its time because adequate materials or powerplants are not available. It is all too easy to invent something, but it is much more difficult to get it to work and successfully put it into production so that other people can use it.

A case in point is the variable-sweepback aircraft (academically not an aeroplane because its wings move), the idea for which goes back to a 1942 patent of Messerschmitt aerodynamicist Dr Alexander Lippisch who wanted to improve the low-speed handling characteristics of aeroplanes with sweepback. The idea also occurred to Barnes Wallis in England for application to very long-range aircraft, and models were flown, but the first full-scale aircraft to fly was the Bell X-5 in June 1951. (The X-5 was derived from the design of the Messerschmitt P 1011 whose wings, like those of the Short SB.5, could have their sweepback angle changed only on the ground).

The Grumman XF10F-1 Jaguar which flew in May 1953 incorporated all that had been learned from the X-5 and from design studies at the National Advisory Committee for Aeronautics (now NASA). Ten Jaguars were ordered by the US Navy, but the concept still proved to have limitations that resulted in development being dropped after only one aircraft had been completed. The "second time around" for variable sweepback at Grumman came with the F-111B, a naval version of the General Dynamics F-111A with longer wings and an armament of six AIM-54A Phoenix missiles. Maiden flight of the F-111B was on May 18, 1965 but only seven were built before unacceptable weight growth (and other problems) brought the programme to an end in April 1968.

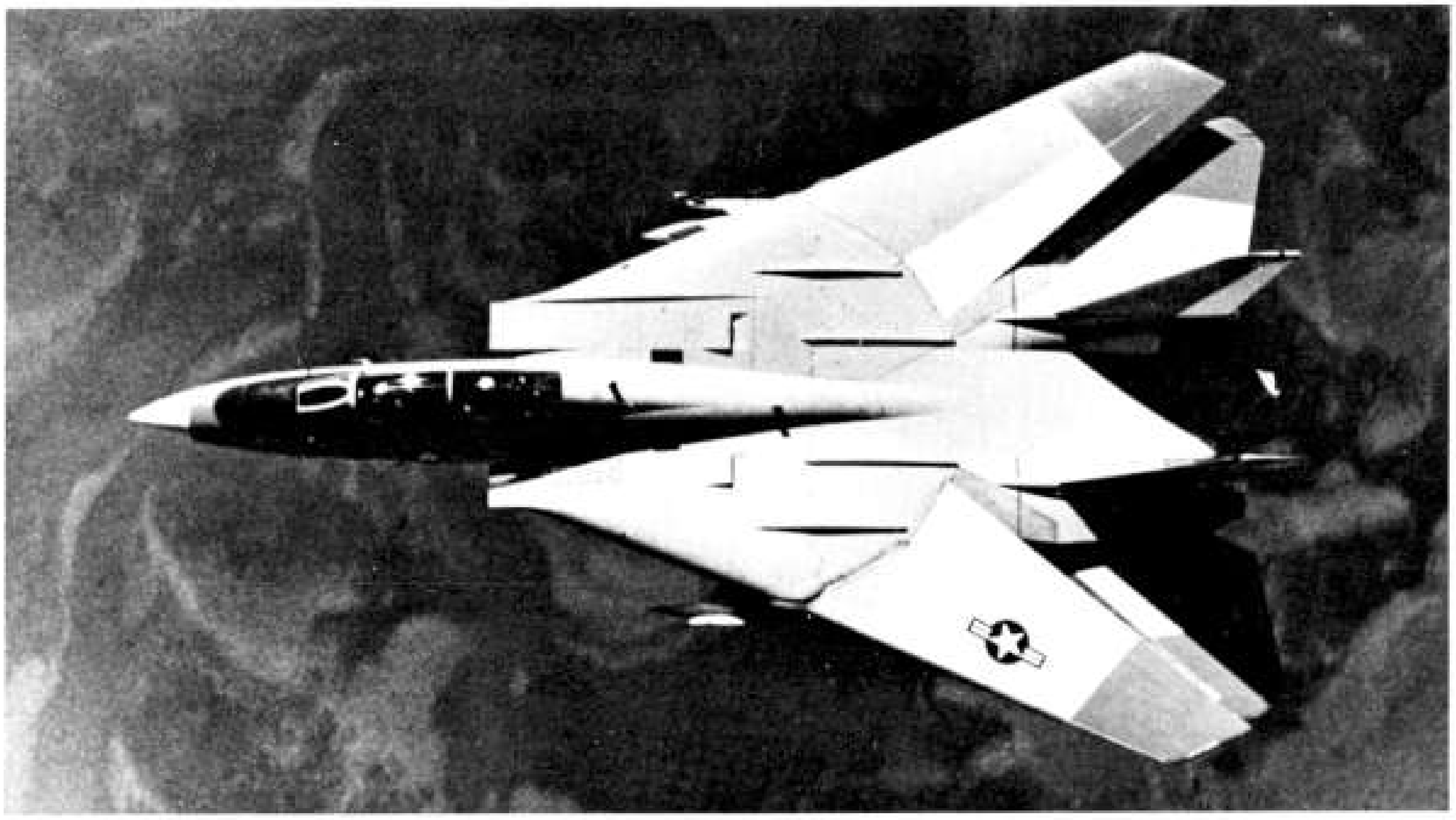
The interesting thing here was that, in effect, Grumman — which had design and production responsibility for the F-111B — pulled the rug out from under its own feet by suggesting to the US Navy that a better aircraft could be developed by using the same technology (including engines) but avoiding the penalties of the "commonality" concept of procurement whereby much of the aircraft was the same as for the Air Force version. Out of this came the VFX design contest (V = heavier than air; F = fighter; X = experimental).

Unencumbered by the requirement to use a modified F-111 airframe, Grumman was now able to go ahead with a completely fresh design, yet had the inestimable benefit of two generations of hindsight with variable-sweepback fighter designs already under its belt. Of course, it was not mandatory to use variable-sweepback, but it was significant that of all the rival designs submitted for the VFX contest only one, that of McDonnell Douglas, had a fixed wing — it being the conclusion of all the other entrants that the mission requirements for versatility in naval air superiority virtually demanded variable sweepback. The two finalists were Grumman and McDonnell Douglas, and these designs were then refined and resubmitted to the Naval Air Systems Command by the end of 1968. Grumman was announced as winning contender on 15 January, 1969.

Configuration compromises

The first thing a student of aeronautical engineering has dinned into him is that all aircraft design is a compromise. The trick is to get such a *good* compromise that the aeroplane is a winner. Nowadays, this process is performed by elaborate analyses in which various trade-offs and variations are made to determine what the overall effects will be. The stages through which the Grumman VFX design studies progressed can be briefly summarised, although there was nothing brief about the analyses themselves.

Grumman design 303-60 of January 1968 had podded engines like the ultimate F-14 design, and a high-set variable-sweep wing. Various modifications followed. Design 303A was similar to 303-60, with a nacelle modification, and was then updated to become 303B. Design 303C had submerged engines; 303D retained the submerged powerplants, but had a low-set variable-sweep wing, and 303F had a fixed wing.



An early F-14A Tomcat test aircraft showing the wings fully swept back to present an almost true delta planform. All external stores — including the Phoenix and Sidewinder missiles just visible in this illustration — are carried on the fixed centre section, avoiding the need for swivelling pylons.

(Above) A Tomcat reveals its large intake area. The intakes are two-dimensional with a single mode of variable geometry through the use of compression ramps visible inside the tops of the intakes. (Below) The No 2 flight test aircraft, showing a spin chute housed between the tailpipes. In addition to six Phoenix and two Sidewinder missiles, this aircraft is carrying two fuel tanks under the engine nacelles.

