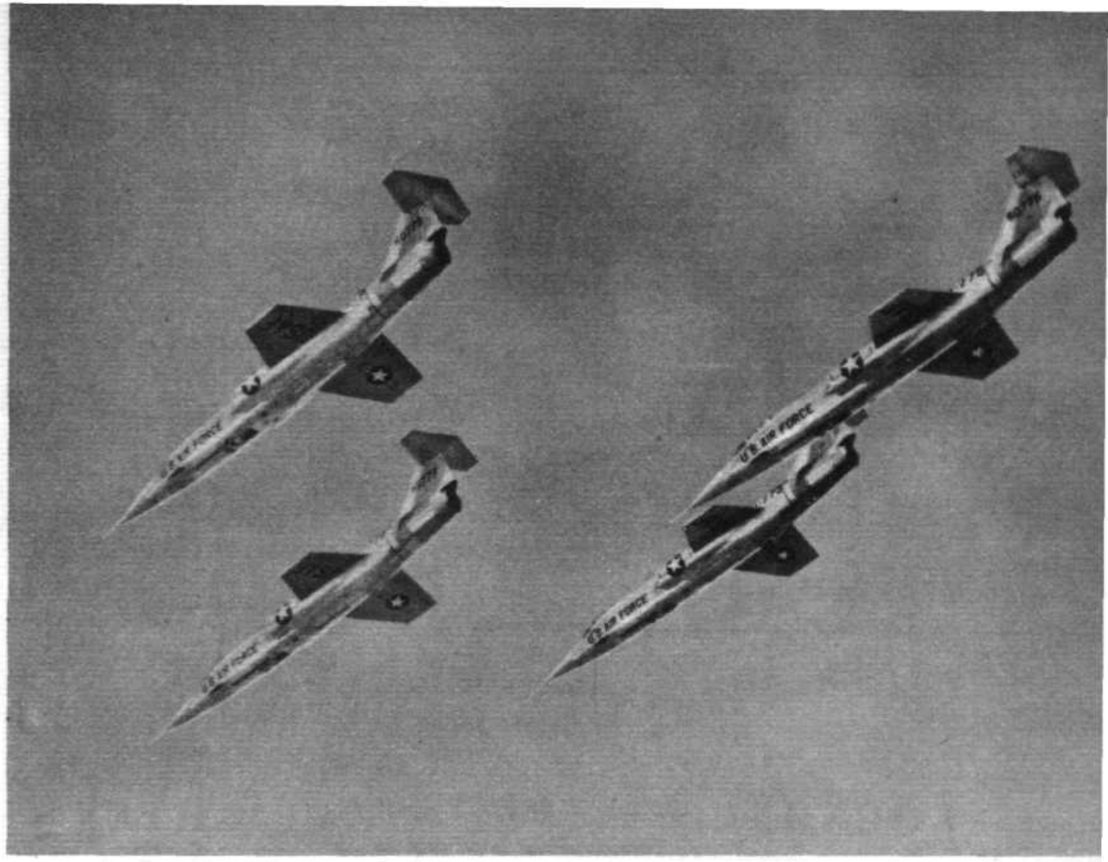
F-104

Holder of the Absolute Records for Speed and Altitude



SUPERLATIVES should have no place in a strictly technical appraisal, particularly when they are the assertions of a publicity-conscious commercial company. It is, therefore, appropriate that this first full description of the Lockheed F-104 should appear at a time when its performance has been demonstrated by officially observed flights which promise to bring to it the world records for both absolute speed and altitude—the first time in history that both records have been held by the same type of aeroplane. The submitted figures are: altitude, 91,249ft; speed, 1,404.19 m.p.h. (about Mach 2.13).

The F-104 Starfighter is a product of the California Division of the Lockheed Aircraft Corporation. Its general configuration, which is unique among aircraft or missiles of which details have been published, was revealed in the spring of 1956. Our issue of April 20 of that year contained an extensive dissertation upon the general design of the aircraft, together with an outline of its history and basic characteristics. It is not proposed to go over any of this ground again; but, given the F-104 as an entity in being, it is now possible to comment upon much of its structural and engineering design which was previously classified as secret.

In the design of a modern high-performance aeroplane there is very little latitude in which a designer can express his own foibles and promote his ideas; and the F-104 seems to be a typical case in which a design team can explain every feature and prove that it is the only possible choice. For example, one can find standard sheet and sections in the airframe, together with shell-mould and other castings, machined skins, integral stiffening, forgings and impact extrusions, all in a great variety of materials. Throughout, the design has been most carefully planned to reduce manufacturing and maintenance costs.

Owing to the relatively insignificant volume of the wings, virtually everything carried by the F-104 is housed in the fuselage. As almost half the latter is occupied by the powerplant and its air supply ducts, it follows that the overall length is considerable; the 104 is, in fact, a full ten feet longer than a Hunter.

To facilitate manufacture, the fuselage is broken down into nose, forward, centre and rear portions, and the main centre portion is further split into port and starboard halves. As the cut-away drawing shows, there are numerous transverse frames, and many of these are very strong forgings—particularly those which carry the five main wing spars, since these frames have to absorb all wing loads and diffuse them into the fuselage. Many of the larger forgings are close-tolerance "zero-draft" pieces, requiring little finishing.

