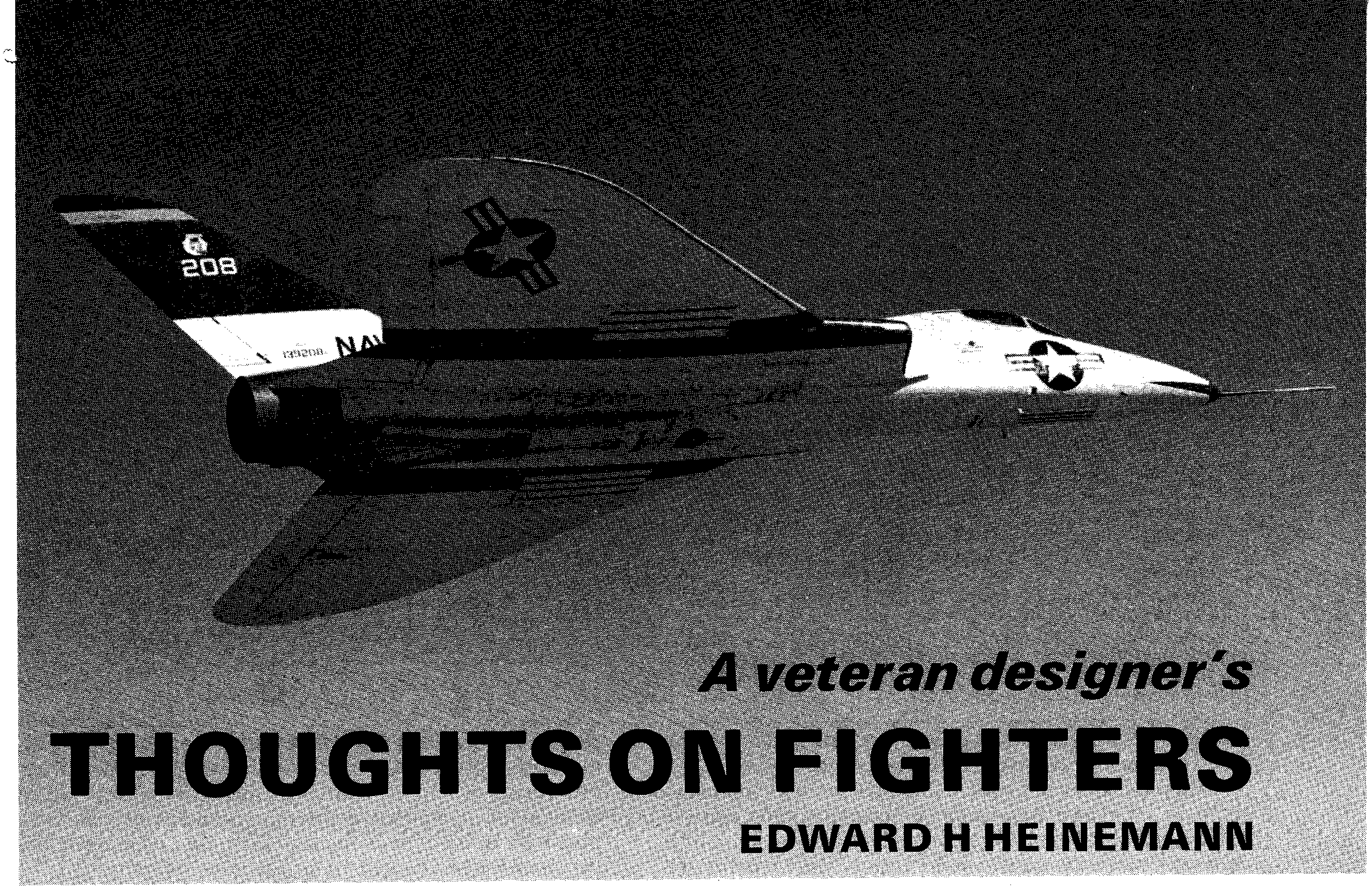


A veteran designer's
THOUGHTS ON FIGHTERS

EDWARD H HEINEMANN

FEW ARE LIKELY TO DISAGREE with the proposition that the *ideal* fighter of the future will competently fulfil the air-air task; will operate satisfactorily across the entire spectrum of counterair, interdiction and other air-ground missions; will be amenable to operation from land bases and carriers alike, and will be readily adaptable from single- to two-seat configuration and *vice versa*. I am well aware that there have been attempts in the past to create such a supremely versatile multi-rôle fighter and that all have failed, either as a result of design inadequacies or political interference. But it is patently obvious that the dedicated single-rôle fighter concept is now as antiquated as the steam-driven locomotive.

The last fighter aircraft for which I had complete design responsibility, the F4D Skyray and F5D Skylancer, can today be viewed as antithetic to the fighter of tomorrow; supreme examples of the one-task fighter — although the F4D was eventually to be classified by the US Navy as a *general-purpose* fighter, albeit a limited versatility resulting from adaptation rather than original design intent. But if F4D and F5D were the antithesis of the fighter necessary to fulfil the exacting multi-mission demands of the 'nineties and on, the wing planform that they shared — and which remains unique to this day — is not so far removed, in my view, from that which, mated with a canard surface, may represent the ideal configuration for the future fighter. But before discussing such a warplane, it is perhaps instructive to recall something of the Douglas shipboard fighters that began to take on definitive shape more than 30 years ago.

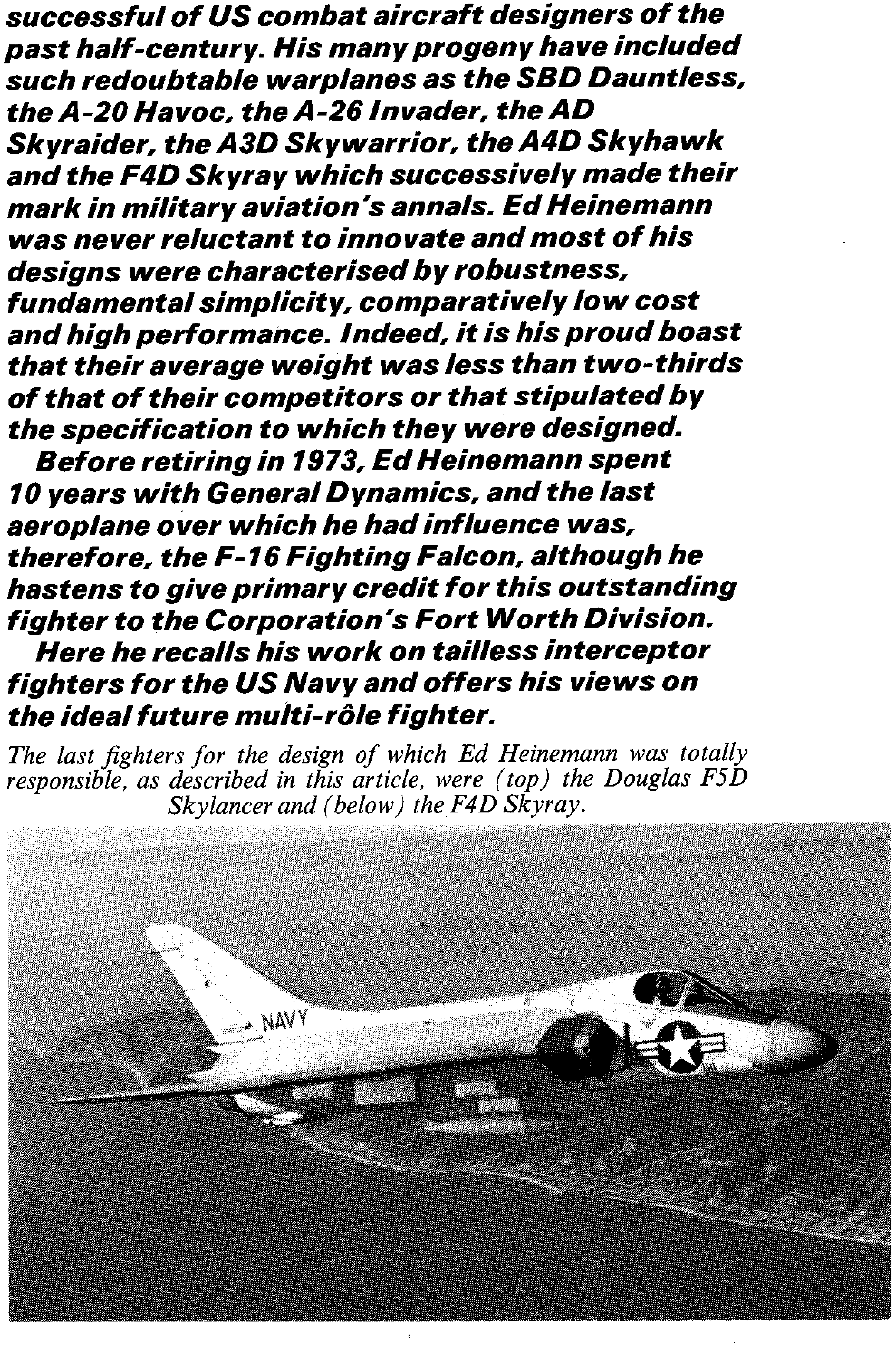
The F4D was tailored to a demand for a high subsonic/transonic interceptor compatible with existing carriers — some of the aircraft being considered for this rôle were actually too large for the elevators of some of the carriers from which they were intended to operate. I had concluded that a tailless arrangement was the only means of achieving both the desired dimensions and an acceptably low wing loading. Investigation of the classic equilateral triangle of the delta indicated promise but not a complete solution and we eventually evolved what might be regarded as a conventional wing with an unusually

Ed Heinemann is internationally recognised as having been one of the most consistently successful of US combat aircraft designers of the past half-century. His many progeny have included such redoubtable warplanes as the SBD Dauntless, the A-20 Havoc, the A-26 Invader, the AD Skyraider, the A3D Skywarrior, the A4D Skyhawk and the F4D Skyray which successively made their mark in military aviation's annals. Ed Heinemann was never reluctant to innovate and most of his designs were characterised by robustness, fundamental simplicity, comparatively low cost and high performance. Indeed, it is his proud boast that their average weight was less than two-thirds of that of their competitors or that stipulated by the specification to which they were designed.

Before retiring in 1973, Ed Heinemann spent 10 years with General Dynamics, and the last aeroplane over which he had influence was, therefore, the F-16 Fighting Falcon, although he hastens to give primary credit for this outstanding fighter to the Corporation's Fort Worth Division.