One configuration, 303G, had podded engines and a high, variable-sweep wing, but was a "fighter only" version with the AWG-10 fire control system of the F-4 and four Sparrow missiles. Since it lacked Phoenix long-range all-weather capability, it was dropped. The 303D design was soon eliminated because it had poor subsonic longitudinal stability, excessive subsonic induced drag, high fuel consumption in cruise, and reduced supersonic thrust with maximum afterburner power. Also, this configuration had the air intakes designed for maximum pressure-recovery which required them to be located so far forward that they blocked the pilot's view and obstructed access to stowage areas in the sides of the fuselage nose. To limit this effect, the sweep of the forward wing glove was reduced and the movable part of the air intake was shortened. However, it was known from F-111 experience that the TF30 engine was extremely sensitive to intake imperfections, and the shortened movable air intake would have been harder to match to the engine both for moderately high angles-of-attack and up, and for take-off and high-altitude loiter. Again, by comparison with high-wing installations, the fixed part of the intake was longer and more curved, which would result in greater duct losses in pressure recovery at the engine compressor face.

The 303C design with submerged engines was then compared with the podded-engine 303B. Each had a high, variable-sweep wing and had about the same weight and carrier suitability, but 303B was superior in installed fuel flow and maximum afterburner thrust; supersonic combat-ceiling performance; isolated engine intakes and exhaust nozzles (to avoid F-111-type maximum-performance problems); large separation between air intakes and fuselage to eliminate boundary-layer diverter systems; and good potential for installation of larger engines later on (*ie*, in VFX-2 which led to the F-14B and C).

The 303B design was then refined to become the 303E and compared with the 303F fixed-wing configuration. The 303F was the loser for two main reasons:

(1) Aircraft take-off weight would have been nearly 5,000 lb (2 268 kg) higher for the Sparrow fighter mission, primarily because of the larger wing area provided for carrier-suitability requirements. Even with a much larger wing of 745 sq ft (69,2 m^2) compared with 565 sq ft (52,5 m^2), the 303F still did not meet the requirements for the six-Phoenix combat air patrol mission with the double-slotted flap high-lift system assumed. Boundary-layer control would have been needed with another weight increase. Wave-off single-engine rate of climb was also not acceptable because of the small wing span and low aspect ratio which reduced low-speed lift.

(2) The large wing with its concomitant high-lift system degraded low-altitude performance.

The original 303-60 design progressed to the final 303E configuration over a period of nine months. Extensive compromises were made in studies to trade-off stability, performance, weight, and operational characteristics against development risk, complexity and cost. The ultimate, contract-winning configuration best met the fighter-rôle requirements with minimum risk and maximum growth flexibility.

Progress and problems

In compliance with normal procurement procedures, the US Navy placed an initial contract with Grumman covering the first six research and development aircraft; included in Fiscal Year 69 funds, this became Lot I of the total planned procurement. Lot II (FY 70) was for another six R & D aircraft; Lot III (FY 71) was for the first 26 production F-14As, Lots IV (FY 72) and V (FY 73) each being for a further 48 aircraft. It had originally been intended that a switch would be made from the F-14A to the F-14B after 28 F-14As had been completed in Lot IV — all of Lot V and subsequent then being F-14B. The latter model differed in only one significant respect, that being its use of Pratt & Whitney F401 turbofans, these being navalised equivalents of the F100 that the USAF had meanwhile picked to power its new TAC fighter, the McDonnell Douglas F-15A. Further in the future would be the F-14C, having the F401 engines and a new, updated avionics fit. In the spring of 1971, however, the Navy became aware of development problems with the F401 engine which indicated it would not be ready for use in the F-14B as planned; consequently, the F-14B was eliminated from Navy plans (other than prototype testing) and an all-F-14A programme was drawn up in June 1971 covering 301 production aircraft plus the 12 R & D prototypes.

Despite the benefit of hindsight *vis a vis* the F-111B "cuckoo's egg", the F-14A programme has not been without its share of major problems, although the most serious of these have been financial/political rather than technical. Flight testing of the first F-14A began on 21 December, 1970, a good month ahead of the contract milestone date. However, during its second flight, on 30 December, it was lost following total failure of the hydraulic circuits to the flying controls, although both crew members ejected safely. This set the programme back several months and testing was resumed with the second aircraft on 24 May, 1971, seven more F-14As joining the programme before the end of the year. On 30 June 1972, the tenth F-14A crashed when the pilot left his pull-up until too late while practising for an air show at the Naval Air Test Center, Patuxent River, Maryland. A third F-14A was lost near the Naval Missile Center, Point Mugu, California, in June 1973 when a Sparrow missile was ejected in level — rather than nose-down — attitude, pitched up to puncture a fuel tank in the centre fuselage and caused an explosion, fire and an aircraft pitch-up to 70 degrees angle-of-attack. The crew ejected safely. By the end of October 1973 Grumman had delivered more than 40 F-14As to the Navy for squadron use; had six more on acceptance testing at Calverton, Long Island; and was then starting to assemble the 70th airframe.

BIS trials are being handled by the Naval Missile Center at Point Mugu, and by the Naval Air Test Center at Patuxent River. The task of working-up ground and aircrews in preparation for operational deployment is assigned to a Readiness Unit, VF124, at NAS Miramar, where the first two squadrons, VF1 and VF2, are also now working up. The next two Tomcat units will be VF3 and VF4.

Just as Grumman had warned the Navy of unacceptable weight growth with the F-111B, so did the company lose no time in sounding the alarm on costs for the F-14A late in 1969, less than a year after award of the contract. Grumman had first bid $2,900 million (£1,200m) to build 469 airframes (later increased to 722 and then cut to 313), but reduced its asking price to $2,426 million (£1,010m) just before the contract-award date — thereby undercutting McDonnell Douglas by $100-million (£40m), although the latter's design was fixed-wing and therefore inherently cheaper.

The crunch came with Lot V of the F-14A contract for 48 aircraft, included in the Fiscal 1973 budget, which Grumman stated could not be built for the January 1969 "total package procurement" contract price because of inflation, and because the company's operating base was smaller than had been predicted at the time of contract award, thereby increasing overhead costs. The then Deputy Secretary of Defense, David Packard, decided to try and hold the company to the letter of the contract despite the latter's statement that it had become ". . . commercially impractical. . .".

In August 1972, Grumman chairman and president E Clinton Towl stated emphatically that unless his company was paid an additional $545 million (£225m) for the final 227 of the 313 aircraft on order, ". . . we will close our doors if we have to. We can't proceed." At that date, a $65 million (£26m) loss had already been written off. The point was that although total production had been cut from a possible 722 and a definite 469 to 313, the research and development spending of $1,500 million (£600m) could not be reduced in proportion. So the unit price of the F-14A went up from $11·5 million (£4·6m) to $16·8 million (£6·8m) and the extra $545 million (£225m) would have raised this to $19 million (£7·9m). This, of course, was not Grumman's fault and the company would have still been $23 million (£9·5m) out of pocket at this figure.

As Towl put it to his stockholders, the form of procurement (total package) which the Lot V option exercise sought to perpetuate ". . . has proven to be so contrary to the government's own interests that its further use has been prohibited by the Department of Defense procurement regulations. The terms of the option are such as to seriously threaten Grumman Aerospace Corporation's ability to remain a viable producer of essential defence and space hardware, and to meet its responsibilities to shareholders". (The F-14A order was the last of the now-notorious "total package procurement" contracts; another was the Lockheed C-5A Galaxy.)

Eventually, the Lot V difficulty was resolved by Grumman accepting a loss of $205 million (£81m) on the first 134 F-14As ordered including $70 million (£29m) in 1972. The Navy will now make annual purchases of 50 F-14As instead of exercising the original options; thus, aircraft numbers 135 through 184 will be built against Fiscal 1974 funds. Grumman expects to be profitable overall in Fiscal 1973 and thereafter, since the 1973 and 1974 losses on the F-14A have been anticipated, and most other aspects of its business are profitable.