In the design of the wings Lockheed faced a particularly acute set of problems. The thickness/chord ratio of 3.4 per cent accentuated the difficulties inherent in driving powered ailerons and flaps (and, in this case, a hinged leading edge), as well as those attendant upon designing pipe-runs, electric wiring and fuel-system equipment. At one time it was thought that each wing would have to be machined from a single slab of light alloy. Another study centred upon the use of a honeycomb core, another on the use of forged or cast interior structure and another on casting a semi-wing complete. Finally a conventional structure was adopted: the major loads are taken by very thick, tapered upper and lower skins and the interior consists of simple, compression-formed channel spars and three ribs, one at the root, one at the tip and the third about midway.

As far as possible the wing is free from cut-outs. The undercarriage retracts into the fuselage, and accordingly it was found possible to run the skins continuous from root to tip. Each skin panel is step-milled, stretched to the aerofoil profile and through-riveted to the interior structure. When only one side remains to be skinned the pipes are put in to carry fuel from the tip or pylon tanks, together with weapon-system wiring for stores at the same locations. The simple ailerons are hung on multiple piano-hinges and are actuated by ten hydraulic jacks arranged side-by-side. This provides distributed forces along the length of the surface (greatly reducing aileron distortion) and permits the use of diminutive jacks capable of being accommodated within the inch or so of depth available.

Flap actuation is effected by an Eemco electric unit arranged on each side of the fuselage, driving the surface directly. A different type of Eemco actuator is used to move the hinged leading edge, which can be depressed to preserve the airflow at high angles of attack. A special feature of the 104 is its use of boundary-layer control over the flaps by compressor-bleed air (a system known in Britain as supercirculation or flap-blowing). Air from the main engine compressor delivery is taken out through two large ducts, controlled by high-temperature proportional gate valves, and led outwards to connections at the roots of the wings. These admit the air to spanwise tubes, running the whole 47in length of each flap and arranged just above the flap leading edge. In the rearward-facing portion of the tube is cut a row of 55 thin slots, each 0.09in deep, 0.55in wide and spaced 0.9in apart.

Blowing starts as soon as the flap angle reaches 15 deg, and is progressively increased until the system is at full throttle when the flaps reach their full deflection of 45 deg. Under normal conditions the flow velocity through the slots is completely supersonic at 2,300ft/sec; the system reduces the stalling speed by from 12 to 17 kt and the landing run by some 25 per cent, a typical touch-down speed for an operational 104 being 135 kt.

As was explained in our issue of April 20, 1956, the horizontal tail is mounted at the top of the squat fin. Both surfaces are built, like the wing, with heavy skins and relatively simple interiors. In addition a 5ft-long ventral stabilizing fin is fitted.

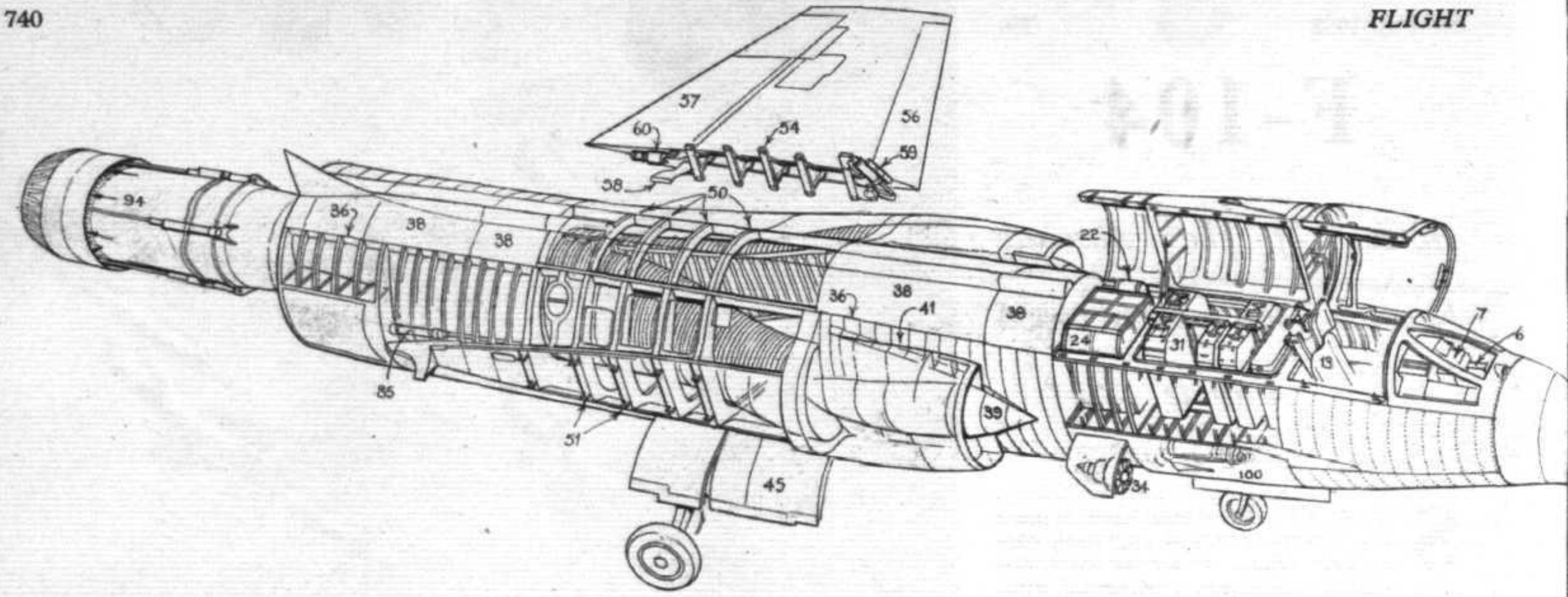
The horizontal tail is pivoted aft of mid-chord and is driven by an actuator in the fore-part of the fin. To it is attached the upper rear part of the vertical surface, which slides partially inside the forward portion of the fin-tip as the horizontal tail assumes a negative angle of incidence. Early flight-testing revealed that the 104 could, at extreme speed and altitude, enter a super-stalled condition leading to uncontrollable pitch-up. To counter this an angle-of-attack sensing unit was incorporated, which first causes stick-shake and then, should the pilot persist in pulling back, reverses the movement of the horizontal tail. The 104 is fitted with a fully transistorized three-axis autostabilizer, by Lear, Inc.