Here he recalls his work on tailless interceptor fighters for the US Navy and offers his views on the ideal future multi-rôle fighter.

The last fighters for the design of which Ed Heinemann was totally responsible, as described in this article, were (top) the Douglas F5D Skylancer and (below) the F4D Skyray.



Douglas F4D-1 Skyray Specification

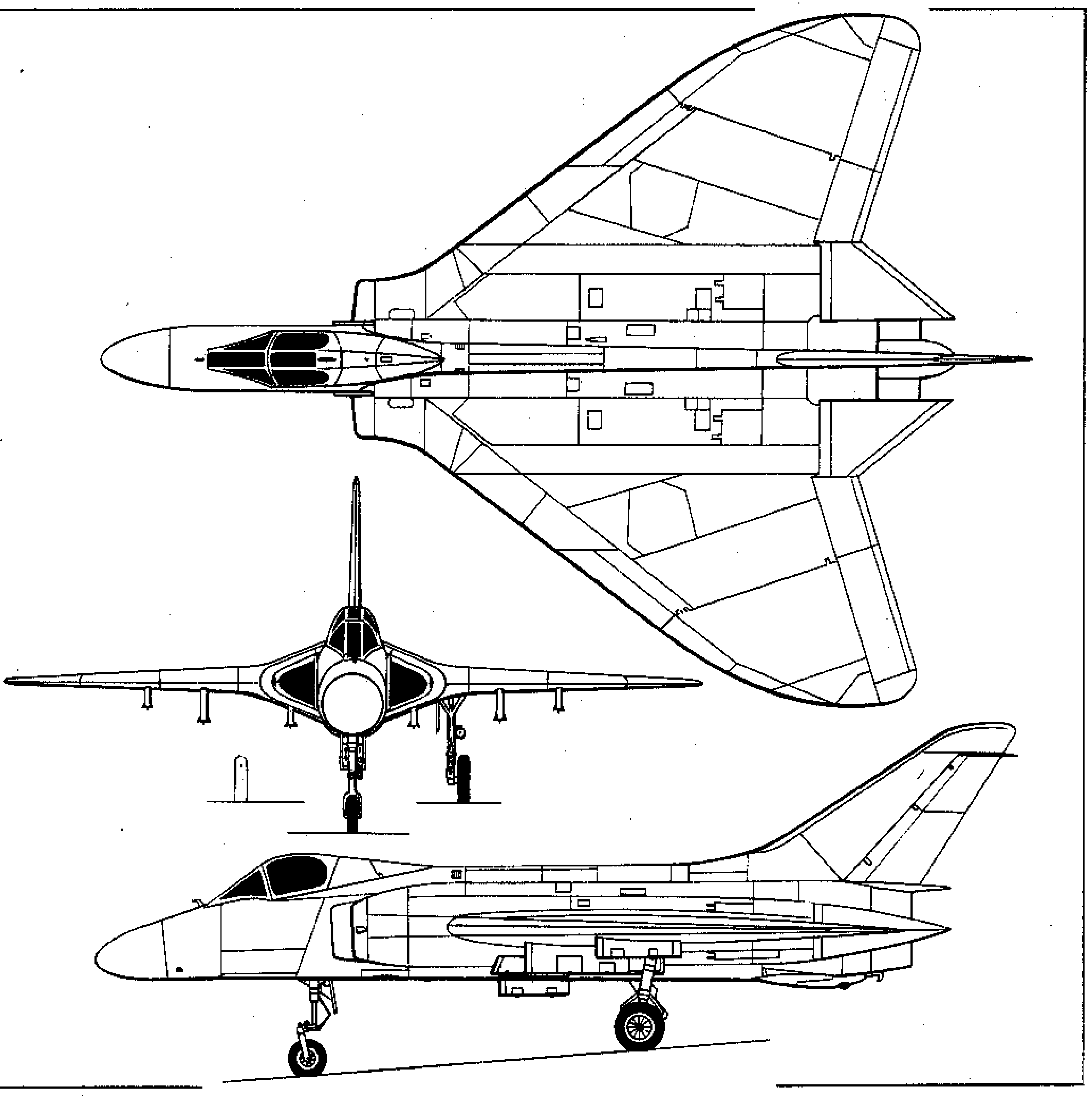
Power Plant: One Pratt & Whitney J57-P-8 or -8B turbojet rated at 8,700 lb st (3 946 kgp) normal, 10,200 lb st (4 627 kgp) military and 16,000 lb st (7 258 kgp) with max reheat. Total internal fuel capacity, 640 US gal (2 423 l) distributed between two 320 US gal (1 211,5 l) wing root tanks. Provision for two 300 US gal (1 136 l) drop tanks.

Performance: (At combat weight with four AIM-9 Sidewinder AAMs and full internal fuel) Max speed, 717 mph (1 154 km/h) at sea level, or Mach = 0·94; combat speed, 650 mph (1 047 km/h) at 35,000 ft (10 670 m), or Mach = 0·98; initial climb rate, 17,300 ft/min (87,88 m/sec); climb rate at 35,000 ft (10 670 m), 8,400 ft/min (42,67 m/sec); (with four Sidewinders and two 300 US gal/1 136 l drop tanks) max speed at military power, 609 mph (980 km/h) at 15,000 ft (4 570 m); initial climb rate on military power, 5,400 ft/min (27,43 m/sec); time to 20,000 ft (6 095 m), 5·1 min, to 30,000 ft (9 145 m), 10·5 min; service ceiling (100 ft/min-0,50 m/sec), 37,600 ft (11 460 m); combat range, 1,120 mls (1 803 km) at average cruise of 515 mph (828 km/h) at 34,900-41,800 ft (10 640-12 740 m).

Weights: Empty, 16,024 lb (7 268 kg); basic, 16,667 lb (7 560 kg); combat, 22,648 lb (10 273 kg); max take-off (catapult), 28,000 lb (12 701 kg).

Dimensions: Span, 33 ft 6 in (10,21 m); length, 45 ft $4\frac{3}{4}$ in (13,84 m); height, 13 ft 0 in (3,96 m); wing area, 557 sq ft (51,74 m^2).

Armament: Four 20-mm M-12 cannon internally with 70 rpg, or (externally) four packs each containing seven 2·75-in (6,98-cm) folding-fin rockets, or four packs of 19 2·75-in (6,98-cm) rockets, or four AAM-N-7 Sidewinder AAMs.



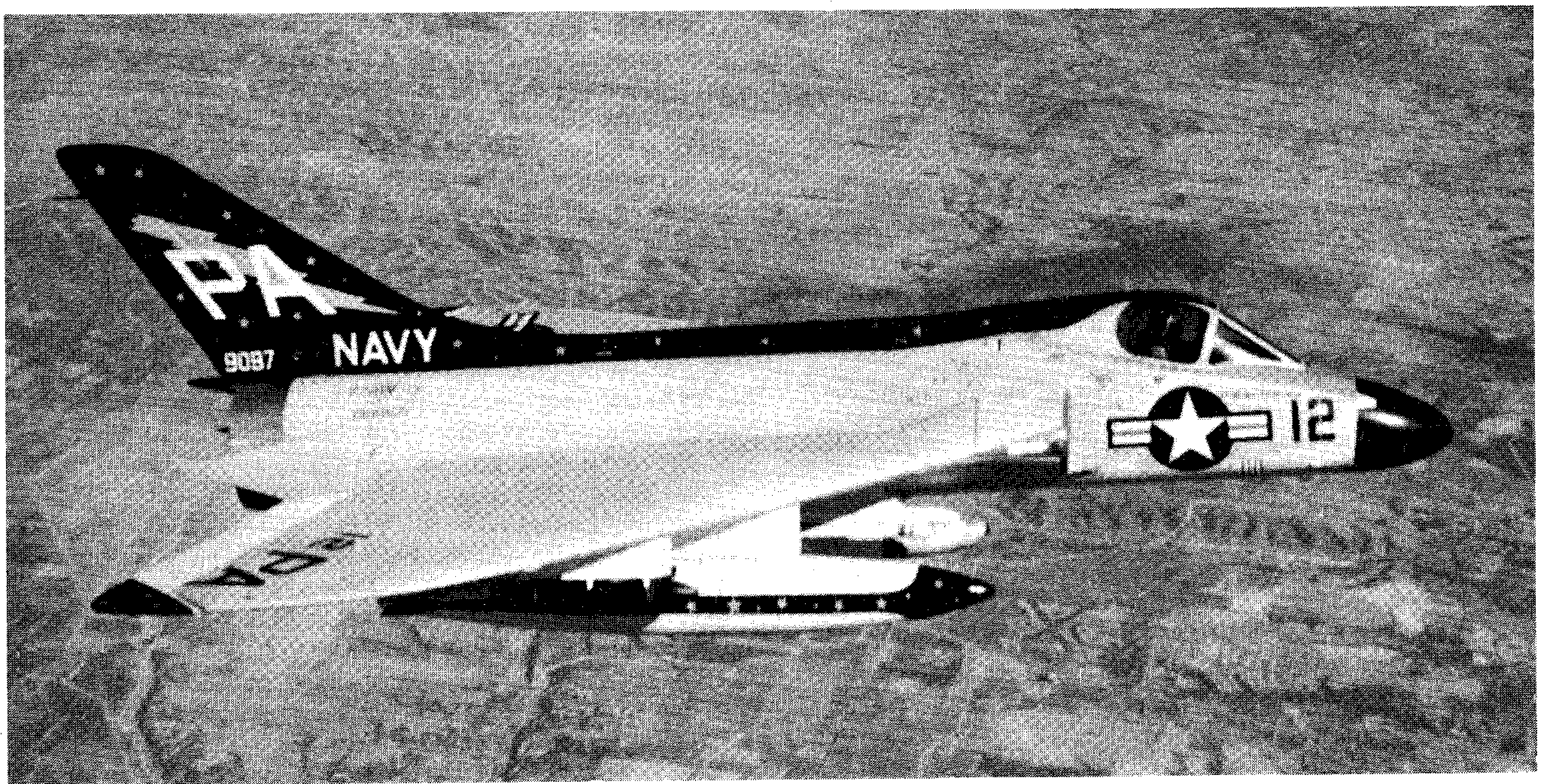
low aspect ratio, swept trailing edges and broad, rounded tips. It was certainly far removed from the classic delta planform.