Early last September, it was announced that the Navy had negotiated a contract with Grumman to pay $13·9 million (£5·8m) each for 50 F-14As purchased with fiscal 1974 funds. Based on a fiscal 1974 budget request for $702·7 million (£302m) for 50 F-14As (including airframes, government-furnished equipment, spare parts, and support), a reduction of $9·6 million (£4m) has been negotiated with Grumman for the total number of aircraft. Airframe ceiling costs for the cancelled Lot VI contract option have been reduced from $334·6 million (£140m) to $325 million (£135m).

This does not include $40 million (£16·7m) in research and development funds included in the fiscal 1974 request. Spread over the 50 aircraft, this would raise the unit production cost to $14·7 million (£6·15m). Assuming that approval is now given by the Senate Armed Services Tactical Air Power Subcommittee, the Navy will go on procuring F-14As up to a total of 334. However, Deputy Secretary of Defense William P Clements is eager to reduce the cost of additional aircraft. This could be achieved principally by adopting a less-expensive missile system despite the Navy's feeling that the Hughes AIM-54A Phoenix long-range air-to-air system is essential. Alternatives to changing the missile system include redesigning the main undercarriage, and changing the gauge of the aluminium honeycomb-core material in the airframe. The trade-offs for these cost reductions are increased weight. Redesigning the beaver tail would also save money and increase weight, but would increase cruise radius by lowering subsonic drag. Removing the glove vanes would reduce cost and weight, but would also reduce the maximum speed and supersonic manœuvrability. More money would be saved by Grumman taking back into-house subcontract work on the nacelles and gloves from Rohr, and on the aft fuselages from Fairchild. (Some 60 per cent of F-14A production is at present handled by subcontractors.)

Other changes considered include several system simplifications such as deleting Mach-hold from the autopilot; removing the outboard spoilers; deleting the back-up analogue sweep channel from the central air data computer; redesigning the air-intake bleed doors; replacing beryllium disc brakes with steel; and replacing the vertical display system with a head-up display and an automatic direction indicator.

Design features

Although the VFX design contest did not specify the use of variable-sweepback wings, it was almost inevitable that the chosen design would have this feature because of the performance flexibility demanded by naval mission rôles and the carrier-suitability requirements. And this was found to be so during the design configuration trade-offs already described.

Use of a supercritical wing section was seriously considered because of its advantages in delaying Mach drag rise and extending transonic buffet-free performance. However, although the supercritical wing did offer better subsonic lift/drag ratio, maximum value, and better buffet-free lift coefficients, the results from trailing-edge pressure readings were not so encouraging and it was doubtful whether the wind-tunnel benefits would show up in full scale. There were also unresolved problems of sealing the underside of the wing at the wing/glove juncture, so the supercritical wing was not adopted.

Wing-pivot location stemmed from NASA research and was chosen to minimize the subsonic neutral-point shift with sweep, thereby avoiding the trim drag and manœuvrability penalties of excessive longitudinal stability at the supersonic full-sweep position. Great emphasis was placed upon optimization of wing configuration. In selecting wing area, maximum combat agility was an important parameter achieved by a low

(Above) The F-14A No 22, one of the first delivered to the Readiness Squadron, VF-124, was subsequently demonstrated at the Paris Air Show last May and has consequently become the most-photographed of all Tomcats. It is shown with two Sparrows under the fuselage. (Below) A production aircraft in the markings of VF-2, one of the first two operational Tomcat units.

(Below) The F-14A No 14 during trials aboard the USS Forrestal *during 1972. The "boar's head" markings are those of one of the units aboard the* Forrestal *at that time, which temporarily adopted the Tomcat during its time at sea.*

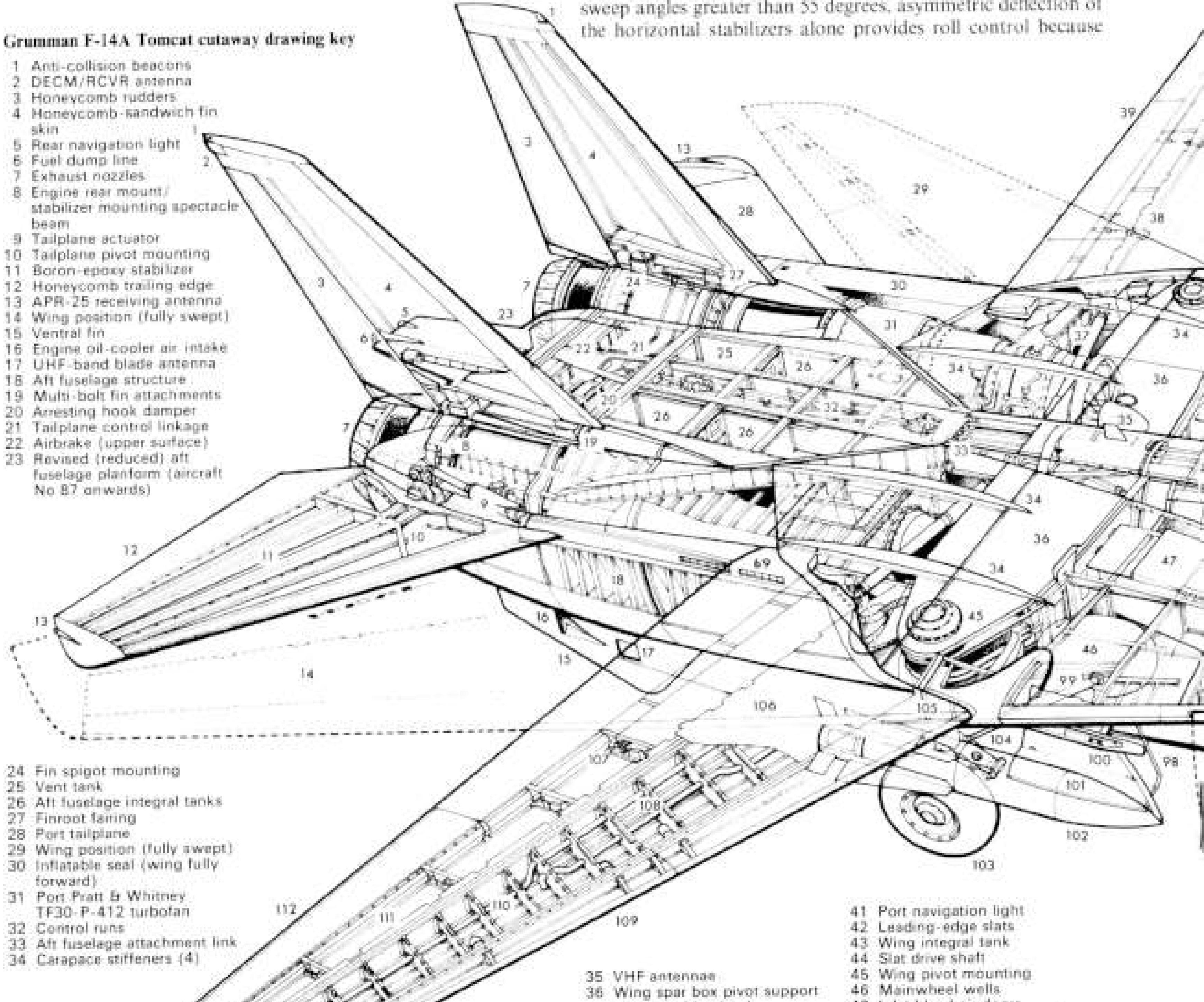
basic wing loading using a simple manœuvring-flap system. The factors of wing area considered to meet the Navy's requirements were high combat agility due to low wing loading; low take-off gross weight for the fighter mission; manœuvring flaps to increase transonic combat agility; and the deck spotting factor (maximum number of aircraft that may be parked on the carrier deck with wings at the oversweep angle).

Selection of wing-sweep angle for transonic and supersonic flight is based on minimizing drag for dogfight turning conditions because a fighter may have air superiority only if it controls the battle by being able to engage or disengage at will. Such an advantage is gained by the aircraft with the greatest ability to accelerate because of its superior ratio of excess thrust to weight (specific excess power). For a given thrust and aircraft weight, this ability is optimized by minimizing drag for any flight condition by automatic provision of best wing-sweep angle.

