

STARFIGHTER

Lockheed's Mach 2 Fighter for the U.S.A.F.

By THE TECHNICAL EDITOR

FOR more than two years aeronautical enthusiasts have been eagerly swopping meagre "unconfirmed details" of the Lockheed F-104 supersonic fighter. In conformity with a possibly unrealistic Pentagon decision, its characteristics, like those of other recent U.S.A.F. prototypes, have been a closely guarded secret. Now, however, "the wraps" are off. A Press unveiling was being held in California on Tuesday of this week and there are grounds for believing that at this function an attempt was to be made on the world speed record. A *Flight* representative was present and his despatch will appear in a future issue. This account has been prepared in advance, so that readers can become familiar with the remarkable F-104 at the earliest possible moment.

Fast aeroplanes have always been a *forte* of the Lockheed Aircraft Corporation. America's first real jet fighter was the Lockheed Model 80 (later XP-80 Shooting Star), which was enabled to fly 100 days from the start of design by the generosity of the de Havilland Engine Company, who shipped to Lockheed the only flight-cleared Goblin they had to hand. The Shooting Star went into major production shortly after World War 2 and over 7,000 derivatives have since been built (many powered by turbojets similar to the Rolls-Royce Nene, which, incidentally, was first air-tested in a Shooting Star airframe). During 1947 a large twin-engined fighter was developed to meet the U.S.A.F. requirements for a long-range "penetration" fighter. Designated L.153, or XF-90, two prototypes were flown extensively. It is not generally known that the type was dived beyond the speed of sound, but no production order was placed.

The opportunity for Lockheed to enter the true supersonic lists came in 1951, when the Air Force worked out its specification for an "air-superiority fighter." This concept has changed somewhat in recent years, but can be considered principally as a fighter which can destroy enemy fighters. All-weather capability, long range and ability to operate from forward bases were not requirements of the specification, which was biased in favour of extreme all-round performance and cheap and reliable operation.

Behind the specification lay long, and often heated, discussions with pilots back from Korea. The encounters between Sabres and Migs had served to emphasize the importance of maintaining a high standard of serviceability and reliability throughout all combat operations. A classic example of the Air Force's failure to do so is provided by the A-1CM radar gunsight, which gave so much trouble that Col. Francis Gabreski, a Korean "ace," went on record as saying that he would rather sight his guns with the aid of a piece of chewing-gum stuck on the windscreen.

This state of affairs gradually gave rise to pressure for a smaller, lighter and more reliable fighter which could not only be kept in fighting trim but would also provide a marked increase in all-round performance. American pilots had become heartily sick of looking up at the undersides of Migs, and the lightweight fighter was frequently looked upon as the panacea which would put its owners literally on top.

Some relief was provided by new equipment such as the A-4 gunsight, the "black box" components of which could be removed and replaced in a matter of minutes. The shortcomings in performance were more fundamental and gave rise to the air-superiority concept. Several firms submitted projects, but it was early decided that responsibility for this development would be placed

with Lockheed's California division at Burbank, with the Air Force designation F-104. A powerful design team was quickly assembled around Clarence L. ("Kelly") Johnson, the chief engineer. Johnson has never quite subscribed to the idea of a light fighter and certainly not to the concept of a stripped-down aircraft. His opinion, which seems to be common-sense, is that one might get a few top-notch men capable of doing well with such equipment, but that in practice one must design for the run-of-the-mill pilot for whom a "gum-sight" is strictly out.

Initial weight estimates, therefore, came out somewhere near that of a Sabre, but in most other respects the Lockheed design was startling. At the end of 1951 Lockheed knew they would be using a single turbojet with afterburner and it has stayed that way through a large number of projected airframe configurations. The basic design work was immeasurably assisted by the Air Force/N.A.C.A. research with supersonic aircraft, which had obtained aerodynamic data at Reynolds numbers appropriate to the F-104 at up to 90,000ft and Mach 2. Lockheed also ran several thousand hours in their own tunnels and in the Southern California Co-operative Tunnel, in which they have a one-sixth share.