Our proposal for this radical interceptor was submitted to the Navy's Bureau of Aeronautics in September 1948. Because of the highly innovative configuration that we were proposing, there was, of course, great concern over its likely stability and control characteristics. There was also anxiety as to our ability to meet the weight limitations of the requirement and this was to dictate rigid weight consciousness throughout design. As if we were not presenting ourselves with sufficient problems, we compounded them with a decision to use an entirely new Westinghouse J40 engine.

A Letter of Intent was duly issued by the BuAer on 16 December 1948, covering two prototypes and a static test airframe of what now became the XF4D, but somewhat belated appreciation of the inordinate risks that we were running in mating so fundamentally new an airframe with a totally new engine resulted, in the following May, in our proposal to install for initial flight test of the first airframe the thoroughly proven Allison J35-A-17, switching later to the J40. Acceptance by the BuAer of this proposal was indeed fortunate as Westinghouse soon proved incapable of keeping pace with airframe development. Thus, on 25 January 1951, the first XF4D-1 flew with an interim power plant.

Barely two weeks had passed before the BuAer issued a Letter of Intent for a buy of a dozen production aircraft, and it took quite a lot of courage to proceed to production with so radical an airframe that had still to receive its definitive engine, and, in any case, had logged no more than a couple of hours flight test with an interim power unit. Nevertheless, what little flight testing had been accomplished had tended to bear out wind tunnel data and so we decided to proceed. Continuing problems with the J40 dictated installation of the J35 in the second XF4D-1 also, and it was not until February 1952 that the re-engined first aircraft was to fly with a J40, and then the non-afterburning WE-6 version of the engine rather


The Douglas F5D represented a final attempt by Ed Heinemann to improve on the tailless F4D configuration, featuring an ultra low aspect ratio wing. Only four F5D-1s were built, all being seen in this photograph; data and a three-view drawing appear opposite.



More than 400 F4D Skyrays were built for the US Navy and proved the effectiveness of the tailless layout adopted by Ed Heinemann, for the reasons discussed in the article. Data and a three-view drawing appear opposite.

than the WE-8 with afterburner intended.

It would be idle to deny that XF4D flight testing had thrown up a fair share of problems meanwhile, calling for a variety of fixes, and detail changes that we progressively introduced to the production design were sufficiently numerous to warrant a contractual change, one of the initial production batch aircraft being designated as a further test model. By this time, the need for a really fast-climbing interceptor was viewed as a matter of very considerable urgency by the Navy — the F4D was intended to reach 40,000 ft (12 190 m) within 2·5 minutes — and two months after the XF4D-1 began flight test with the J40 (eight weeks dogged by intermittent engine problems), an order for an additional 230 F4D-1s was placed.

Many of the problems that were being presented by the F4D were typical of high-performance combat aircraft of its era and not peculiar to its unusual configuration. The control system was a complex one — it was hydraulically powered and it was the Douglas Company's policy to retain the manual reversion principle — and there were handling and control difficulties, but these were steadily ironed out, and finally the afterburning J40-WE-8 was installed in the second XF4D-1 in September 1953. Now sufficient power was available to extend the flight envelope, and evidence of this came somewhat dramatically in the following month with two world speed records.*

Continued doubts as to the future of the J40 engine had, during the previous March, led to the decision to drop the Westinghouse power plant and switch to Pratt & Whitney's J57, which change demanded no fundamental alterations, but the innumerable detail modifications called for inevitably

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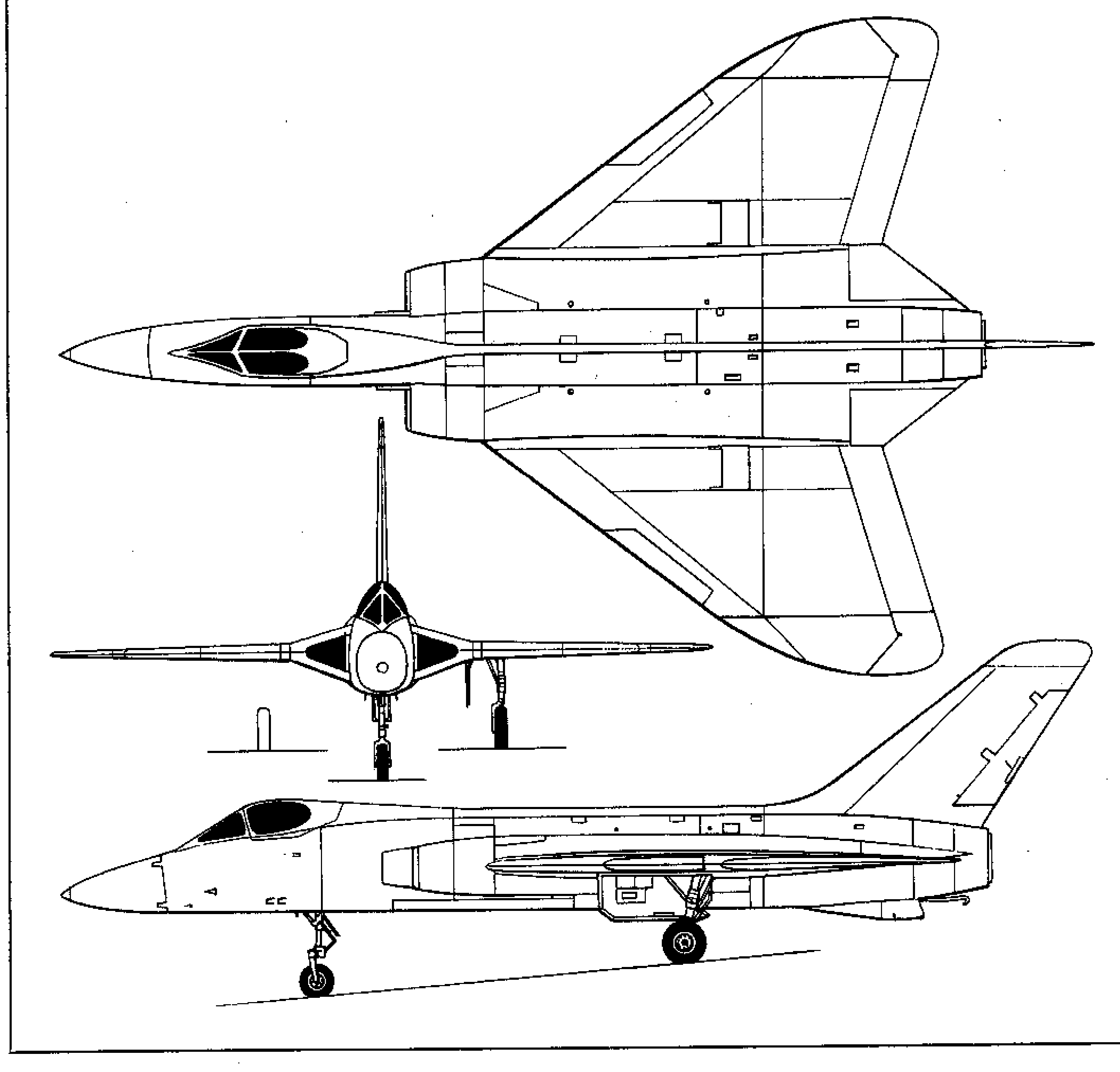
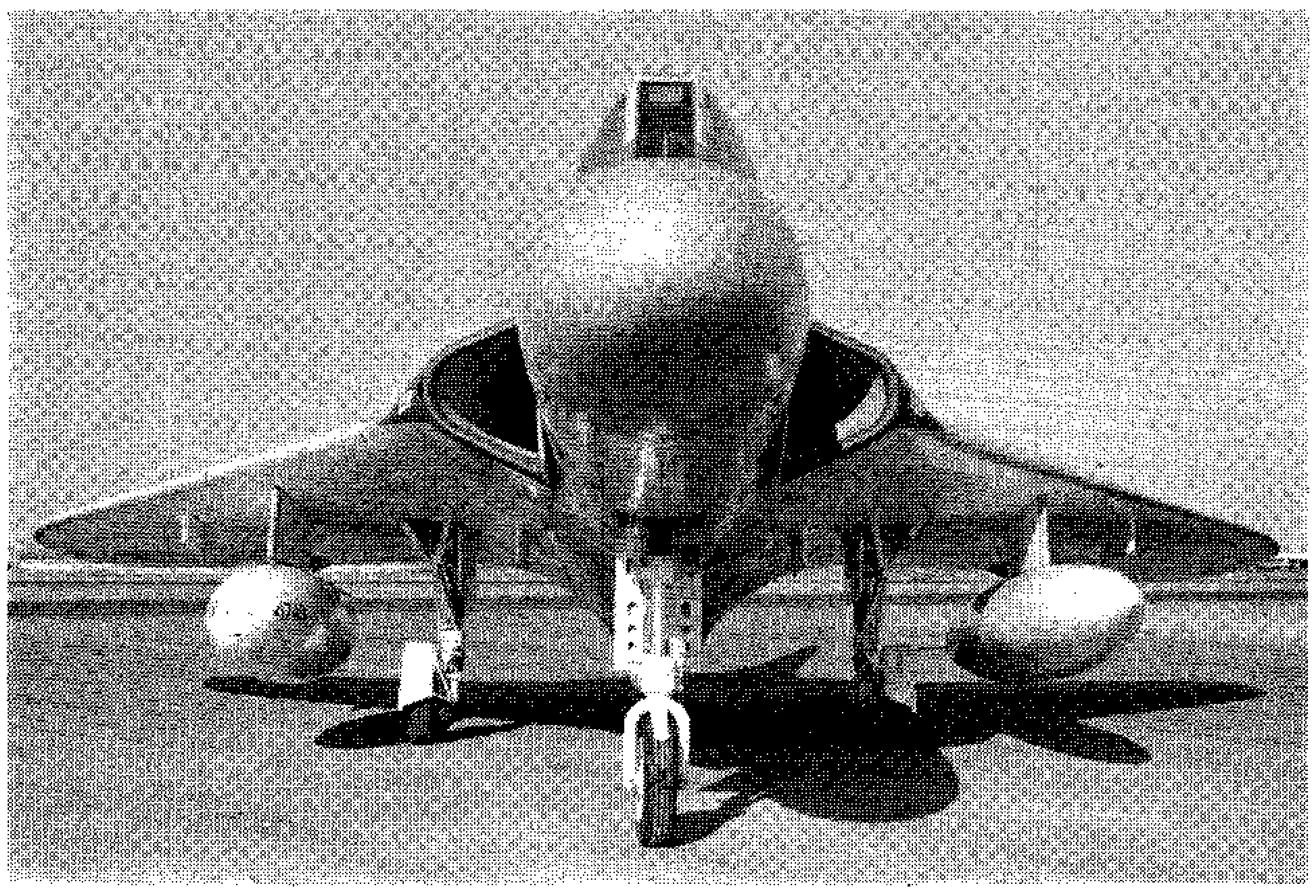
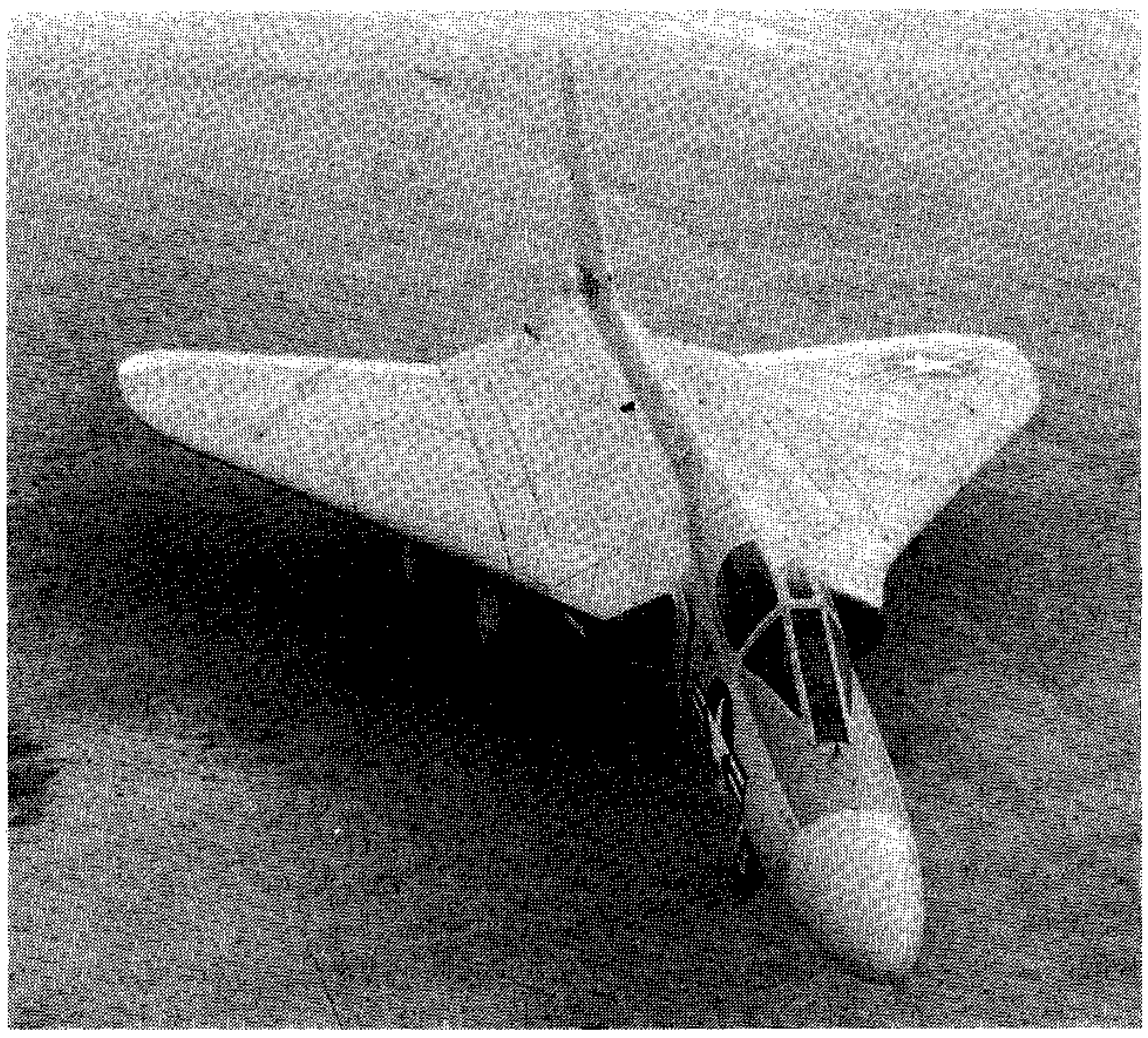
**On 3 October 1953, the second XF4D-1 established an absolute speed record of 753·4 mph (1 212,5 km/h) in four runs over the shore of the Salton Sea, one of the many flat lake-beds in southern California, with Lt Cdr James Verdin at the controls. The runs were made at altitudes between 100 and 200 ft (30 and 60 m). Thirteen days later, Douglas test pilot Robert O Rahn captured the 100-km closed-circuit record in the same aircraft with a speed of 728·11 mph (1 171,7 km/h).*