Whereas the F-111B was limited by having a fixed combat-detent position for the movable outer wing panels, the F-14 has a Mach Sweep Programmer (MSP) which provides fully automatic wing sweep as a function of Mach number and altitude. By selecting the MSP mode, the pilot can use all available advantage of the inherent performance-buffet characteristics which give variable-sweep its superiority over either a variable-sweep aircraft with a fixed combat-detent, or a fixed-wing aircraft.

The MSP gives improved combat manœuvrability and specific excess power in turns without the pilot having to attempt to optimize sweep angle manually. In any case, optimum sweep angle varies so rapidly during manœuvres — and is so complicated by longitudinal accelerations and decelerations — that the pilot would find it difficult to both sense and manually select appropriate sweep angles at each stage of combat.

Actuation of the manœuvring flaps is co-ordinated with wing sweep for maximum delay of buffet onset when wing lift increases. Spoilers augment the rolling power of the differential movement of the horizontal stabilizers at sweep angles less than 55 degrees. These spoilers also provide direct lift control during landing approach to vary altitude without changing attitude, and serve as lift dumpers after alighting. At wing-sweep angles greater than 55 degrees, asymmetric deflection of the horizontal stabilizers alone provides roll control because



Grumman F-14A Tomcat cutaway drawing key

1 Anti-collision beacons
2 DECM/RCVR antenna
3 Honeycomb rudders
4 Honeycomb-sandwich fin skin
5 Rear navigation light
6 Fuel dump line
7 Exhaust nozzles
8 Engine rear mount/ stabilizer mounting spectacle beam
9 Tailplane actuator
10 Tailplane pivot mounting
11 Boron-epoxy stabilizer
12 Honeycomb trailing edge
13 APR-25 receiving antenna
14 Wing position (fully swept)
15 Ventral fin
16 Engine oil-cooler air intake
17 UHF-band blade antenna
18 Aft fuselage structure
19 Multi-bolt fin attachments
20 Arresting hook damper
21 Tailplane control linkage
22 Airbrake (upper surface)
23 Revised (reduced) aft fuselage planform (aircraft No 87 onwards)
24 Fin spigot mounting
25 Vent tank
26 Aft fuselage integral tanks
27 Finroot fairing
28 Port tailplane
29 Wing position (fully swept)
30 Inflatable seal (wing fully forward)
31 Port Pratt & Whitney TF30-P-412 turbofan
32 Control runs
33 Aft fuselage attachment link
34 Carapace stiffeners (4)
35 VHF antennae
36 Wing spar box pivot support structure (titanium)
37 Wing-fold screw-jack
38 Flap drive shaft
39 Flaps
40 Wingtip formation lights (low intensity)
41 Port navigation light
42 Leading-edge slats
43 Wing integral tank
44 Slat drive shaft
45 Wing pivot mounting
46 Mainwheel wells
47 Inlet bleed air doors
48 ECS heat exchanger outlets
49 Navigation light (above & below glove vane)
50 Glove vane (open position)
51 Hinged canopy

the large sweep of the hinge line would render the wing roll-control devices ineffective. Roll inertia and damping are comparatively low for the highly swept configuration, so the roll power of the tail surfaces is adequate.

Wing-sweep range is from 20 to 68 degrees (measured at the leading edge), with an oversweep angle of 75 degrees for carrier stowage and maximum deck spotting factor. At the 68-degree setting, the F-14A reaches a top speed of Mach 2·34; stalling speed at the 20-degree setting is 103 kt (191 km/h).

Small, triangular vanes extended forward from the wing-root gloves are used in both subsonic and supersonic flight, being extended by the pilot operating the direct-lift-control manœuvring-flap thumbwheel on the control column. At subsonic speeds the glove vanes are extended with the slats and flaps to increase lift coefficient for added manœuvring power. In this speed regime there is no altitude restriction and the vanes are extended between 5 degrees at 20 degrees of wing sweep to the full 15-degree extension at and beyond 35 degrees of sweep. At supersonic speeds, the glove vanes are extended manually up to Mach 1·4 while the slats and flaps remain retracted. Above this speed, the vanes are controlled automatically by computer to reach full extension at Mach 1·5 and above where they remain extended and over-ride pilot commands. At supersonic speeds the vanes extend linearly from 5 degrees at 7,000 ft (2 134 m) to 15 degrees at and above 10,000 ft (3 048 m), and linearly from zero degrees at Mach 1·0 to 15 degrees at and above Mach 1·1. At higher supersonic speeds the vanes counteract the increase of aircraft longitudinal stability and so relieve loads on the tail. (In this, they serve the same purpose as canards, as do the wing-root extensions of the Lockheed SR-71 and the Northrop YF-17.)

Conventional leading-edge slats and single-slotted trailing-edge flaps were chosen for the F-14 wing to provide the high

Grumman F-14 Tomcat Specifications

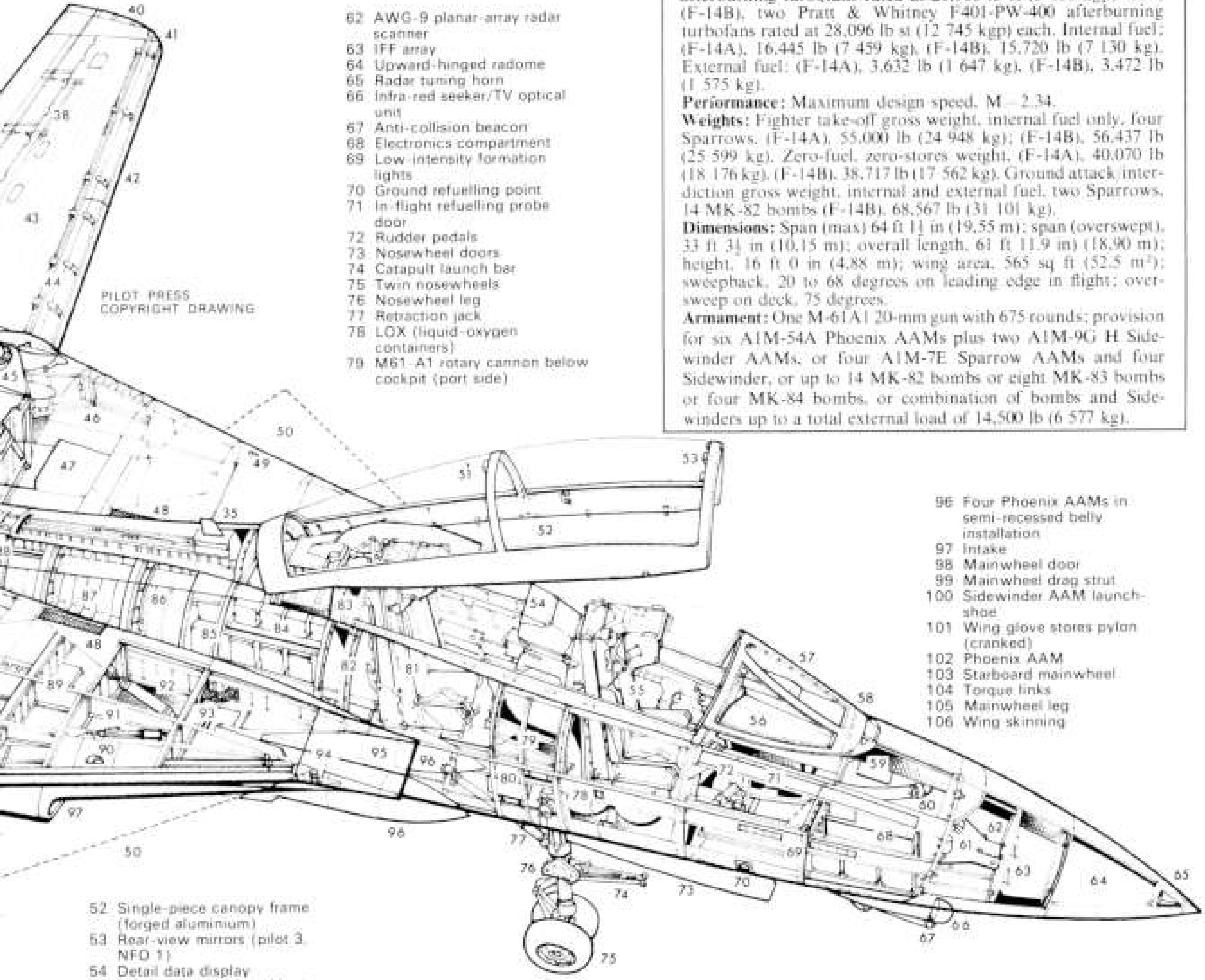
Power Plant: (F-14A) Two Pratt & Whitney TF30-P-412 afterburning turbofans rated at 20,900 lb st (9 480 kgp) each. (F-14B), two Pratt & Whitney F401-PW-400 afterburning turbofans rated at 28,096 lb st (12 745 kgp) each. Internal fuel: (F-14A), 16,445 lb (7 459 kg), (F-14B), 15,720 lb (7 130 kg). External fuel: (F-14A), 3,632 lb (1 647 kg), (F-14B), 3,472 lb (1 575 kg).