In the F-90 the company made some use of ballistic models dropped from high altitude, but the terminal velocity thus attained was insufficient for the new fighter. Free-flight work entailed the use of vehicles fitted with F-104 aerodynamic surfaces and launched from ramps in the desert under the thrust of 5in rocket motors. Data were also obtained from existing aircraft embodying components expected to be designed into the future fighter. Assistance was given by the N.A.C.A. and Cornell with variable-stability aircraft capable of simulating the behaviour of the F-104.

One of the first design choices was the type of wing to use. After looking extensively at other wings, the company settled upon a true supersonic aerofoil with very low aspect-ratio, no sweep-back and the unprecedented thickness/chord ratio of 3.4 per cent. No other aircraft, then or since, has had so thin a wing, and Lockheed's firm determination to employ such an aerofoil can only be regarded as courageous. In passing, we remember that Johnson was once introduced as a member of the fraternity "No Delta Wing."

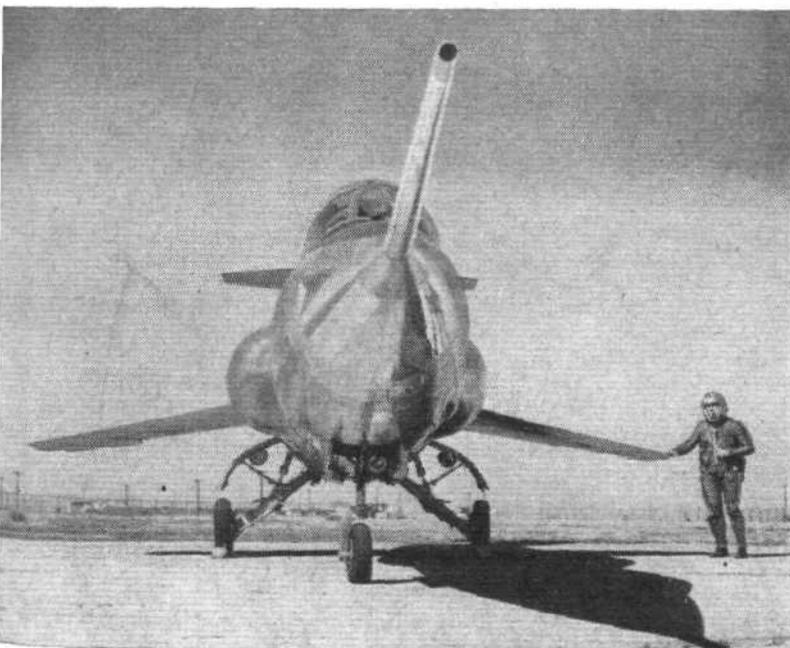
As in most missiles, virtually everything had to be put inside the fuselage, which, at the same time, had to be of minimum frontal area with a profile suitable for high supersonic speeds. Lockheed were well aware of the N.A.C.A. area rule, but transonic interference drag was never a problem with the 104. Area rule is less applicable to "wholly supersonic" aircraft, and in any case the Lockheed fighter's wing volume is exceedingly small.

Fuselage design was complicated by the overriding importance of obtaining optimum flow into, and out of, the turbojet—particularly when, as in this case, the engine was to develop half its maximum-speed thrust as a ramjet. Supersonic-intake design is an exceedingly complex subject which Lockheed and the N.A.C.A. had to explore thoroughly. With a modern axial engine most of the trouble is likely to occur at the top end of the speed range. It is essential to get rid of the boundary layer and singular importance also attaches to the manner in which this is accomplished. Boundary-layer growth is usually a function of fuselage length ahead of the intake, and so it is remarkable that Lockheed believe they have attained a better inlet-air distribution than in any other aircraft now flying.





The aircraft above is one of the 17 prototypes powered by the Wright J65-W-3 Sapphire. That shown below and opposite is the first J79-powered machine and it is noteworthy that the intakes have been blanked off with metal sheet, presumably owing to a change in design which is still regarded as secret. There is no evidence of armament on either of the aircraft illustrated in these pages. The Starfighter is, however, considered as ready for release to the U.S. Air Force and will enter service with Tactical Air Command in the very near future.