Shown well in the drawing, the undercarriage is exceptionally neat and comprises three units all retracting forwards into the fuselage (the nose gear on the XF-104 and F-104B retracts to the rear). Each main leg is a forging pivoted at its upper end and braced by a single Liquid Spring strut (Dowty patent) manufactured by the Cleveland Pneumatic Tool Co. Owing to the restricted size of the wheel bays, the tyre pressure is over 250 lb/sq in; in the past it has been customary to discard tyres after four landings but a new Goodrich sine-wave pattern promises to extend this by a factor of four.

Heart of the aircraft is its powerplant. It is remarkable that —as far as one can tell—neither the U.S.A.F. nor Lockheed have made any effort to fit the F-104 with a rocket motor. Sole means of propulsion remains the General Electric J79 turbojet, with afterburner—which, it must be admitted, is an exceptionally fine powerplant.

Some notes on the J79 appear on page 731 of this issue. It is well suited to flight at Mach numbers up to about 2.5, and in

(Continued on page 742, after double-page drawing of the F-104)

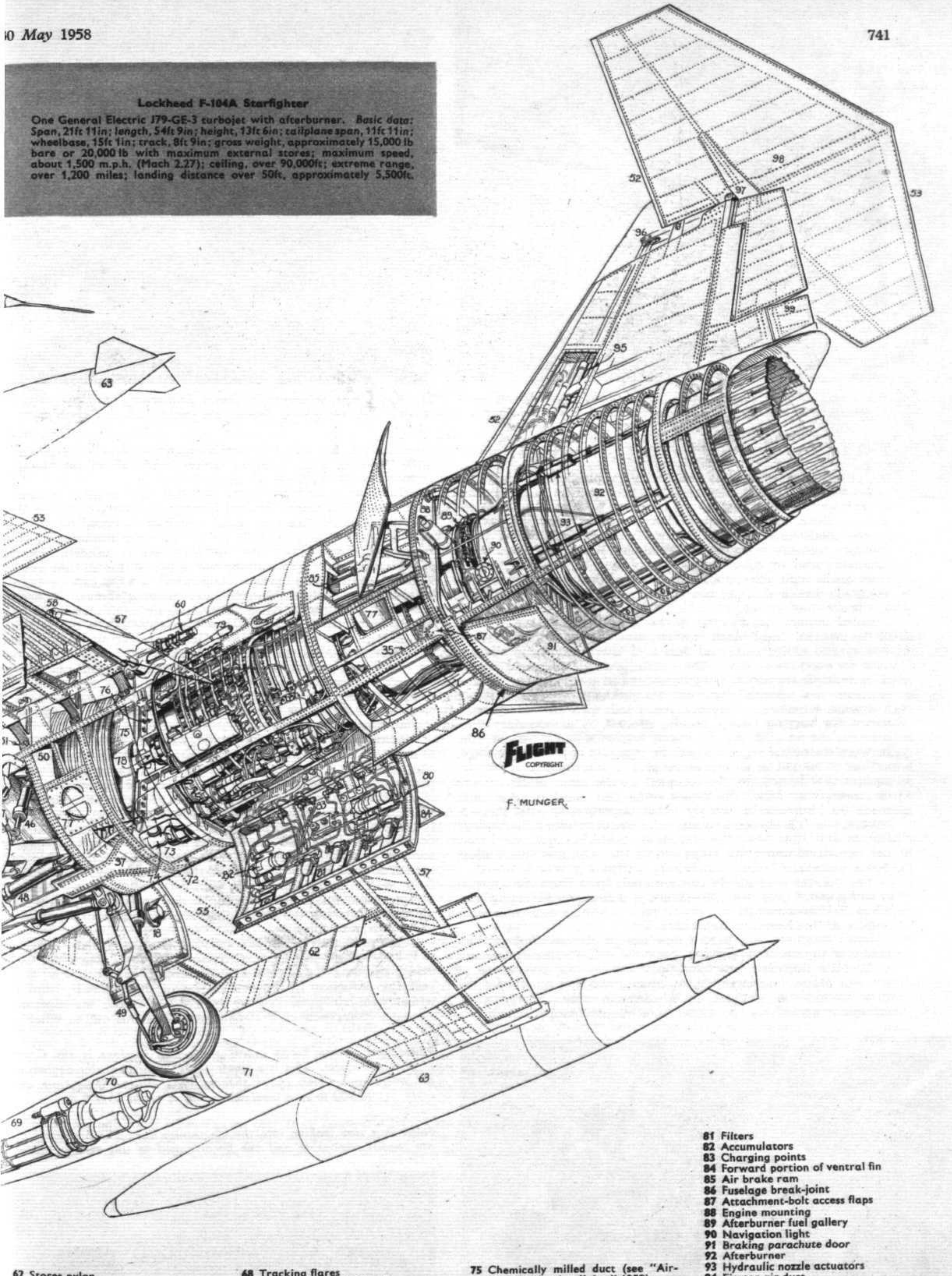


LOCKHEED F-104A STARFIGHTER . . .

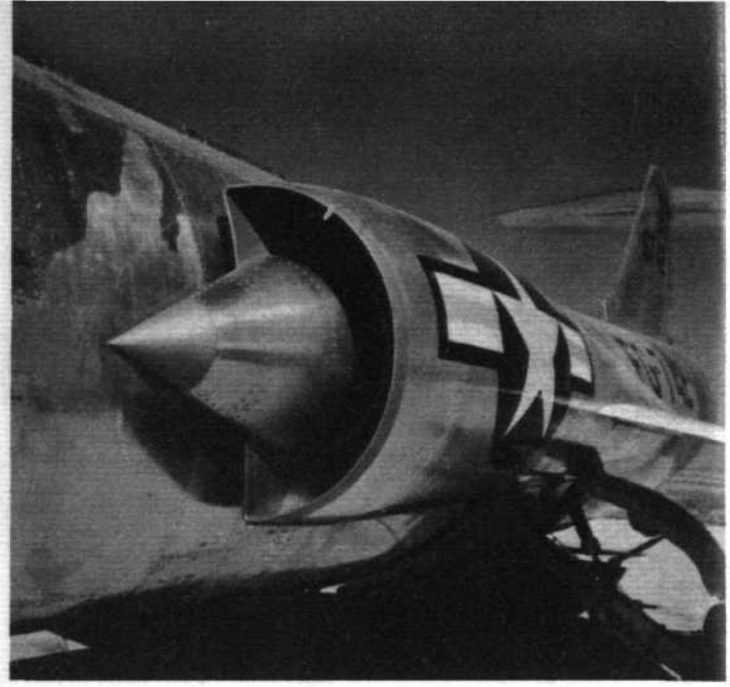
1 Erosion-resistant dielectric nose, rail-mounted for access
2 Nose mounting runners
3 Packaged ASC-14 fire-control unit
4 Radar cooling air supply
5 Cooling air outlet
6 Battle camera
7 Radar gunsight
8 One-piece casting below windscreen
9 Retracting shroud
10 Radar scope
11 Angle of attack vane
12 Rear-view mirror
13 Downward-ejecting seat
14 Servicing and escape hatch
15 Radar aerial
16 Steerable nose undercarriage
17 Mechanical door linkage
18 Taxying lamps
19 Air exit louvres