Performance: Maximum design speed, M = 2.34.

Weights: Fighter take-off gross weight, internal fuel only, four Sparrows, (F-14A), 55,000 lb (24 948 kg); (F-14B), 56,437 lb (25 599 kg). Zero-fuel, zero-stores weight, (F-14A), 40,070 lb (18 176 kg), (F-14B), 38,717 lb (17 562 kg). Ground attack/interdiction gross weight, internal and external fuel, two Sparrows, 14 MK-82 bombs (F-14B), 68,567 lb (31 101 kg).

Dimensions: Span (max) 64 ft 1½ in (19,55 m); span (overswept), 33 ft 3½ in (10,15 m); overall length, 61 ft 11.9 in) (18,90 m); height, 16 ft 0 in (4,88 m); wing area, 565 sq ft (52.5 m²); sweepback, 20 to 68 degrees on leading edge in flight; oversweep on deck, 75 degrees.

Armament: One M-61A1 20-mm gun with 675 rounds; provision for six A1M-54A Phoenix AAMs plus two A1M-9G H Sidewinder AAMs, or four A1M-7E Sparrow AAMs and four Sidewinder, or up to 14 MK-82 bombs or eight MK-83 bombs or four MK-84 bombs, or combination of bombs and Sidewinders up to a total external load of 14,500 lb (6 577 kg).



52 Single-piece canopy frame (forged aluminium)
53 Rear-view mirrors (pilot 3, NFO 1)
54 Detail data display
55 Pilot's ejection seat (Martin-Baker GRU-7A zero-zero)
56 Vertical display indicator group
57 Windscreen (armoured glass)
58 Windscreen rain-removal ducting
59 UHF/ADF antenna
60 Fuel probe (retracted)
61 Windscreen temperature controller
62 AWG-9 planar-array radar scanner
63 IFF array
64 Upward-hinged radome
65 Radar tuning horn
66 Infra-red seeker/TV optical unit
67 Anti-collision beacon
68 Electronics compartment
69 Low-intensity formation lights
70 Ground refuelling point
71 In-flight refuelling probe door
72 Rudder pedals
73 Nosewheel doors
74 Catapult launch bar
75 Twin nosewheels
76 Nosewheel leg
77 Retraction jack
78 LOX (liquid-oxygen containers)
79 M61-A1 rotary cannon below cockpit (port side)
80 ECM receiver/transmitter
81 NFO's ejection seat
82 Aft pressure bulkhead
83 Canopy actuator
84 Transformer rectifiers
85 Air-data computer
86 Machined fuselage frames
87 Forward fuselage integral tanks
88 Main fuselage longerons (titanium)
89 Intake "ramp" doors (three)
90 Navigation light (above & below glove vane)
91 Glove vane actuator
92 Pneumatic inlet actuator
93 Wing glove machined spars
94 Glove vane pivot
95 Inlet upper surface
96 Four Phoenix AAMs in semi-recessed belly installation
97 Intake
98 Mainwheel door
99 Mainwheel drag strut
100 Sidewinder AAM launch-shoe
101 Wing glove stores pylon (cranked)
102 Phoenix AAM
103 Starboard mainwheel
104 Torque links
105 Mainwheel leg
106 Wing skinning
107 Manœuvre-flap actuating linkage
108 Fuel vent and scavenge lines
109 Leading-edge slats
110 Integral wing tank
111 Spoilers
112 Flaps
113 Wingtip formation lights (low intensity)
114 Starboard navigation light

lift needed for good low-speed performance of a carrier-based aircraft at minimum weight and cost. (The second F-14B has slats on the gloves, the F-14A does not.) One of the advantages of choosing simple slotted flaps was the ease with which they can be used as manœuvring flaps during subsonic and transonic flight.

Deflection of the manœuvring flaps is monitored by the air data computer at no increase in design bending moments, which are based on "clean" wing-load distributions at 6·5 *g*. They are operated to improve specific excess power in combat to give an advantage at the higher load factors by delaying buffet and flow separation because of the increased wing camber created.

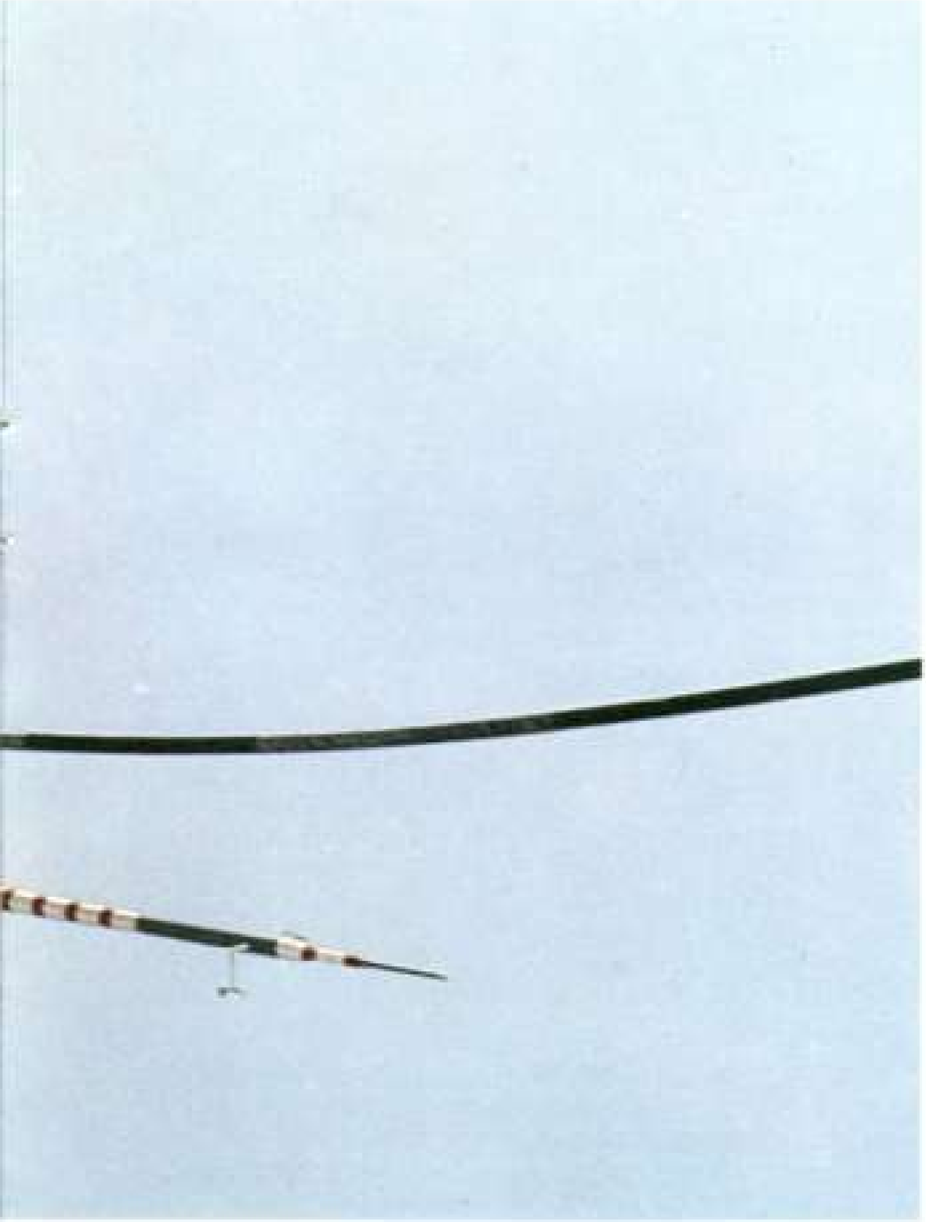
Variable sweepback necessitates dividing the flaps into three sections on each pivoting outer wing panel — two main sections outboard and one auxiliary section inboard. With the wings set aft of 22 degrees sweepback, the subsonic cruise setting, the auxiliary flap sections are prevented from operation because their roots start to enter the wing gloves. Beyond 50 degrees of wing sweep, operation of the main slat/flap linkage is also prevented.