Douglas F5D-1 Skylancer Specification

Power Plant: One Pratt & Whitney J57-P-8 turbojet rated at 8,700 lb st (3 946 kgp) normal, 10,200 lb st (4 627 kgp) military and 16,000 lb st (7 258 kgp) with max reheat. Total internal fuel capacity, 1,333 US gal (5 046 l) distributed between two 277 US gal (1 048 l) and two 165 US gal (625 l) wing root tanks, and one 265 US gal (1 003 l) and one 184 US gal (696 l) fuselage tanks.
Performance: (At combat weights with internal rocket packs and 60 per cent fuel) Max speed, 750 mph (1 206 km/h) at sea level, or Mach = 0·986, 953 mph (1 534 km/h) at 35,000 ft (10 670 m), or Mach = 1·44; initial climb, 20,790 ft/min (105,6 m/sec); climb rate at 35,000 ft (10 670 m) combat altitude, 10,200 ft/min (51,8 m/sec); combat ceiling (500 ft/min-2,54 m/sec), 49,200 ft (14 995 m); (with max internal fuel) max speed at normal power, 680 mph (1 095 km/h) at 16,000 ft (4 875 m); initial climb at military power, 5,560 ft/min (28,24 m/sec); time at military power to 20,000 ft (6 095 m), 4·5 min, to 30,000 ft (9 145 m), 7·9 min; combat range, 1,335 mls (2 148 km) at average cruise of 602 mph (969 km/h) at 37,500-42,500 ft (11 430-12 955 m).
Weights: Empty, 17,444 lb (7 913 kg); basic, 18,147 lb (8 231 kg); combat, 24,445 lb (11 088 kg); max take-off (catapult), 26,900 lb (12 202 kg).
Dimensions: Span, 33 ft 6 in (10,21 m); length, 53 ft 9⅗ in (16,40 m); height, 14 ft 9⅗ in (4,51 m); wing area, 557 sq ft (51,74 m^2).
Armament: (Internal) Four retractable packs each containing 18 2-in (5,08-cm) folding-fin rockets or four 20-mm M-12 cannon with total of 470 rounds, plus (external) two Sparrow II AAMs.



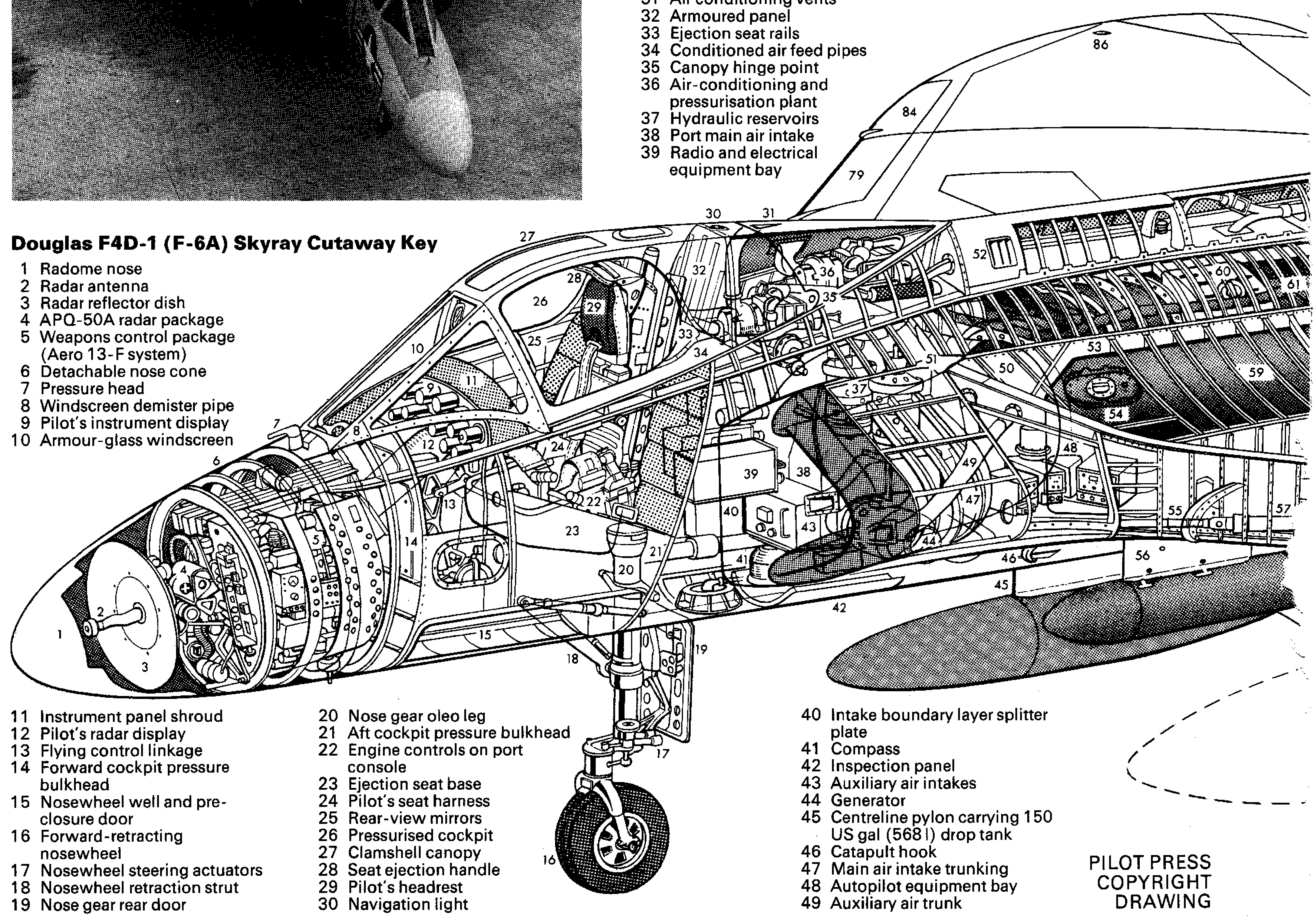


(Above and below) Photographs of the F4D-1 (redesignated F-6A in the revised Department of Defense system introduced in June 1962) which shows well the distinctive planform — not so much a delta as a sweptback wing of very low aspect ratio.