20 Gun blast tube
21 Six-barrel T.171-E3 gun (20 mm)
22 Ammunition feed chute
23 Ammunition compartment
24 Ammunition tank
25 Case ejection chute
26 Gun drive motor
27 Recoil shock mountings
28 Floor to electronics and ammunition compartments
29 Supply and circuit-breaker box
30 Common shock-mounted electronics racking
31 "Jeep-can" electronics, cooled through rack supply
32 Flush aerial
33 Access to tank booster pump
34 Ram-driven emergency hydraulic pump and alternator
35 Bottom longerons
36 Top longerons
37 Central keel member
38 Stressed access panels along decking
39 Double-shock half centre-body
40 Boundary-layer bleed on 39
41 Space for boundary layer inboard of intake
42 Precision-cast intake lip
43 Drape-type fuel cell
44 Stressed floor to aft-fuselage tank bay
45 Pre-closing main-undercarriage doors
46 Liquid Spring unit
47 Door linkage
48 Main retraction jacks
49 Wheel-pivoting linkage
50 Wing carry-through frames
51 Wing pick-up points
52 Machined leading edge (R=0.016in)
53 Machined trailing edge
54 Wing root forged brackets
55 Continuous machined skin, root to tip
56 Hinged leading edge
57 Plain flap with blowing
58 Bleed air duct for flap-blowing
59 Leading-edge actuator
60 Flap actuator
61 Grouped aileron actuators (10)

Lockheed F-104A Starfighter

One General Electric J79-GE-3 turbojet with afterburner. *Basic data: Span, 21ft 11in; length, 54ft 9in; height, 13ft 6in; tailplane span, 11ft 11in;* wheelbase, 15ft 1in; track, 8ft 9in; gross weight, approximately 15,000 lb bare or 20,000 lb with maximum external stores; maximum speed, about 1,500 m.p.h. (Mach 2.27); ceiling, over 90,000ft; extreme range, over 1,200 miles; landing distance over 50ft, approximately 5,500ft.