With the wings set at 20 degrees of sweep, the flap handle DOWN position gives a 17-degree slat extension, a 35-degree main-flap extension, and a 35-degree auxiliary-flap extension. Structural damage to the wings is prevented by the computer commanding the main-flaps/slats to the retracted position above 230 kt (426 km/h) calibrated airspeed. This is an electrical command which over-rides any mechanical command due to the position of the flap handle within the normal operating range. The auxiliary-flap actuators are sized to permit these flaps to blow back under excessive air loads.

The main-flaps/slats (and glove vanes) may also be extended over a large portion of the subsonic flight envelope, to maximum angles of 10 and 8·5 degrees respectively, to augment aircraft manœuvring capability. When the flap handle is in the UP position, and wing sweepback is less than 50 degrees, the command is initiated with the direct-lift-control/manœuvre-flap command thumbwheel on the control column. The signal is processed through the computer to limit main-flap/slat deflection as a function of dynamic pressure and Mach number. The computer maintains control of the deflection of the manœuvre portion of the main-flap/slat and glove-vane extension until the pilot removes his thumbwheel command.

There are four spoilers on the upper surfaces of each outer wing panel to augment rolling power, provide direct lift control, and provide air-braking/lift-dumping to reduce landing roll. Spoiler panels are arranged as independent pairs, inboard and outboard. As wing sweep increases, the spoiler contribution to roll control decreases. Moreover, spoiler geometry and the presence of the overwing fairing requires the spoilers to be closed for sweep angles beyond 62 degrees. So, the spoiler-command signal is removed at 57 degrees of sweep and the spoilers retracted; mechanical spoiler locks are inserted at 62 degrees of sweep.

In-flight deceleration for combat, glidepath control in bombing runs, and landing approach is obtained by actuation of large air brakes located both over and under the boat-tail section of the aircraft between the exhaust nozzles. Trim changes required when using the brakes are minimized by balancing the areas of the upper and lower brakes. The lower brake is the smaller, but the endplate effect of the engine pods increases its efficiency. Ground clearance is obtained by an interlock which limits deflections of the lower brake when the undercarriage is lowered.



Twin vertical stabilizers were selected for the F-14 because they effectively counter the destabilizing flow from the tops of the air intakes at high angles-of-attack. Apart from this aerodynamic reason, deck spotting factor requires a high-speed aircraft to be as short as possible, and the carrier lift dimensions also limit size. Since a vertical tail must have as much area as far aft as possible for maximum tail volume, the geometrical limits to overall length demand an unswept trailing edge. Choice of twin fins (and rudders) also avoids the need to fold the vertical tail surfaces, the height-above-deck restriction for CVA-41 class carriers being 17 ft (5 18 m).

The horizontal stabilizers are of the all-movable type, operating together for pitch control and differentially for roll control — since there are no ailerons, only the spoilers operating at wing-sweep angles of less than 55 degrees.

Power plant installation

Variable-sweepback wings excepted, the dominating feature of the F-14 design is the installation of the twin power plants in large pods that run about three-quarters the length of the aircraft.

In line with the rear cockpit are simple, all-external-compression two-dimensional air intakes which have their ramps orientated horizontally and located well away from the fuselage sides and well ahead of the flow fields of the wings. This type of intake has outstanding overall characteristics for high-speed (above Mach 2·0) fighters.

Advantages of these intakes are high pressure-recovery with low flow distortion, turbulence and drag between subsonic and high supersonic speeds without sacrificing simplicity or angle-of-attack characteristics. A single mode of variable geometry is required — opening and closing the compression ramps — because of the wide range of natural airflow regulation inherent in the design. This regulation, plus the insensitivity to angle-of-attack, allows a simple, lightweight control to be used because high response rates are not needed. The ramps over-collapse to provide additional intake area for take-off and landing without the need for suck-in doors, or sliding or hinged cowls.

This type of intake system avoids ingestion of fuselage boundary-layer air without having to resort to using splitter plates by simply locating the intakes 7 in (17,8 cm) outboard of the fuselage sides. Compared with the F-111B, this results in a substantial drag saving for the same engine. Free airstream approaching the intakes is compressed by the forward-facing ramps and refined by removal of the boundary layer through a throat-bleed slot. High-quality air remaining is delivered to the engine after further compression in the subsonic diffuser duct.

The rapid diffusion necessary for short, light ducts is made possible because of the clean air and its local flow angle. The special geometry of the slot turns the airflow and directs it down the rearward-facing ramp. Without the slot, flow separation would occur in the 10 to 15-degree range. Also, variable slot size acts as both a bleed and a bypass for extra air when required. When engine airflow demands are small, the slot opens wide to dump surplus air overboard and rearward over a short path to recover most of the momentum as thrust.

Experience with the F-111B, added to wind-tunnel tests for the F-14, showed that the engine exhausts should have nozzles

(Above) The No 2 flight test Tomcat refuels from a KC-130F Hercules, using the Navy-preferred probe-and-drogue in-flight refuelling system.
(Below) The first of two prototypes of the F-14B with Pratt & Whitney F401 turbofans, sporting a distinctive colour scheme.