It is possible that a special form of nose intake would have been employed had it not been for a remarkable armament which the Air Force specified. Apart from the homing air-to-air missile, the only type of weapon capable of employment in supersonic combat was considered to be a gun capable of placing many strikes on a target in firing periods measured in fractions of a second. To achieve this object, General Electric evolved something like a hot-rod development of the Gatling, known as Project Vulcan. This "firing mechanism" hurls 20 mm shells from multiple barrels, each of which is in a different part of the firing cycle at any given moment. An account of a test firing was published in our special armament issue dated January 28th, 1955. Vulcan was tailored to fit the nose of the first type of F-104A, forming a single murderous package firing 20 mm ammunition at a rate of several thousand rounds per minute. Total firing endurance per mission is probably of the order of five seconds.

Of particular interest to British readers is the fact that the early life of the 104 was linked to a British engine. In 1952 only the Armstrong Siddeley Sapphire, as the Wright J65, promised to

form a satisfactory afterburning powerplant capable of fitting the space envelope of the F-104.

Nevertheless, even this engine almost completely filled the available space, and Lockheed had to be very clever in finding room for sufficient fuel. Their solution almost gives the impression that they poured fuel all round the intakes, ducting and powerplant and then sealed it up in fireproof bays. The F-104 fuselage carries more fuel than did the twin-engined Lightning long-range fighter of World War 2, and Lockheed are able to describe the 104 as having range "comparable to that of present operational jet fighters."

In some respects it is unfortunate that provision has to be made for a human pilot. Even though he wears a T-1 partial-pressure suit, his cockpit has to be pressurized and air-conditioned, and means must be provided for his escape in emergency. Lockheed found that the optimum escape arrangement was to employ an automatic downward-ejection seat (already used on S.A.C. bombers but not in any production fighter) which not only eliminated the possibility of the pilot hitting the empennage, but permitted a simpler canopy and better cockpit design. Lockheed carefully studied the capsule concept, but concluded that, on balance, the best pod was the airframe itself. An incidental advantage was that, during ground servicing, the escape hatch could be removed and the seat slid out to provide stand-up working space in the cockpit.

Maintenance requirements received particular attention, and a typical example of the way this problem was tackled is provided by the "integrated electronics system." Virtually all the radio and "operational" electronics are packaged into readily removable units, the idea being carried to its logical conclusion by the evolution of several standard arrangements, each suited to the electronic requirements of a particular mission. Another aid to servicing is the grouping of all the centralized hydraulic components on the inside of the large access door under the engine compartment.

At present the F-104 has a conventional undercarriage, with tiny tyres inflated to approximately 300 lb/sq in. Each main leg is a forged cantilever hinged along an oblique axis to one of the main engine-support frames. The leg is also hinged along a horizontal axis to enable it to deflect outwards under landing loads under the restraint of a vertical shock-strut. Each unit retracts forwards hydraulically into bays closed by two doors on each side, each rear door being linked to its appropriate leg. Anti-skid, multi-disc brakes are used, the static discs being restrained by external torque links. The steerable nosewheel likewise retracts forwards into an unpressurized box sealed by twin doors. Landing lights and taxiing lamps are mounted on the nose leg and inside the main-wheel doors.

Owing to the high bending moments in the wing—which, as a result of the extreme thinness, generate unprecedented root stresses per foot run of chord—it looked at one time as if Lockheed would have to make the wing as a single slab from tip to tip. This in turn dictated a low wing-position in order to clear the crowded fuselage interior. As the design progressed it was found possible to make the fuselage frames strong enough to take out all the wing loads, each semi-wing being cantilevered, missile-fashion, from the fuselage. It has thus been possible

STARFIGHTER . . .



The shape of the Starfighter — this is a J79-powered F-104A—appears unusual to eyes accustomed to subsonic airframes, but will become quite familiar and acceptable during the forthcoming decade.

to adopt a mid-wing arrangement with something like a 12 per cent reduction in drag over that of the low-wing project.

Each half-wing projects from the fuselage mould line rather less than eight feet. As this is approximately the same as the height of the vertical tail above the fuselage, the rudder has considerable influence on rolling behaviour and tends to act as an aileron. This fact was counteracted by giving the wing ten degrees of anhedral. The short span is inevitable (in the present state of the art) wherever the thickness/chord ratio has to be so low. Such wings are, in any case, the optimum form for the high-supersonic regime in which the F-104 ideally performs, where considerations of induced drag cease to have their subsonic importance.