62 Stores pylon
63 Tip tank (200 U.S. gal)
64 GAR-8 (Sidewinder) air-to-air missile
65 Infra-red seeker head
66 Control servo section
67 Norris-Thermador or Hunter Douglas motor tube
68 Tracking flares
69 Pod containing T.171-E3 gun
70 Linkless ammunition feed
71 Tank holding 750 rounds
72 Generator access panel
73 Generators (Red Bank division of Bendix)
74 Generator cooling-air feed
75 Chemically milled duct (see "Aircraft Production," April 1958)
76 Inner wall of starboard duct
77 Low-speed auxiliary intake doors
78 Hamilton Standard pneumatic starter (60 h.p.)
79 Variable-stator actuator
80 Hydraulic group on engine-bay door
81 Filters
82 Accumulators
83 Charging points
84 Forward portion of ventral fin
85 Air brake ram
86 Fuselage break-joint
87 Attachment-bolt access flaps
88 Engine mounting
89 Afterburner fuel gallery
90 Navigation light
91 Braking parachute door
92 Afterburner
93 Hydraulic nozzle actuators
94 Ejector air duct
95 Tailplane actuator group
96 Tailplane horn
97 Tailplane hinge
98 Single skin, tip to tip
99 Autostabilizer tab
100 Air-conditioning bay



The very neat main undercarriage (left) utilizes Liquid Spring shock struts of the type pioneered by Dowty Equipment, Ltd.; the units are produced by the Cleveland Pneumatic Tool Co. On the right is a close-up of the port intake, showing the centre body and bleed ducts.

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the 104 is of necessity associated with a sophisticated intake and exhaust system which enable its full potentialities to be realized at such speeds. The intakes, one of which is depicted in a photograph (above, right) comprise lateral scoops provided with a central shock-forming ramp and two boundary-layer bleed ducts. Pressure recovery is claimed to be almost equivalent to the ideal attainable with an infinity of weak shocks. The ducts are formed from thick light-alloy slabs which are chemically milled to an integrally stiffened form and then stress-relieved by stretching to the required profile.

Equal importance attaches to the propelling nozzle. In view of the fact that flight Mach number, mass flow, ambient pressure, density and temperature and degree of afterburning can all vary over an exceptional range, the nozzle is of an advanced design with multiple segments giving considerable area variation. These segments are operated by four Aeroproducts high-temperature hydraulic actuators. They are associated with an aerodynamic means for varying nozzle profile, effected by a secondary flow between the jet-pipe and the nozzle segments and a further flow between the nozzle segments and the structure of the rear fuselage.

Fuel is housed in almost every part of the fuselage aft of the cockpit that is not already occupied by the main undercarriage or powerplant. Much the largest single cell is a drape-type tank made by Firestone in two-ply nylon impregnated with Buna-N rubber, which is shaped to occupy the spaces between the fuselage frames and thus have the maximum possible capacity. Tanks can be carried under the wings and on the wing tips, much effort being necessary before satisfactory jettisoning was achieved.

The cockpit is relatively conventional, apart from the unusual —and possibly controversial—choice of a downward-ejecting seat. Most F-104s currently in service have a simple seat somewhat similar to those used in B-47s and 52s.