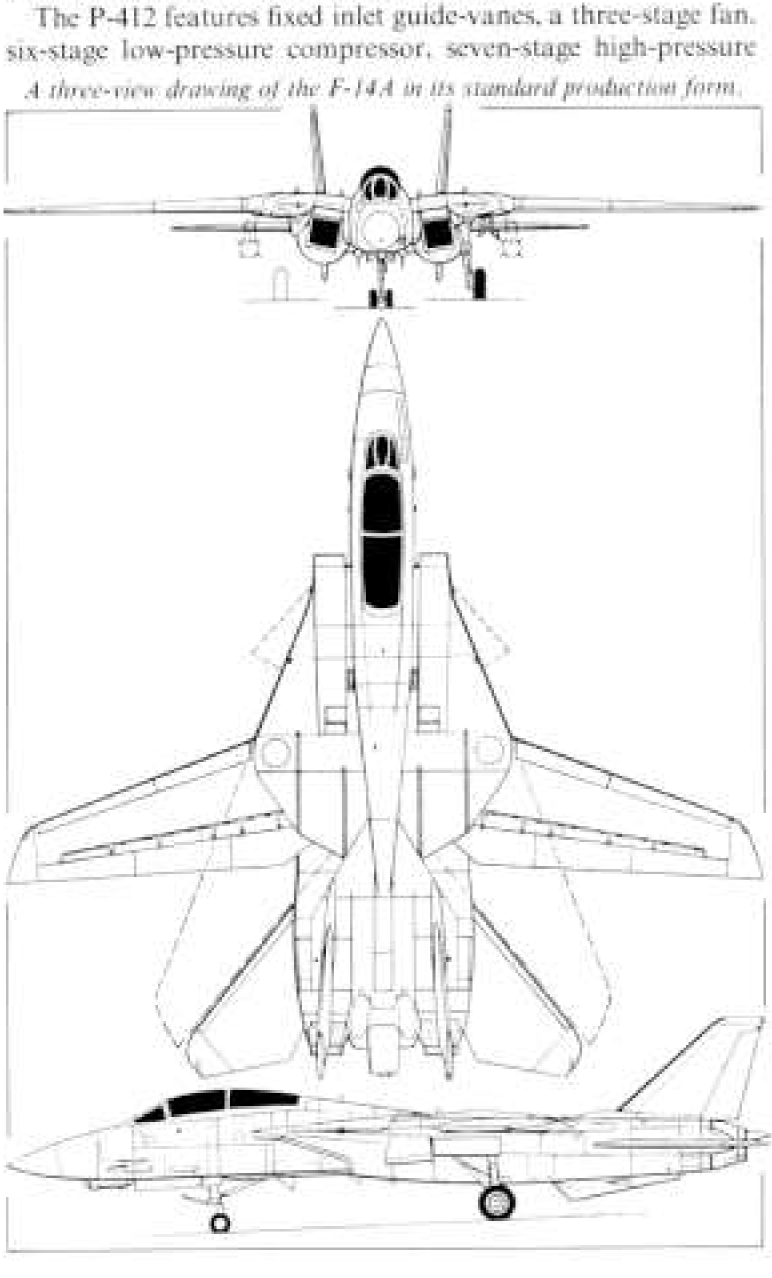
that did not lose thrust when installed; external contours that blended with fuselage shape for minimum drag; an aerodynamically "clean" installation with nozzles spread far enough apart and away from airframe surfaces to avoid flow interference (the F-111B nozzles almost touch); self-cooling to avoid compromises endemic to airframe-supplied cooling air; and no increase in airframe weight as a result of using minimum-weight nozzles.

A wind-tunnel programme at NASA-Langley confirmed that the Grumman design of convergent/divergent iris nozzle — with associated fuselage and interfairing shapes — outclassed all others at the critical subsonic conditions. The iris-type nozzle was also chosen for supersonic operation because of good performance, lower installed weight, and low overall development risk. Thus, the higher thrust potential of the long, variable-flap ejector and of the iris blow-in door ejector nozzles were exchanged for lower weight and elimination of airframe-air nozzle-cooling systems. In any case, Pratt & Whitney will not guarantee the thrust of nozzles that use airframe-supplied secondary airflow.

Since Grumman deliberately set out to use as much as possible of the technology derived from the F-111B programme, the F-14A is powered by two Pratt & Whitney TF30-P-412 turbofans each of 20,900 lb (9 480 kgp) maximum afterburning thrust. These were developed from the 20,250-lb (9 185-kgp) P-12 turbofans of the F-111B and, although only a little higher in nominal power, actually develop about 20 per cent more thrust than the F-111B installation in supersonic flight because of the superior integration of engines and airframe — particularly the type and location of the air intakes (the F-111B had an under-arm problem).

The P-412 features fixed inlet guide-vanes, a three-stage fan, six-stage low-pressure compressor, seven-stage high-pressure compressor, can-annular combustion system, single-stage high-pressure turbine, three-stage low-pressure turbine, and five-zone spraybar afterburner with iris-type variable-area convergent/divergent exhaust nozzle. Diameter is 50·5 in (128,3 cm) and dry weight is 3,970 lb (1 801 kg).

A three-view drawing of the F-14A in its standard production form.



The Pratt & Whitney F401-PW-400 turbofans for the F-14B are each rated at 28,096 lb (12 745 kgp) afterburning thrust. These are basically similar to the F100-PW-100 engines of the McDonnell Douglas F-15A, but are of slightly higher power due to the addition of a half-stage at the rear of the three-stage fan. The F401 also has variable-angle fan-exit guide-vanes. Both the F401 and F100 have a 10-stage compressor with variable-incidence stators on the first three stages; a short, annular combustion chamber operating on the ram-induction principle; a two-stage high-pressure turbine with air-impingement cooled blades on both stages (as on the J58 in the Lockheed SR-71); and a two-stage low-pressure turbine. The lightweight balanced-beam, variable convergent/divergent afterburner nozzle has an area ratio of 1.4:1 for the F401 (1.6:1 for the F100).

The F401's maximum afterburning thrust is attained at 11,923 rpm for an sfc of 2·211 lb/hr/lb (2,211 kg/hr/kgp). The intermediate thrust rating is 16,489 lb (7 479 kgp) for an sfc of 0·674, and maximum continuous thrust is 14,871 lb (6 745 kgp) for an sfc of 0·653. The F-14B's air intakes each have a capture area of 1,150 sq in (7 419 cm^2); a height of 39·5 in (100,33 cm); and a width of 29·2 in (74,2 cm). Engine diameter is 50·6 in (128,5 cm), and length with afterburner is 245 in (622,3 cm). Dry weight is 3,420 lb (1 551 kg).

Weapon systems

One of the main factors leading to selection of the F-14 concept for the VFX-1 was the availability of the Hughes AWG-9 weapon control system developed for the F-111B. However, to attain an acceptable weight, it was essential not to follow the F-111B system too closely, but to use its avionics innovations — multimode sensors, built-in self-test, etc — as the basis for planning. A basic difference was that the F-14A was an air superiority fighter rather than a fighter bomber. So systems design emphasis was placed upon having the pilot, rather than automatic systems, fly the aircraft.

The F-14A systems take advantage of second-generation, lightweight solid-state airborne computers and other advances (power supplies, antennas) to give the designers more latitude for redundancy, back-up modes, and other features to increase capability and reliability. The US Navy specified a modified version of the AIM-54A Phoenix system developed by Hughes for the F-111B, but capable also of dealing with Sidewinder, Sparrow, later missiles (Agile), and the General Electric M-61A1 20-mm or a later gun (Philco-Ford GAU-7A 25-mm gun firing caseless rounds). For this reason, the original computer was replaced by a higher-speed, digital system to concentrate many functions previously handled separately.

The Hughes AWG-9 weapon control system provides a long-range volume coverage about 15 times that of the AWG-10 used in the F-4. It has two major sensors — pulse-Doppler radar, and a gimbal-mounted infrared sensor. In a dogfight, both sensors are used for lock-on; one sensor is then slewed onto the target detected by the other. The radar operates in a pulse-Doppler mode for long and medium ranges, and in a conventional pulse-radar mode for long and very short ranges. It detects, tracks, and ranges targets for the F-14's total armament — six long-range AIM-54A Phoenix, six medium-range AIM-7P Sparrow, or a Phoenix/Sparrow mix; four short-range AIM-9L Sidewinder; and the M-61A1 gun. Also, it provides ranging for air-to-ground weapons.

The Naval Flight Officer (NFO) in the rear cockpit has a 10-in (25,4-cm) diameter display of tactical information, and a 5-in (12,7-cm) diameter multi-mode storage detail-data display.

(Above) A fine portrait of the F-14A No 2 with its full armament load of six AIM-54 Phoenix missiles and two AIM-7 Sidewinders plus two drop tanks. (Below left) The No 4 Tomcat fires a Phoenix during early weapons trials at the Naval Missile Center, Point Mugu.

The NFO can monitor the latter to ensure that the computer is tracking all targets, or to help select targets using electronic countermeasures. These two displays provide full information for firing of Phoenix and Sparrow missiles.