At lower speeds, however, the old $\frac{W}{b^2}$ formula applies stringently and, as the 104 has greater span-loading than any other combat aircraft, induced drag becomes serious towards the lower end of the speed range and particularly acute at high altitudes. This fact must tend to put the 104 in the unfortunate class of aircraft where enormous "island performance" exists at high altitude and high supersonic speed, but where the medium-altitude, medium-speed conditions leave little in hand for climb and acceleration. At present, however, the F-104A (without external stores) can get through to the upper limits of speed and altitude in a matter of a few minutes.

In order to improve wing behaviour at high angles of attack, the leading edge can be drooped some 20 deg. This feature significantly reduces airfield requirements and should make it possible to fly controllably at full load at roughly 200 kt. Incidentally, the leading-edge drooping mechanism is accommodated in a maximum interior depth of less than 2in, which is no mean feat. The supersonic profile of the wing is complex, involving flats and smooth curves joined by a 0.016in nose radius and a knife-edge at the rear. Such a profile can generate high lift at low angles of attack and, with the leading edge drooped, can reach reasonable lift coefficients, although in this respect it cannot match subsonic wings. Wing loading on the Starfighter is naturally considerable, but it should not be forgotten that even at low speeds the fuselage generates substantial lift. Jettisonable tanks, each carrying 200 U.S. gallons, can be fitted over the wing tips like gloves. Although these tanks increase supersonic interference drag, they exert a beneficial end-plate effect equivalent to an increase in span. Spanwise flow on a straight wing is not worth worrying about, so no fences are required.

In some respects the control system is remarkably conventional. Moments of inertia in supersonic aircraft are usually much larger in yaw and pitch than in the rolling plane, and cross-coupling between these moments in an F-100 took the life of George Welch, engineering test pilot of North American. N.A.A. distributed the results of the ensuing investigations throughout the U.S. industry and this may have saved Lockheed from similar trouble by warning them to include second- and third-order terms in their calculations. The upper limits of altitude and airspeed of the F-104 have yet to be matched by any other combat aircraft.

Rolling control is effected by large-chord, small-span gapless ailerons, operated hydraulically without tabs. Control in the pitching plane is provided by a slab tailplane hinged at its mid-chord point near the tip of the fin. In this position it forms a useful end-plate, and Lockheed reckon the 104 fin to be approximately twice as effective as equivalent areas on other fighters. Structural problems in the tail were considerable, but any other arrangement would have placed the tailplane in fluctuating downwash and shock waves.

With a thin straight wing the aircraft c.g. needs to be forward of 20-per-cent-chord. As the c.p. travels aft in the transonic regime a considerable nose-down pitching moment is introduced, which must be counteracted by a downward force on the tailplane. This is just what the 104 does not want, particularly when combined with a marked reduction in C_L of the wing. One might suppose that, had Lockheed had more time to think in the early stages, they would have gone for the canard layout, i.e. with a nose-plane. Another advantage of such a layout could be that the lack of downwash on the present tailplane results in its experiencing pure drag, instead of—under some conditions with low tailplanes—forward thrust. Inboard of the ailerons are large-chord split flaps; in addition air brakes are hinged on each side of the rear fuselage and a ribbon braking parachute is located in a box under the afterburner.

Throughout the structural design one can detect Lockheed's efforts to evolve an airframe capable of cheap and rapid production. The wing is machined all over, much of the structure being of steel—not only on grounds of kinetic heating, for with a wing like this the use of light alloy places too much of the material too close to the neutral axis to do much good. Control surfaces and access doors are conventional sheet assemblies stabilized by a filling of Lockfoam. Parts of the skin are integrally stiffened. Lockheed claim that the F-104 airframe costs roughly half as much as do the structures of its contemporaries, this being partly due to the fact that it is only half as heavy.

Flight Trials

During 1953 Lockheed received orders for 17 prototypes, each a little more advanced than its predecessor, the last examples being virtually to production standard. All were built in production tooling, following the "Cook-Craigie plan" to the letter. The first prototype XF-104 was taken by road to Edwards A.F.B. early in 1954 and flew there on February 7th of that year. The pilot was A. W. ("Tony") LeVier, Lockheed's director of flying operations. This XF-104 has logged over 300 experimental flights and many hundreds of hours on the 17 prototypes have now been flown from both Edwards and the Air Force Jet Center at Palmdale.