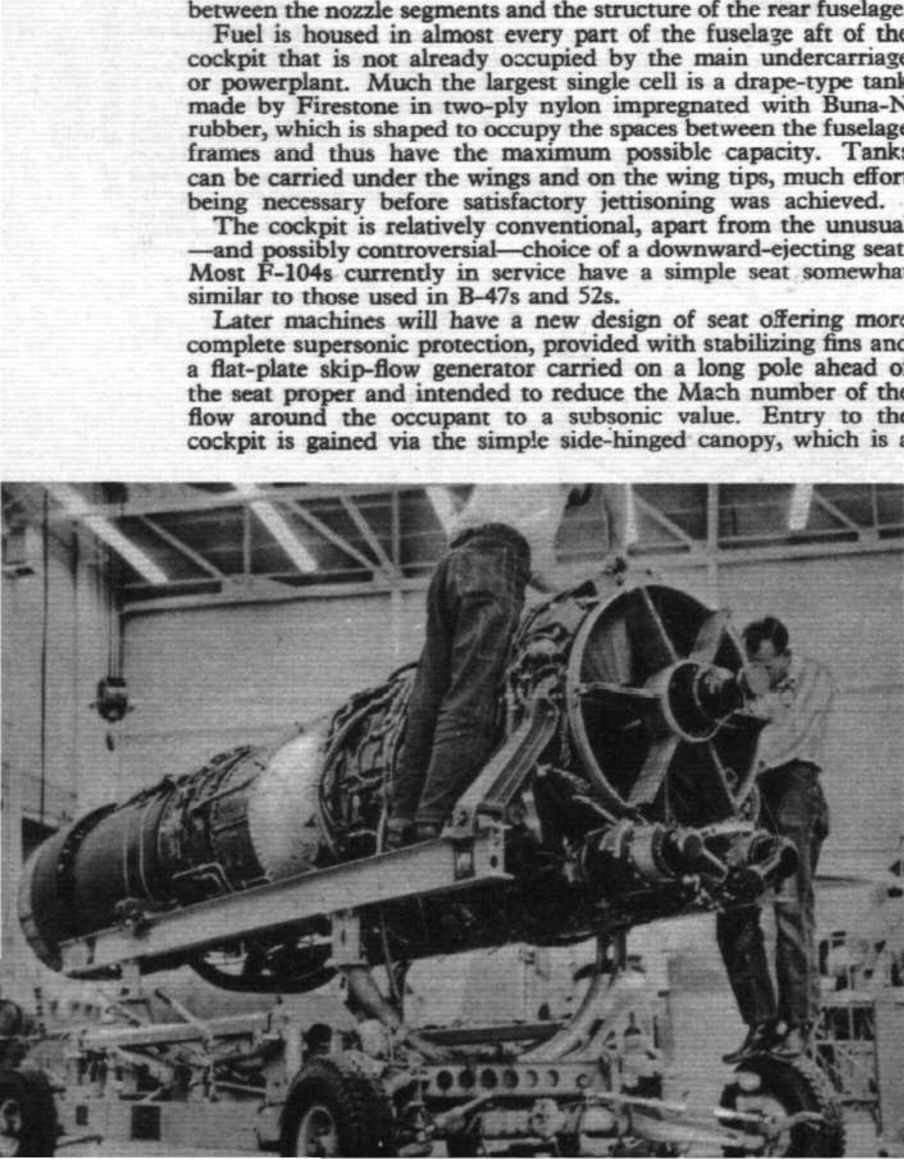
Later machines will have a new design of seat offering more complete supersonic protection, provided with stabilizing fins and a flat-plate skip-flow generator carried on a long pole ahead of the seat proper and intended to reduce the Mach number of the flow around the occupant to a subsonic value. Entry to the cockpit is gained via the simple side-hinged canopy, which is a Swedlow product with high optical qualities, sealed by a Goodrich inflatable strip with a ribbed striker bead. Hamilton Standard supply the air-conditioning unit.

All F-104s so far built for the U.S.A.F. have built-in armament in the form of a single General Electric T.171 six-barrel revolver gun (the Vulcan "Gatling" gun), which is mounted on the port side of the forward fuselage. It is fed with ammunition from tanks behind the pilot's seat and is driven by either an electric or hydraulic motor. Maximum rate of fire of this 20 mm weapon is 6,000 rounds per minute. Additional T.171s can be carried in underwing pods, as the cut-away drawing shows. Secondary armament comprises GAR-8 Sidewinder air-to-air missiles, carried on the wing tips. The F-104 is also reported to be currently engaged in tests with the MB-1 Genie nuclear air-to-air rocket.

In offensive rôles the aircraft can carry up to five stores, two on the wing tips, two on the underwing pylons and one on the centreline ahead of the main-wheel doors. At least one, and probably three, of these locations can accept tactical nuclear weapons, although no 104 has yet been reported to be equipped for automatic toss-bombing.

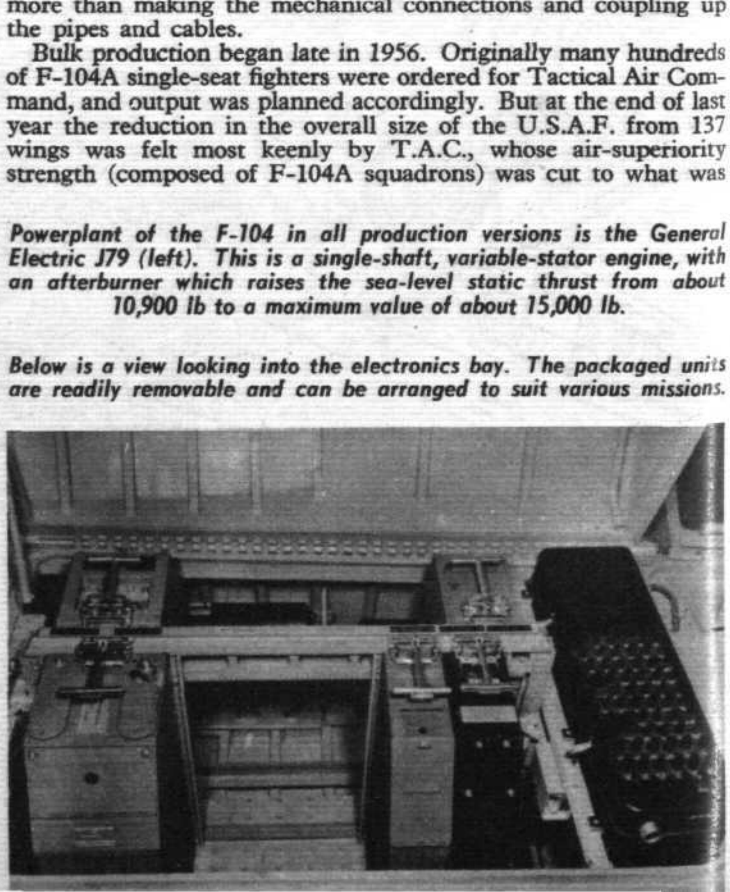
Assembly of the production 104 was initially assigned solely to the main plant of the Lockheed California Division at Burbank; and, following a practice common among major U.S.A.F. aircraft programmes, manufacture of 40 per cent of the airframe was allocated to a number of sub-contractors. Chief of these are Beech (Wichita), rear fuselage; Goodyear (Litchfield Park), nose; Rheem (Downey), complete tail unit; and Temco (Dallas), port and starboard wings. Lockheed manufacture the mid and forward fuselage sections at both Burbank and their new facility at Palmdale, and the latter plant is now handling all the assembly and flight testing. It is worth noting that each portion is delivered to Palmdale complete and functionally tested, so that assembly involves little more than making the mechanical connections and coupling up the pipes and cables.