The pilot can fire all weapons including the Sidewinders and the gun. For dogfighting, he can lock onto the target by aligning his boresight. Computer-generated target data are presented to him on his horizontal-situation display. In cases where a high-*g* manœuvre might prevent him from easily aligning his sight, he can use the AWG-9's vertical-scan lock-on feature in which the radar scans only in pitch as the pilot rolls the aircraft. Once the target is seen by the radar within a 5-mile (9,3-km) radius, the radar locks onto the target automatically so that the pilot may fire weapons without having to point his aircraft at the target. The NFO can also slew the radar line-of-sight onto the target.

Developments and prospects

Several countries have expressed interest in purchasing the F-14, notably Iran (the F-14A) and Australia (the F-14B). Overflights of Iran by MiG-25 *Foxbats* have created a threat to which the only practical answer appears to be either the F-14A or the McDonnell Douglas F-15A. The Grumman aircraft's earlier availability, and the recent serious problems with the F100-PW-100 engine of the F-15A, are understood to have led to a preference being shown for the F-14 by the Shah of Iran, who was most impressed with the Tomcat's demonstrations at Paris in 1973, and who subsequently visited Andrews Air Force Base, Maryland, to see both the F-14A and TF-15 demonstrated. This interest was followed-up by visits to Iran by USN and USAF teams during September, leading to a specific request to the US government for the purchase of 36 F-14s and 50 F-15s. Grumman has been asked to quote a firm price for the F-14s by this month (January) to provide a basis for final contractual arrangements, but the F-15 price will not be quoted by McDonnell Douglas until later in the year, and there is now a possibility that the second batch of aircraft to be purchased will be F-14s.

The Australian need is for a Mirage IIIO-replacement, but here the situation is complicated by the necessity for a co-production programme to be worked out to give much-needed work to the Australian aircraft industry. Indeed, the industry's need for something to build is somewhat ahead of the requirements of the Royal Australian Air Force for a new fighter. However, Grumman has made comprehensive proposals for an F-14B co-production programme in which Australian industry would supply raw materials, forgings, castings, control surfaces, panels, doors, missile launchers, and avionics systems.

The first five RAAF aircraft, if the F-14B is selected, would be assembled and flight-tested in the US. Concurrently, Australian industry would be preparing for final assembly and testing of the sixth and subsequent aircraft. Final assembly would be of the cockpit canopy, fuselage nose, horizontal stabilizers, vertical stabilizers, and wings to the assembled cockpit/engine-nacelle/fuselage unit; and the installation of such self-contained units as avionics and navigation equipment, ejection seats, engines, undercarriage and arrester gear, and control surfaces. Final painting, checking, and flight testing would also be done in Australia. Grumman has suggested that up to 90 per cent of the value of an RAAF purchase (excluding engines) could be offset by production of airframe parts in Australia. Based on a possible combined US Navy and Marine Corps purchase of 540 aircraft, including about 40 for attrition, the flyaway unit price for export — which *excludes* a share of the non-recurring costs — would be about $5·2 million (£2·1m) in 1973 funds.

As already noted, the Navy decided nearly three years ago that it would not need to go ahead with the F-14B version with F401 engine, and as early as 9 July 1971 the USAF was officially notified that the USN would not take up the option it held on a first quantity of 58 production F401s. At that time, Pratt & Whitney told the Navy that the earliest date for delivery of a test engine that "would come within five per cent of specification throughout its operating envelope" was December 1972. A new programme was then agreed between the USN, USAF and Pratt & Whitney establishing a Preliminary Flight Rating Test (PFRT) date of December 1972 and a Military Qualification Test (MQT) date of June 1973. On this basis, work on the prototype F-14B (actually the No 7 test F-14A converted) went ahead; it eventually flew on 12 September 1973 and is being followed by a second (aircraft No. 31).

In making this decision, the Navy showed that it was confident the two-dimensional air intakes located well ahead of the wings would avoid the problems experienced by the F-111B with the same TF30 engine. There was, no doubt, also the rationale that the Air Force would *have* to go ahead with the F100 version of the engine — which was originally an Air Force programme in any case — for the F-15A and therefore it would still be possible, once procurement problems of the

F-14A and technical problems of the F100/F401 had been ironed out, to pick up the latter engine for the F-14B if it proved to be needed for the 1980s. Furthermore, it might be possible to then proceed from the F-14A directly to the F-14C (VFX-2) with both advanced engines *and* advanced avionics/weapons systems. This would be a refinement of the original game plan to get the VFX-1 going with erstwhile F-111B funds, then switch to the more sophisticated VFX-2 at a later stage before many of the earlier model had been built. Be that as it may, the Navy decision to opt out of the F401 programme had the immediate effect of adding about $500 million (£208m) to the cost of the F100 programme for the F-15A.

As it has turned out, the F100 engine has struck repeated and serious trouble despite initial Air Force relaxation of the test requirements that created a furore all of its own — the more so since, when the full 150-hour test was insisted on by the Pentagon as the result of Congressional pressure, the engine caught fire and was destroyed late in August before 132 hours had been completed. No doubt the F100 will be fixed in due course, but the Navy was well out of F401 procurement and so received no censure.

In March 1973, McDonnell Douglas made an interesting counter-move by proposing to the Navy that is should use the F-15 as an alternative to the F-14 (then still embroiled in the Lot V controversy). However, the strengthened F-15N ("N" for Navy) that was proposed would be 3,000 lb (1 361 kg) heavier and the Navy had already spent a great deal of money on the F-14A flight-test programme, much of which would have to be repeated for the F-15N Bureau of Inspection and Survey (BIS) trials. Admittedly, the F-15N unit costs looked good by comparison with the F-14A, but it was not the same sort of aircraft with variable-sweep versatility that the Navy needed, and the money that would have to be spent developing the F-15N would have gone a long way toward solving the F-14A cost problems.

Meanwhile, the Directorate of Defense Programs Analysis and Evaluation in the Pentagon had completed a report on candidates for an Improved Manned Interceptor (IMI) which included both the F-14 and F-15, along with proposals from General Dynamics for a stretched F-111-X-7 ("7" for a 7-ft /2,13-m longer fuselage to house more fuel and avionics), and from Rockwell International for the NR-349, a heavily modified RA-5C Vigilante powered by *three* J79-GE-8 engines instead of two.

In parallel, Grumman presented an unsolicited proposal to the Air Force for the F-14 to replace the F-15 in a variety of missions for Air Defense Command and Tactical Air Command. This proposal (see AIR Enthusiast February 1973) was, in effect, a slightly "massaged" version of a previously submitted study funded by the Air Force to review the F-14 for the IMI role. Should the Air Force buy the F-14, Grumman estimated that the service would save about $1,000 million (£415m) based upon combined Navy/Marine Corps/Air Force procurement of 1,400 aircraft.

A "fly-off" of the F-15N against a stripped version of the Tomcat, designated the F-14D, by December 1975 was proposed by the New Deputy Secretary of Defense, William P Clements, as the means of selecting the best air superiority fighter for the Navy. However, at cost estimates ranging from $250 to $473·8 million (£104 to £195m) this was not favoured by the Senate Armed Services Tactical Air Power Subcommittee, and the issue has yet to be resolved. Certainly, such an exercise that would cost more than a squadron of F-14As simply to make a decision would be a case of diminishing returns for the taxpayers' dollars. However, the proposal *was* fruitful in getting about 7,000 lb (3 175 kg) in weight and $1-million in cost stripped from the F-14D by making it a visual-contact aircraft, eliminating direct lift control and automatic power control as the means of attaining the angle-of-attack and speed required for all-weather carrier landings, and by control and display changes. Thus, Grumman now has available, either for the USN, the Marine Corps or export, a second version of the Tomcat which can be offered at a lower unit cost if certain restrictions on its operational capabilities are accepted. If nothing else, this exercise demonstrates the proof of the old, old adage that you get what you pay for — and there seems little doubt that the US Navy is getting, in the F-14A, a thoroughly excellent fighting aeroplane at a unit price that is not out of line with current standards, even if that cost is more than the Department of Defense expected to have to pay. □