As had been anticipated, the 104 needs plenty of space in which to get airborne, for, even with the leading edge drooped, the wing is by no means an optimum aerofoil in the take-off regime. Nevertheless, with an afterburning thrust/weight ratio of better than unity, a run of 4,000ft puts the speed well over 200 kt and, once in the air with the gear tucked away, the 104 becomes an extremely clean aeroplane.

To Tony LeVier, Herman R. ("Fish") Salmon—the chief engineering test pilot—and their colleagues, their supersonic charge was no mean responsibility, although long hours spent in the mock-ups before the first flight made them less unnerved by the gleaming projectile than they might have been. Their work was arduous, although by British standards development has been rapid—such is the advantage of pulling out one prototype after another.

Thus it was that, over a year ago, air-firing trials were already in progress. By this time Phase I testing was virtually complete and the J65-powered aircraft had been investigated over its complete design Mach spectrum; but trouble struck during high-speed firing runs, when an expended shell-case was sucked into one of the intakes. Here it refused to follow the duct into the engine (which it might have wrecked) but plunged through the wall into a fuselage tank. Luckily the hot case did not blow up the tank; but fuel streamed from the puncture and swamped the engine. The result was a skilfully-executed, dead-stick landing at Edwards without further damage to the aircraft. The pilot was LeVier.

One prototype was, however, lost. This occurred later in

STARFIGHTER . . .

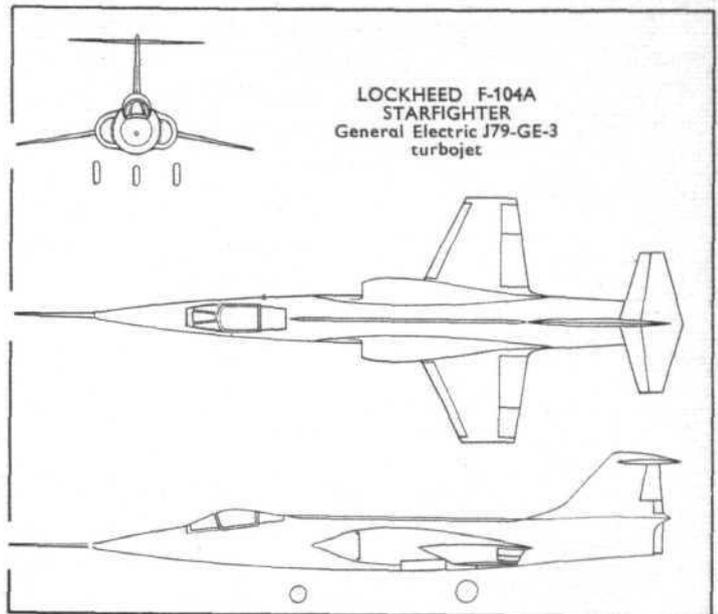
1955, when Salmon suffered unspecified trouble while flying near the tropopause over rugged Sierra-type country. Any attempt to ride the 104 down would have been suicidal, so "Fish" baled out at about 15,000ft at under 300 m.p.h., eventually to be picked up by helicopter. It is recorded that, when frantic company engineers finally reached him by telephone, he asked imperturbably, "Why, what happened?"

About a year ago it was clear that the production version would have a new engine. This was in no way due to dissatisfaction with the J65, but arose from successful bench trials of a truly remarkable turbojet which G.E. were preparing up at Evendale. Designated J79, this engine has a single axial compressor, of high pressure-ratio, incorporating several variable-pitch rows of stators. The resulting combination of performance, specific thrust, light weight, handling characteristics and efficiency (in both subsonic and supersonic flight) is of an altogether exceptional nature.