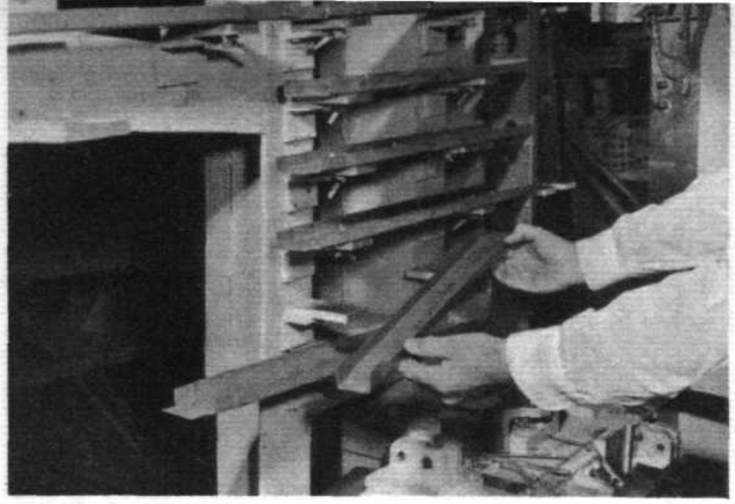
Bulk production began late in 1956. Originally many hundreds of F-104A single-seat fighters were ordered for Tactical Air Command, and output was planned accordingly. But at the end of last year the reduction in the overall size of the U.S.A.F. from 137 wings was felt most keenly by T.A.C., whose air-superiority strength (composed of F-104A squadrons) was cut to what was



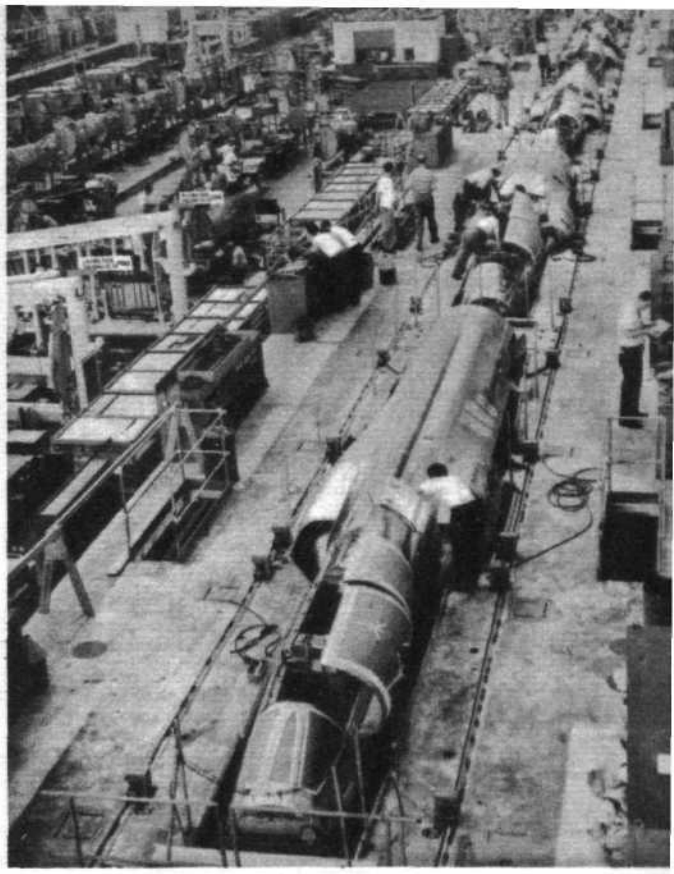
Powerplant of the F-104 in all production versions is the General Electric J79 (left). This is a single-shaft, variable-stator engine, with an afterburner which raises the sea-level static thrust from about 10,900 lb to a maximum value of about 15,000 lb.

Below is a view looking into the electronics bay. The packaged units are readily removable and can be arranged to suit various missions.





The photograph on the left gives an indication of the diminutive size of the wing. Compression-formed 75ST spars are being set up in the main wing jig, each spar covering half the semi-span.