resulted in further frustrating delays in the programme. Other problems were to be exposed by early service experience; the thin skinning gave trouble and the large numbers of vacuum tubes provided constant sources of headaches. By December 1958, however, when the 419th and last production F4D was to be rolled out, the Skyray was acknowledged as a thoroughly competent interceptor with excellent high-altitude dogfighting capabilities and outstanding climb performance. Its low-speed characteristics were perhaps unusual, but its pilots soon accustomed themselves to these. A planned attempt on the world altitude record back in 1954 with the J40-WE-8-engined second prototype had been abandoned as a result of afterburner blow-out problems, but the remarkable climb of the F4D was to be demonstrated in May 1958 with five FAI-recognised time-to-altitude records.*

In October 1953, when ordering a further batch of 178 F4D-1s, the BuAer had also ordered two prototypes of what, at the time, was designated the F4D-2. The F4D-2 represented an attempt on our part to correct the weaknesses of the F4D by means of aerodynamic, structural and other advances that had taken place in the half-decade that had elapsed since the original design concept had been fixed. In the event, the F4D-2 design work gradually evolved as an entirely new aeroplane retaining nothing in common with the F4D-1, apart from the actual wing planform, and this development was, in consequence, to be redesignated F5D-1.

**These records were established during 22-23 May 1958 by Maj Edward N LeFaivre, USMC, and were as follows: 3 000 m (9,842·5 ft) in 44·39 sec; 6 000 m (19,685 ft) in 1 min 6·13 sec; 9 000 m (29,527 ft) in 1 min 29·81 sec; 12 000 m (39,370 ft) in 1 min 51·23 sec, and 15 000 m (49,212 ft) in 2 min 36·05 sec.*



Douglas F4D-1 (F-6A) Skyray Cutaway Key

1 Radome nose
2 Radar antenna
3 Radar reflector dish
4 APQ-50A radar package
5 Weapons control package (Aero 13-F system)
6 Detachable nose cone
7 Pressure head
8 Windscreen demister pipe
9 Pilot's instrument display
10 Armour-glass windscreen
11 Instrument panel shroud
12 Pilot's radar display
13 Flying control linkage
14 Forward cockpit pressure bulkhead
15 Nosewheel well and pre-closure door
16 Forward-retracting nosewheel
17 Nosewheel steering actuators
18 Nosewheel retraction strut
19 Nose gear rear door
20 Nose gear oleo leg
21 Aft cockpit pressure bulkhead
22 Engine controls on port console
23 Ejection seat base
24 Pilot's seat harness
25 Rear-view mirrors
26 Pressurised cockpit
27 Clamshell canopy
28 Seat ejection handle
29 Pilot's headrest
30 Navigation light
31 Air conditioning vents
32 Armoured panel
33 Ejection seat rails
34 Conditioned air feed pipes
35 Canopy hinge point
36 Air-conditioning and pressurisation plant
37 Hydraulic reservoirs
38 Port main air intake
39 Radio and electrical equipment bay
40 Intake boundary layer splitter plate
41 Compass
42 Inspection panel
43 Auxiliary air intakes
44 Generator
45 Centreline pylon carrying 150 US gal (568 l) drop tank
46 Catapult hook
47 Main air intake trunking
48 Autopilot equipment bay
49 Auxiliary air trunk

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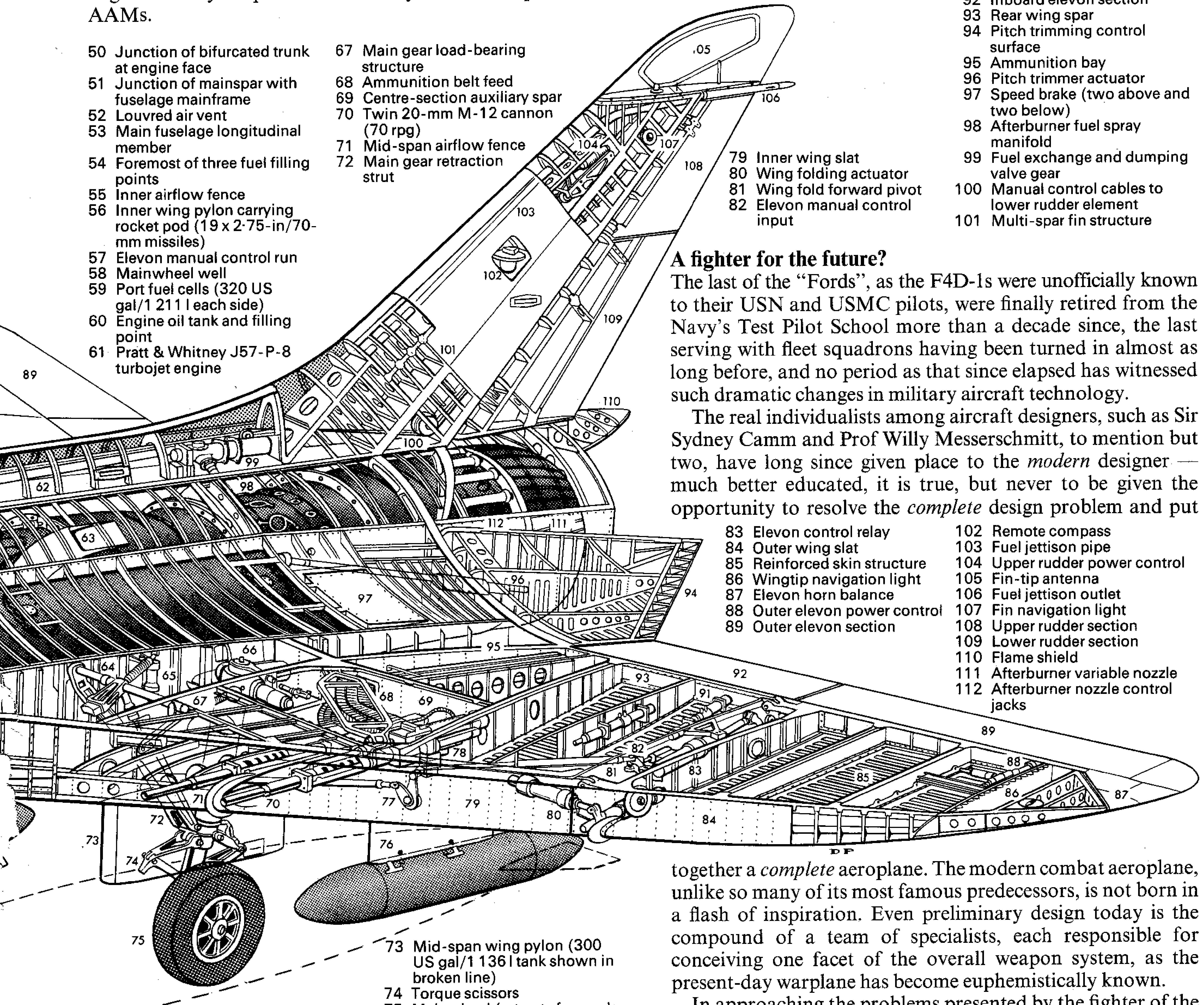
DRAWING

The F5D-1 had appreciably thinner wing sections; its slimmer, lengthened fuselage offered improved vision; internal fuel capacity was markedly increased, a wing skin of one-tenth of an inch (0,25 cm) thickness with integral stiffeners was adopted, and solid state transistorised autopilot and flight data computer were installed — these were designed by Douglas engineers and the F5D was believed to be the first aeroplane in the world so equipped. It was proposed that the definitive F5D would be powered by the General Electric J79 turbojet and would incorporate the missile weapons systems that the rapidly advancing technology of the period promised.

The first F5D, retaining the J57-P-8 engine standardised for the production F4D, flew on 21 April 1956. By this time, the two-aircraft contract had been amended twice to call for a total of 17 additional aeroplanes. At this stage, the proposed armament comprised four retractable rocket launchers in the underside of the fuselage toting a total of 72 2-in (5,08-cm) missiles, with four 20-mm cannon as an alternative installation, and it was planned that this internal weaponry be augmented by a pair of externally-mounted Sparrow II AAMs.

By comparison with the F4D, the F5D was a vastly improved fighter and technologically a generation on, with a speed capability of fractionally below Mach = 1·0 at sea level to Mach = 1·44 at 35,000 ft (10 670 m) with the J57 which it was intended to replace with a more powerful engine. Competing with the Grumman F11F and Vought F8U, the F5D lost out in the contest, much to my disappointment, the business going to Vought and the F5D programme being curtailed, only four of our aeroplanes being completed.

The F5Ds eventually went to Moffatt Field where they were turned over to the NACA for tests. I gained some little personal consolation some months later when we received a phone call from the NACA asking, "Why was the Vought chosen over the F5D since your fighter is two-tenths of a Mach faster?" What could I reply? There was no good answer. But then, Vought had no other work in hand while we had five projects on the stocks! Such is the military aircraft business and so ended our tailless fighter efforts.



50 Junction of bifurcated trunk at engine face
51 Junction of mainspar with fuselage mainframe
52 Louvred air vent
53 Main fuselage longitudinal member
54 Foremost of three fuel filling points
55 Inner airflow fence
56 Inner wing pylon carrying rocket pod (19 x 2·75-in/70-mm missiles)
57 Elevon manual control run
58 Mainwheel well
59 Port fuel cells (320 US gal/1 211 l each side)
60 Engine oil tank and filling point
61 Pratt & Whitney J57-P-8 turbojet engine
62 Fuel pipes in dorsal spine
63 Compressor bleed air vent
64 Main gear retraction linkage
65 Main gear retraction actuator
66 Main gear oleo crown and pivot point
67 Main gear load-bearing structure
68 Ammunition belt feed
69 Centre-section auxiliary spar
70 Twin 20-mm M-12 cannon (70 rpg)
71 Mid-span airflow fence
72 Main gear retraction strut
73 Mid-span wing pylon (300 US gal/1 136 l tank shown in broken line)
74 Torque scissors
75 Mainwheel (retracts forwards to lie flat)
76 Outer wing pylon carrying rocket pod (19 x 2·75-in/70-mm missiles)
77 Elevon manual control linkage
78 Outer cannon breech
79 Inner wing slat
80 Wing folding actuator
81 Wing fold forward pivot
82 Elevon manual control input
83 Elevon control relay
84 Outer wing slat
85 Reinforced skin structure
86 Wingtip navigation light
87 Elevon horn balance
88 Outer elevon power control
89 Outer elevon section
90 Wing fold rear pivot
91 Inboard elevon power control
92 Inboard elevon section
93 Rear wing spar
94 Pitch trimming control surface
95 Ammunition bay
96 Pitch trimmer actuator
97 Speed brake (two above and two below)
98 Afterburner fuel spray manifold
99 Fuel exchange and dumping valve gear
100 Manual control cables to lower rudder element
101 Multi-spar fin structure
102 Remote compass
103 Fuel jettison pipe
104 Upper rudder power control
105 Fin-tip antenna
106 Fuel jettison outlet
107 Fin navigation light
108 Upper rudder section
109 Lower rudder section
110 Flame shield
111 Afterburner variable nozzle
112 Afterburner nozzle control jacks

A fighter for the future?