The F-104 fitted this paragon of virtue like a glove, the only external changes being larger intakes of modified profile and a fatter rear fuselage to accommodate the J79 afterburner; in addition an extra bay was inserted into the fuselage behind the cockpit to provide increased tankage. In spite of the startling advance in performance conferred by this engine, the miles-per-gallon remain roughly the same as with the J65. Under some conditions thrust exceeds weight and the maximum rate of climb is obtained at maximum forward speed. It is officially stated that, so far as can be determined, the J79-powered machine (designated F-104A Starfighter) is the fastest climber in the world. LeVier once commented on the effects of doing levels at 30,000ft and then zooming to 70,000ft in a matter of seconds; and there seems no reason why, at full speed, such a height should not be maintained.

In parentheses, it is worth recalling that Marquardt have developed a tip-mounted supersonic ramjet which, at the start of each mission, can be faired over and used as a tank. Such an

Although the F-104 has a theoretical 60,000 h.p. supported by a 22ft wing, it is a very tractable aircraft and one Lockheed pilot has even gone as far as accelerating through Mach 1 with his hands clasped behind his head. This is one of the prototypes, with tip tanks in place.



LOCKHEED F-104A
STARFIGHTER
General Electric J79-GE-3
turbojet

arrangement would fit the 104 particularly well; Marquardt subsonic ramjets were once so disposed on a Lockheed F-80. Ramjet boost may well be in hand for the 104, but it would seem to be a case of gilt-on-the-gingerbread, for if the 104A needs more thrust anywhere, it is at Mach 1 and not at Mach 2.

Many pilots from the U.S. Air Force have now flown the 104 and conversions will be facilitated by the dual-control TF-104. Tremendous production of the 104A is building up rapidly—a characteristic of the Cook-Craigie plan, since the aircraft need no modifications whatever. Squadrons will be formed in Tactical Air Command in a matter of weeks.

In service the 104A will be sufficiently flexible for Lockheed to have made provision for "quick-change acts" between missions, and a great variety of stores—not excepting atomic weapons—can be carried externally. Announced roles include day or night interception, tactical interdiction and support, photo-reconnaissance and ground-attack. The present F-104A is fitted with a radar gunsight but not with search radar. Work is well advanced on an all-weather interceptor for Air Defense Command, probably armed with Falcon missiles. With their own money Lockheed built a two-seat prototype to serve both for this aircraft and for the trainer, and a two-seat "tactical fighter," designated F-104B, is already in production.

What then will the present F-104A do? It will fly extremely fast, and at Mach 2 will have tremendous altitude capability, although at lesser speeds its ceiling and other aspects of performance will markedly deteriorate. This raises an anomaly. With gun armament the human pilot can never fight at Mach 2 with a radar gunsight alone, irrespective of what ground control may be provided; and to attack a target moving only half as fast, the 104 must slow up considerably and depart from its best operating regime. Laying guns on a target may well be very difficult even if, as one might suppose, the barrels are spread to give a blanket of fire. Certainly the 104 will give its pilots tremendous moral ascendancy, especially in a "cold war," but its defensive role seems uncertain unless the human element can be removed from the interception procedure.

Flying the Starfighter will have a glamorous attraction, but it may be found that mechanical trouble will result in a high wastage of either aircraft or pilots. Failure of the 104's single engine could be serious. In a power-off approach the airspeed could hardly be less than 300ft/sec; and, even with the leading edge drooped, the gliding angle could scarcely be flatter than 1 in 5, which gives the quite unreasonable vertical velocity of 60ft/sec. Provision must also be made for failure of the wheel brakes or brake chute in otherwise normal landings.

It seems, therefore, that this aircraft will rarely make a power-off landing in service and will also be somewhat restricted as to choice of airfields. It may, in consequence, frighten its pilots; but it will certainly frighten its enemies.

LOCKHEED F-104A STARFIGHTER

General Electric J79-GE-3 turbojet, rated at 12,000 lb dry and giving over 16,000 lb thrust with afterburning to more than 1,800 deg K.

Span, without tip-tanks, 21ft 11in; overall length, 54ft 9in; height to fin tip, 13ft 6in; approximate net wing area, 111 sq ft; approximate tailplane area, 45.5 sq ft; approximate area of vertical tail, 40 sq ft; maximum weight, 15,000 lb, with over 17,000 lb in prospect for future operations.

Maximum speed on the level or in up to about 20 deg climb, more than M=1.85; operational ceiling, more than 65,000ft; radius of action, about 500 miles at the tropopause.