On the right is the fuselage line in the main plant at Burbank. From here the major sections of each machine are trucked to Palmdale for final assembly. Output is working at less than capacity.

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cryptically described as "not very many wings." As a result the total U.S.A.F. order was pruned to the relatively trivial total of 294 aircraft, and the majority of these have now been built. The result is that big surplus productive capacity exists, and Lockheed are in the fortunate position of being able to offer the aircraft at a very competitive price, all tooling costs having been written off on the existing orders. The mean price per aircraft paid by the U.S.A.F. is reported to be $1,112,000; but the 104 is stated to be available, almost "off the shelf," at $678,000. This is the figure alleged to have been quoted to the West German government, and it is one which no other manufacturer of a similar product could hope to match.

In the development of the F-104 Lockheed, G.E. and the U.S.A.F. had to face and overcome many very severe problems. Their solution took longer than had been hoped, and squadrons of 104As were not formed until this year. The first deliveries were made to the 83rd Fighter/Intercepter Wing, based at Hamilton A.F.B., near San Francisco, late in February. It is appropriate to list some of the major development programmes which were completed before this release to the user could take place.

Lockheed's original contract, for two XF-104s, was placed in March 1953. The first of these flew on February 7, 1954. From the XF-104 was evolved the F-104A, the chief differences being an increase in fuselage length to accommodate more fuel, a change in engine from the Wright J65 (Sapphire) to the J79, and minor alterations including a redesigned rear fuselage, a nose undercarriage arranged to retract forwards (XF-104 hinged to the rear) and supersonic intakes. The first F-104A flew on February 17, 1956.

One of the most fundamental and protracted programmes was that which cured the super-stalled pitch-up. This cure, already described, was completed by April last year. Extensive flying at the boundaries of the 104's performance showed that no part of the load-carrying structure could reach a temperature above 200 deg F solely as a result of kinetic heating, and that the 0.016in-radius leading edges of the wing and tail did not erode drastically even in heavy rain or hail. For a considerable period the tip tanks tended to fly in and hit the fuselage after jettisoning, and much work was also necessary to prove the aircraft for gun-firing, GAR-8 firing and stores-dropping. Last winter a machine flying from Eglin A.F.B. showed its range by flying to a target more than 600 miles distant, dropping a simulated nuclear store at maximum speed, flying back and landing with more than 500 lb of fuel remaining.

Squadron pilots seem to have found little difficulty in converting to the type. No simulator is needed, neither does any F-104 squadron yet have the services of a two-seat F-104B. The latter, which is in full production alongside the A model, is fully equipped for operational missions and differs chiefly from the single-seater in having a cockpit which extends back into bays formerly occupied by fuel. Like all recent fighters the 104 is intended for all-weather operation. The ASC-14 radar fire-control system, produced jointly by G.E. (LMEED), Aerojet-General and R.C.A., is packaged into neat sectors which plug-in around the circular space, some 30in in diameter, in the extreme nose of the aircraft. Pilots have found that, in practice, intensive lock-on training is required if targets are to be held, but their task is eased by the fact that the 104 is an outstandingly good gun-platform.

Most of the really dangerous development flying, in which several aircraft were lost, stemmed from difficulties with the powerplant. This in no way reflects upon G.E., since the J79 was even less of a known quantity than the aircraft when F-104A flying started. It is, however, singularly unfortunate that a major engine snag should have been suffered just after the release of the aircraft to the Air Force. Early in April the U.S.A.F. grounded all 104s fitted with the J79-GE-3A, except for machines engaged in current engine development. Notwithstanding the fact that the J79 as a type had then run some 44,000 hr, it was found that "pure engine trouble" (we quote the U.S.A.F.) was the cause of a series of accidents, in one of which the commander of the 83rd F/I squadron was killed. Roughness, backfiring and flameout in the afterburner was vouchsafed as a particular headache.

Nevertheless, it is fair to regard the basic F-104A as a fully proven weapon system. It is now in service with a number of F/I squadrons, together with all its specially designed support equipment (which, for the benefit of British readers, is regarded as the non-flying portion of the weapon system). Every conceivable type of operational problem has been evaluated and, where possible, simulated; and the proving has extended to such simple, but cumulatively important, items as the number of steps the ground-crew chief needs while walking from the starboard intake to remove the cover over the pitot tube in the nose.

Future developments concern such programmes as zero-length launching with rocket-boost, the dropping of real nuclear stores by various delivery methods, the firing of MB-1s, and the introduction of F-104s fitted with the more powerful GE-7 version of the J79 which has a turbine of 2in greater diameter. There may yet be a pilotless version—a sort of thousand-mile Bomarc—but no requirement for such a device has yet been stated by the U.S.A.F.

The photograph below was taken on May 16 at Edwards A.F.B., when Capt. Walter W. Irwin took off on the flight which promises to bring to him the world record for absolute speed. His average speed for the two runs was 1,404.19 m.p.h. The runs were made at 40,000ft in an o.a.t. of −60 deg. C. Even this temperature was too warm, he said, and on other occasions he has exceeded 1,500 m.p.h.