The last of the "Fords", as the F4D-1s were unofficially known to their USN and USMC pilots, were finally retired from the Navy's Test Pilot School more than a decade since, the last serving with fleet squadrons having been turned in almost as long before, and no period as that since elapsed has witnessed such dramatic changes in military aircraft technology.

The real individualists among aircraft designers, such as Sir Sydney Camm and Prof Willy Messerschmitt, to mention but two, have long since given place to the *modern* designer — much better educated, it is true, but never to be given the opportunity to resolve the *complete* design problem and put together a *complete* aeroplane. The modern combat aeroplane, unlike so many of its most famous predecessors, is not born in a flash of inspiration. Even preliminary design today is the compound of a team of specialists, each responsible for conceiving one facet of the overall weapon system, as the present-day warplane has become euphemistically known.

In approaching the problems presented by the fighter of the future, I must admit to the influence of over 50 years of preliminary design experience — a half-century plus is perhaps *too* long, but one does tend to become acquainted with most of the wrinkles of the business over such a period — which emboldens me to assert that, in designing such a warplane, a specification can hinder rather than help. The keynote of any future fighter must be flexibility and a specification tends to inhibit attainment of this desirable quality.

In the past, we have started out with a specification for a fighter optimised for, say, diurnal or nocturnal intercept, close air support, etc, with, perhaps, some provision for secondary mission capability. History has demonstrated, however, that the fighter designed to such a specification will, as likely as not, eventually find its true forté fulfilling a task far removed from that for which it was conceived. Take the Typhoon, for example, designed for the high-altitude intercept mission but finding its métier to be ground attack. More recently, who would have thought so straightforward an extrapolation of the dedicated ground attack Harrier as the Sea Harrier would give such a convincing performance in the fleet defence rôle as during the Falklands fracas!

The most valuable fighter has always been that combining performance competence with the greatest possible flexibility. The astronomical cost of today's fighter renders such flexibility all the more vital, and flexibility can make up, in some measure, for lack of quantity. Regrettably, there has been an increasing tendency to equate the flexible fighter with the complex fighter. Duplicated power plant, three-piece wing, large blended root fairings, multiple tail surfaces — all weight-augmenting features commonplace among the most recent fighters. In US industry there is a simple rule-of-thumb method by which the probable cost of an airframe is arrived at: structural weight in conventional materials of high-rate-of-production airframe manufacture is calculated on a dollars-per-pound basis. This is today running at around $400 per pound, or $880 per kilo, and rising, so every pound of added weight . . . !

Admittedly, this growth in complexity and, in consequence, weight, has been paralleled by dramatically increased efficacy, but, in my view, not commensurately so because of the growth in the tendency to design by consensus which has exacerbated complexity to an unnecessary degree. A team of engineers individually involved in separate aspects of the total design are each inhibited in the creative ability that they can bring to bear on their contribution by the dictates of aspects of the design for which they have no responsibility. Perhaps, therefore, we should stand back and take a look at the way in which we design our combat aeroplanes today; perhaps we should go back to first principles.

I have endeavoured to keep myself abreast of evolving fighter requirements and, in recent years, have kept a fighter design current in the light of the latest developments in engine technology, materials, etc. The conclusions that I have reached, with due attention to cost practicality and the diverse operational scenarios against which the future fighter must be projected, are that the highly flexible fighter of tomorrow should have one engine, be built of conventional materials, have a clean loaded weight of the order of 25,000 lb (11 340 kg) and be of canard configuration.

The argument between those favouring a single engine for fighters and those favouring a twin-engined arrangement has been waged for a very long time. The old maxim "Why have two when one will do?" is singularly apposite to the fighter scene today. A single-engined fighter is both cheaper and more economical to operate. True, under normal peacetime circumstances, the fighter with one engine suffers a higher rate of attrition than the fighter with two. But the single-engined aircraft has nothing like *double* the attrition of the twin, whereas recent experience has shown that the fighter with two engines costs about double that of the fighter possessing only one engine! It is doubtful that many countries can afford the price tag of $30m or so that fighters with duplicated power plant now carry. The luxury of twin engines cannot really be justified in this day and age, and a single GE F404, PW1120 or RB.199 has enough power to endow the fighter of tomorrow with the desired performance and with relative economy.

During the last 50 years, I have seen and used many materials, from "stick and wire" to titanium and boron, and it is up to the designer to utilise the best materials for a specific

XF4D-1 Flight Test

(Naval Air Test Center preliminary evaluation of J40-WE-6-powered second prototype)

THE PRELIMINARY EVALUATION of this aircraft has been conducted by the NATC with an engine not incorporating afterburning. Longitudinal stability and control are satisfactory up to a Mach number of 0·92 except for extremely high control sensitivity near neutral at high indicated airspeeds. The high *g* buffet boundary is one of the most outstanding features of the aircraft. At 40,000 ft (12 190 m) a steady acceleration of 3·4 *g* can be pulled at Mach = 0·9 without airframe buffet, and at 30,000 ft (9 145 m) at Mach = 0·8 a steady 4·0 *g* can be obtained.

Stick force per *g* varies from 4·5 lb (2,04 kg) at 350 knots (649 km/h) at 10,000 ft (3 050 m) at mid CG to 12 lb (5,44 kg) at 175 knots (324 km/h) and 35 lb (15,88 kg) in the landing configuration at 120 knots (222 km/h). This last figure is, of course, very excessive. The use of the pitch trimmers as trim devices and as an aid to longitudinal control is considered unsatisfactory because of their ineffectiveness.

Static lateral stability is strong at high speeds and increases as speed is reduced, becoming excessively strong for the landing approach. Lateral control effectiveness is also marginal for landing, but increases with speed until it becomes exceptionally high at higher indicated airspeeds where it is extremely sensitive near neutral stick position. Manual reversion control gives very large forces which require the pilot to use both hands during the landing approach. Since the control forces appear to increase linearly with speed, the aircraft would probably be unmanageable at high speeds.

Without the yaw damper operating, directional stability is unsatisfactory at low speeds. The present yaw stabilisation system does not sufficiently damp lateral directional oscillations, but the production aircraft will incorporate a two-piece rudder, split chordwise, with one section acting as a yaw damper and the other as a rudder surface. Both sections would tend to move as a unit unless an adverse yaw signal be transmitted by the yaw damper, thus allowing the pilot to feel rudder force and position feedback passed through the rudder pedals by the action of the yaw damper when a single surface is used.

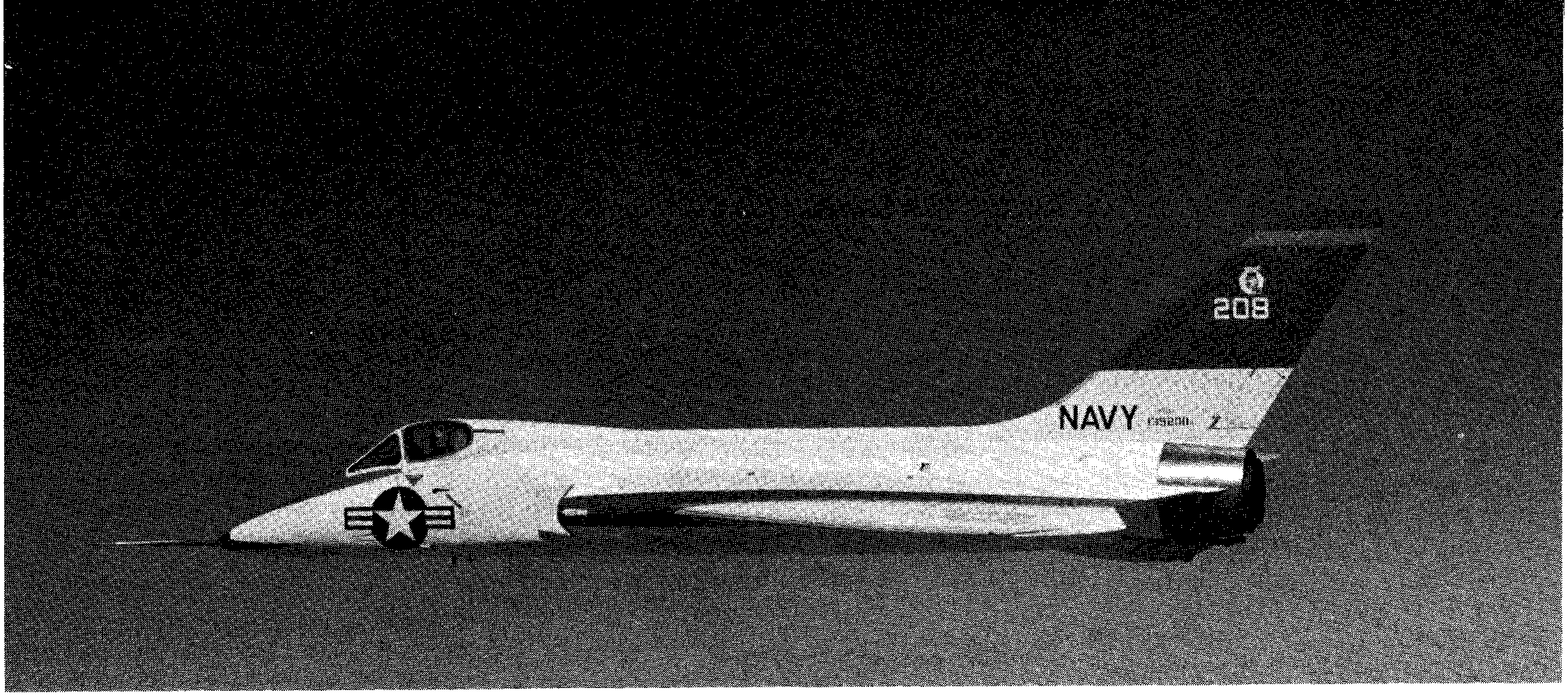
High frequency rudder oscillations are at present encountered above Mach = 0·92 which necessitate locking the rudder mechanically prior to attaining that Mach number. The aircraft has not been flown in excess of Mach = 0·95 with the rudder locked.

The stall characteristics are good, consisting of light buffet starting at 13 knots (24 km/h) before the stall and increasing in intensity until a wing drop occurs at 95 knots (176 km/h) at an AUW of 15,870 lb (7 199 kg) with the aircraft in the powered landing approach configuration. The minimum trim speed, however, is too high so that with full nose up trimmer setting a pull force of 25 lb (11,34 kg) is required to reach the stall.

The view for deck landing is very good at approach speeds down to 100 knots (185 km/h), but the control on the approach is poor below 115 knots (213 km/h) due to sharp increase in drag with increase in attitude, reduced lateral control and increased dihedral effect. Under such conditions the poor engine acceleration characteristics make a wave-off critical.

High Mach number characteristics include the high frequency rudder oscillations already referred to and a fairly mild nose down trim change at Mach = 0·92. Elevator effectiveness is suspected to be marginal in the region of Mach = 1·0. The speed brakes give excessive buffet above 300 knots (556 km/h), ineffective deceleration and a very slight nose down trim change.

It is concluded that this aircraft is really in too early a stage of development to arrive at any final conclusions, but it certainly shows enough promise to warrant hope for high future success.

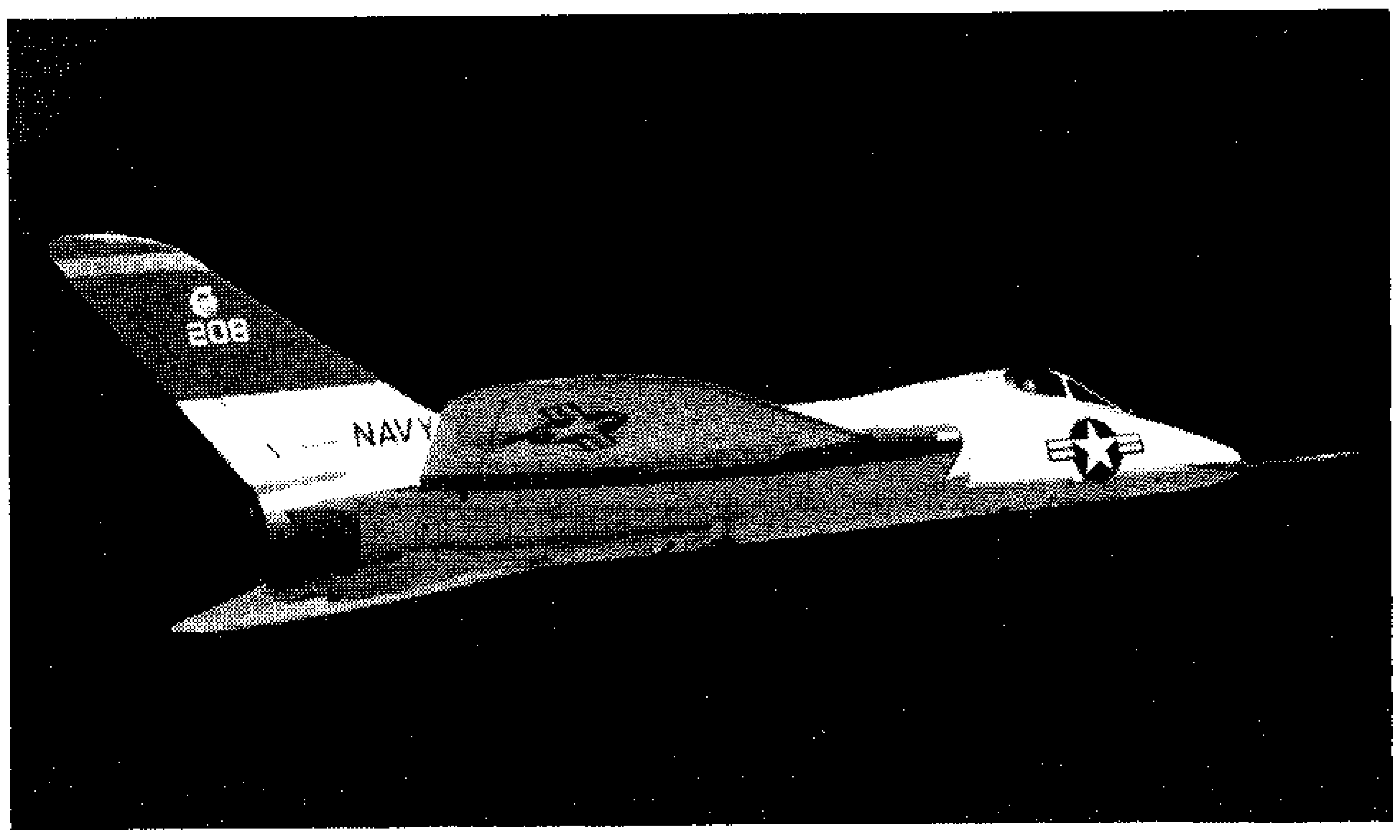


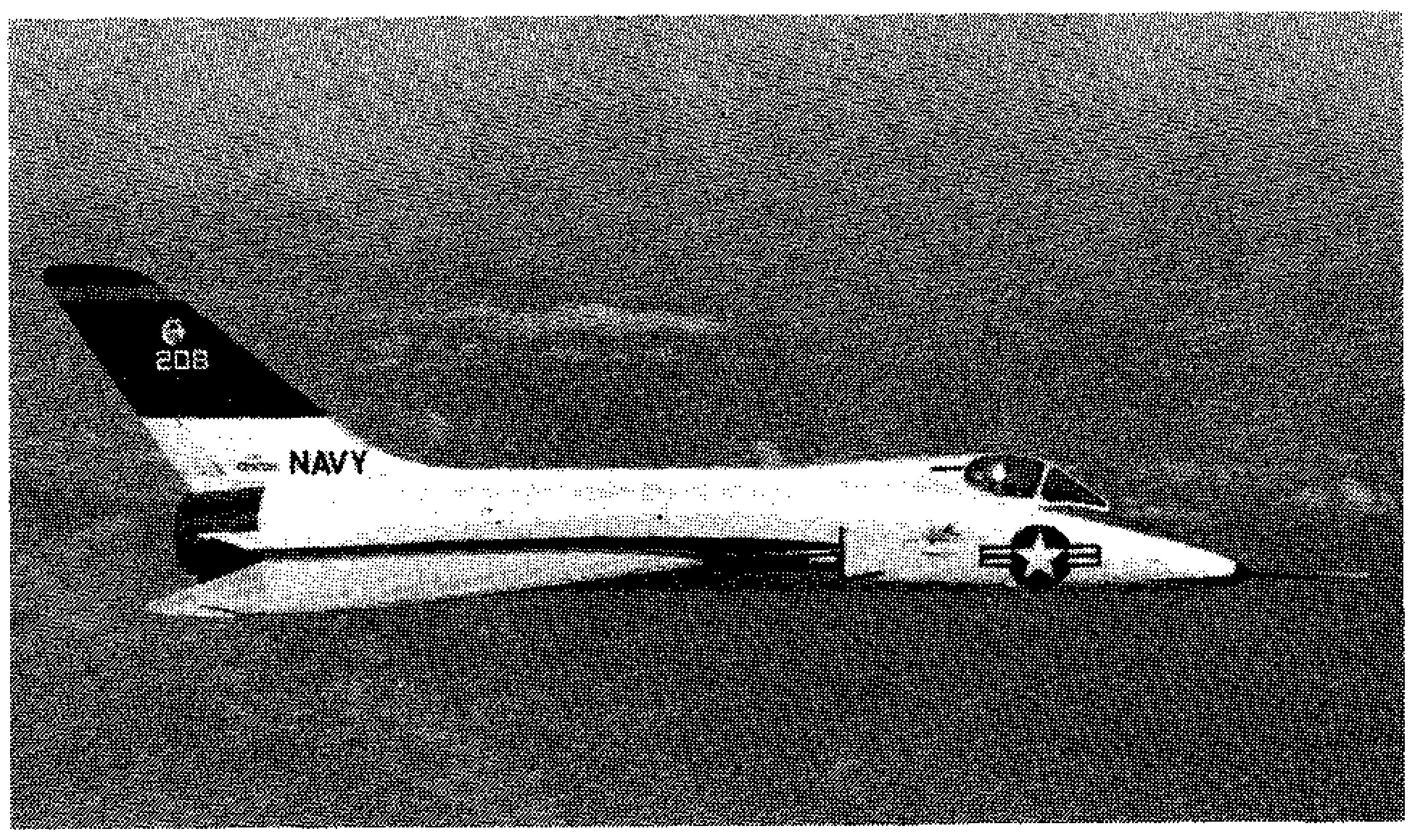
(Above and below right) The F5D Skylancer, launched as the F4D-2, eventually evolved as virtually a new aeroplane, with little in common with the Skyray but the basic wing planform.

job. But this should be material that is readily available, can be formed economically and can be easily maintained. The temptation to a design team to be among the first to use a *new* material is understandable, but such does not necessarily make a fully worthwhile contribution to the capability of the aeroplane in which it is employed, sometimes quite the reverse. The *right* choice of material is vital; newly-developed exotic materials may be attractive because of the saving in weight that they promise, but this saving can be more than outweighed by cost and lack of malleability. For what it is worth, it is my opinion that, in general, aluminium alloy remains today one of the best structural materials from the viewpoints of manufacturing ease and cost, and subsequent maintainability and repair.

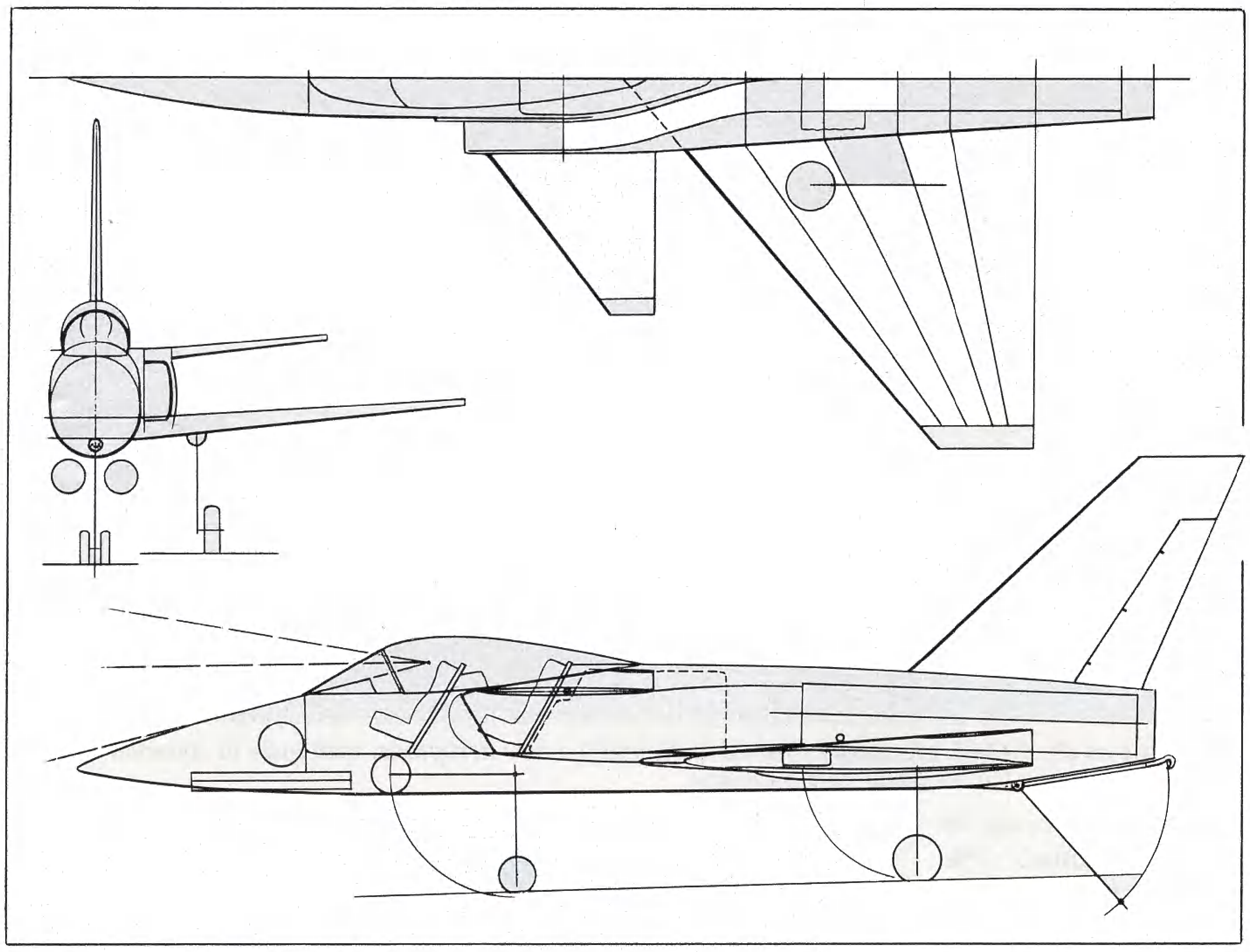
Weight target

Perhaps a clean loaded weight of around 25,000 lb (11 340 kg) rising to a maximum of about 35,000 lb (15 876 kg) *may* err a little on the low side, but, with constant exercise of weight consciousness, I believe such to be feasible. Such figures certainly provide good targets to aim at. The canard arrangement that I favour might be viewed as a logical evolution of the F5D configuration, and with fly-by-wire and other control developments would seem to offer very real advantages. These modern control systems enable for the first time full advantage to be taken of all lifting wing and tail surface during manoeuvering. This extra positive lift during a turn is of vital importance, and of all possible configurations

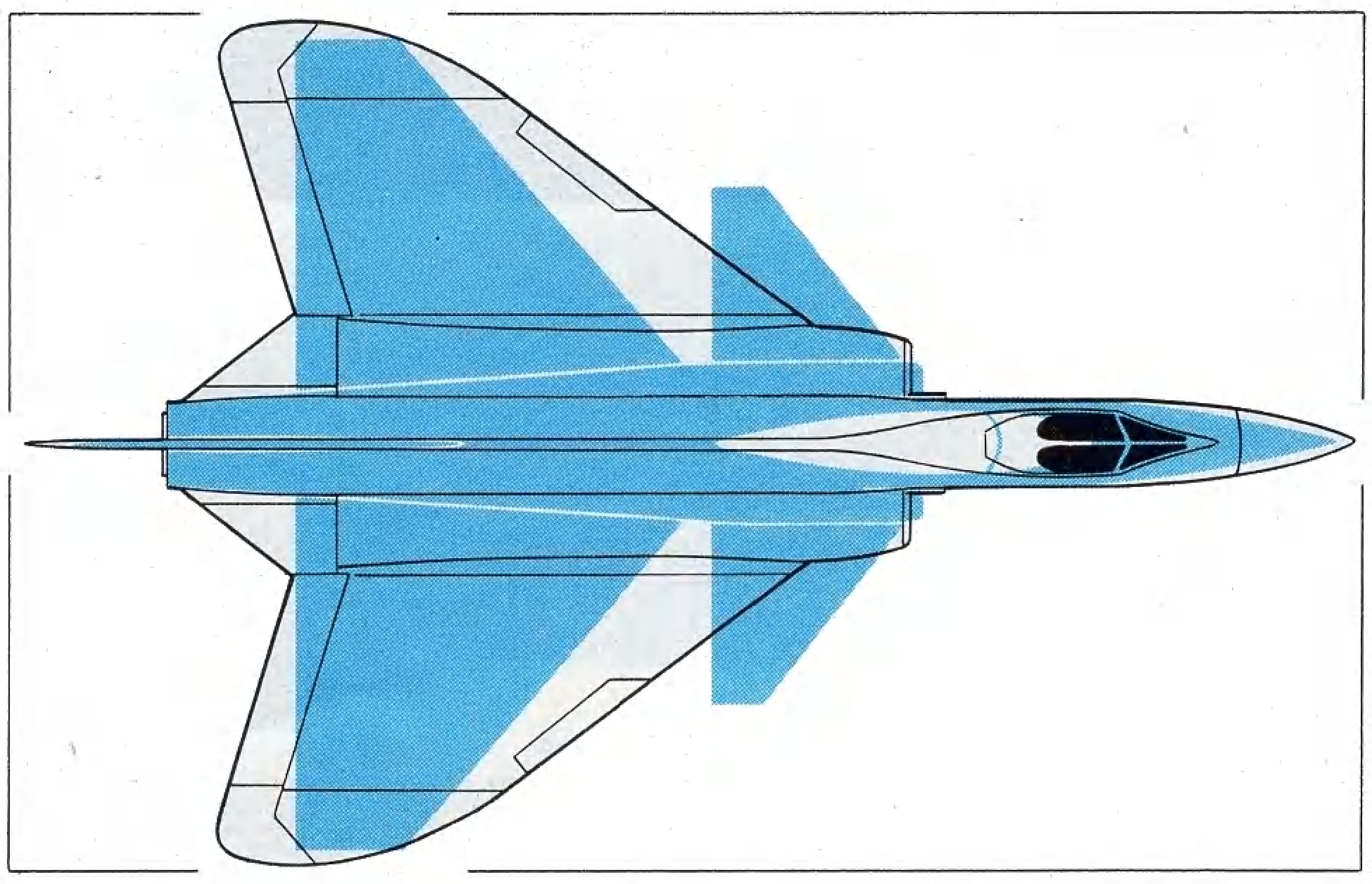




(Below and above right) Only four F5Ds were flown, two prototypes and the first two of a planned production batch of 60. They eventually were used by NACA for aerodynamic research purposes.



Illustrated here for the first time anywhere is Ed Heinemann's latest project design for what he describes as a "highly flexible fighter" — a fundamentally simple aeroplane capable of operation across the full fighter spectrum, from both land bases and carriers. The canard layout is compared, below, with the F5D planform, of which it is a logical evolution.



the canard now offers most. Recent Swedish experience lends weight to this argument.

Twenty years ago, we were sure that we would have to be flying fighters at Mach = 3·0 by this time. Indeed, fighters possessing trisonic capability (eg, the MiG-25) have evolved, but the many problems of materials and fire control motivate against going to such lengths. When it comes to high speed, it would seem that Mach = 1·7 to 1·9, with rapid acceleration from Mach = 0·8 to Vmax are the ideal ballpark figures.

Simple concept

My study for a highly flexible fighter envisages a fundamentally simple aeroplane capable of operation across the full fighter spectrum and from both land bases and carriers. Spanning 32 ft (9,75 m) and possessing an overall length of 50 ft (15,25 m), it supplements 352 sq ft (32,70 m^2) of clipped near-delta wing area with 70 sq ft (6,50 m^2) of similarly-configured canard to provide a total area of 422 sq ft (39,20 m^2). These dimensions would seem to be the optimum for the amount of fuel and equipment required.

The design is based on use of an afterburning PW1120 engine and a total internal capacity (wing and fuselage tanks) of 1,100 US gal (4 164 l), and armament is very much a matter of customer choice. Provision has been made for a single 25-mm GAU-12/U gun located in the fuselage nose, a pair of AIM-9 Sidewinders, two or four 500-lb (226,8-kg) bombs on the fuselage centreline in conformal array, or either one or two cruise missiles.

The optimum fighter would, of course, be a single-seater, but the many requirements for a second seat for a radar operator, for conversion training, etc, are so strong that I have made provision for the additional crew member from the outset, this space being available for an additional fuel tank when operated in single-seat form. No exotic materials are contemplated — many discussions with operating crews have stressed the importance in which they hold familiarity with materials for making repairs — and the wing structure, constructed in one piece from tip to tip for minimum weight, employs simple integral stringers. The mainwheels retract forward into the wing, turning through 90 deg, and the nosewheel, which also retracts forward, is of conventional Navy type equipped for catapult take-off.

I would very much like to build such an aeroplane as I have outlined, but without a factory and design staff . . . I fear that I must leave the task to the younger men who *will* produce the fighter of the future and to whom I say LOTS OF LUCK. ☐