OSPREY COMBAT AIRCRAFT • 101

F-104 STARFIGHTER UNITS IN COMBAT

Peter E Davies

SERIES EDITOR TONY HOLMES

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CONTENTS

CHAPTER ONE

FASTER AND HIGHER 6

CHAPTER TWO

COLD WAR CLASHES 21

CHAPTER THREE

VIETNAM 39

CHAPTER FOUR

ASIA GOES DOUBLE-SONIC 73

CHAPTER FIVE

TAIWAN TENSIONS 88

APPENDICES 93

COLOUR PLATES COMMENTARY 93

INDEX 96

FASTER AND HIGHER

In 2013 the F-104 Starfighter was still contributing to technological innovation. An early F-104A-10-LO (56-0763, once a chase aircraft for the SR-71A, XB-70 Valkyrie and North American X-15 rocket-powered research aircraft) christened the North American Eagle, fitted with a modified J79 engine, custom-built suspension and solid aluminium wheels, was being prepared for an attempt to break the 763-mph speed record on land.

Meanwhile, at NASA's Kennedy Space Center, Rick Svetkoff's Starfighters Aerospace operation uses his privately-owned fleet of nine F-104s for a variety of research and development programmes in support of the US government, academic institutions and commercial space ventures. Like NASA's now-retired F-104Ns, used for many years to train astronauts, Rick's F-104s are uniquely suited to this task. So much so that Starfighters Aerospace has the only Federal Aviation Administration-certified astronaut training programme in North America. In Svetkoff's words, 'We can go from ground to 23,000 ft as fast as some of the rockets launched here. High altitude and high speed is the key'.

These thoughts were also foremost in the mind of Clarence 'Kelly' Johnson some 61 years previously when he began to design the F-104 after USAF fighter pilots in Korea discovered that they needed much better performance for consistent air superiority over communist MiG-15s. The 1950s engendered unprecedentedly rapid development and change, both in aviation technology and defence requirements. The unexpected appearance of Soviet MiG-15 fighters in Korea in November 1950, when the Cold War turned hot, had kick-started a surge of fighter development to restore American aerial superiority. Aircraft designers had to devise complex solutions to unforeseen military situations in record time, requiring enormous expenditure and designers with vision, daring and talent approaching genius level.

Clarence 'Kelly' Johnson at the Lockheed Aircraft Company was one of a number of American designers with all these qualities. He had created the P-38 Lightning long-range interceptor, an innovative twin-boomed aircraft with a distinguished World War 2 record. Experience with compressibility early in the P-38's life showed Johnson that totally new concepts using jet power would be needed for significant increases in speed. Merely doubling the Lightning's power had increased top speed by only 17 mph. Johnson began jet fighter studies in 1939, and by 1942 he had a firm proposal, the L-133-02-01 with an advanced canard planform and two L-1000 jet engines designed by Lockheed's Nate Price. However, the USAAF considered it too challenging a project for them to sponsor.

In 1942 the Bell Aircraft Corporation produced America's first jet fighter, the P-59 Airacomet, but its low-powered General Electric J31-GE-5 engines in a high-drag airframe severely compromised its performance. The unexpected appearance of the Messerschmitt Me 262 jet fighter over Germany changed USAAF perceptions overnight, and a request was issued for an equivalent jet fighter to be delivered within 180 days from 3 June 1943. Although the Lockheed factory was already producing 28 warplanes daily, Johnson managed to assemble a team of designers and they delivered his XP-80 prototype 37 days early. It was the first US production jet fighter, and the first to exceed 500 mph.

Although the USAF achieved a favourable kill-to-loss ratio against communist MiG-15s during the Korean War, F-80 and F-86 pilots generally requested more speed and faster rates of climb to reach the MiGs' combat ceiling when interviewed by Johnson's Lockheed team during a 21-base visit to South Korea to study operational use of USAF fighters. They also requested greater simplicity in operating their fighters' cockpits.

At a time when the USAF was demanding heavier and more complex fighters, Johnson (like his contemporary, designer Ed Heinemann with his A-4 Skyhawk) aimed for light weight, small size and simplicity. The result was a fighter with roughly three times the performance of an F-80. While designers in other countries were conceiving supersonic point-defence interceptors like the MiG-21 and English Electric Lightning, Johnson's new aircraft was intended as a clear air superiority fighter.

Johnson's team conceived the Model 83 (CL-246) in 1952 and showed it to USAF procurement decision makers Gen Don Putt and Col Bruce Holloway, who rapidly concocted a USAF request for the fighter as the XF-104, even though no operational requirement existed at the time. The Model 83 embodied design features that were partly conventional but, in many cases, were revolutionary approaches to achieving the specialised goals that Johnson sought to achieve for America's first Mach 2 fighter, including ease of manufacturing and operation.

Most obvious among the innovations were the unprecedentedly thin, strong tapered wings, extending only 7.5 ft each side of the 54.75 ft (F-104A) fuselage and prompting the question, 'Where are the wings?' from test pilot Tony LeVier, who was one of the first people to see the highly-classified prototype. He was also the pilot for the XF-104's first flight on 4 March 1954. The overall span was a mere 21 ft 9 in, 5 ft 3 in less than the tiny 1930s Boeing P-26 'Peashooter'. One resultant advantage was a rate of roll exceeded only by the small-winged Northrop F-5/T-38.

First flights at Lockheed were usually timed to coincide with Kelly Johnson's birthday. The XF-104 missed it by one day after a year in the building process. Its temporary J65 engine installation limited maximum speed to Mach 1.49 in level flight. Together with the wing anhedral, the ventral fin added to production F-104s decreased the positive dihedral effect of the T-tail. It also significantly improved high-Mach directional stability and provided a convenient location for the radio antenna. The combination of ventral fin, anhedral and unswept wings eliminated 'Dutch roll' tendencies and facilitated turns above 350 knots. The first XF-104-LO is seen here with an F-100A, YF-102A and F-101A – the first four Century Series fighters (*AFFTC/USSAF*)

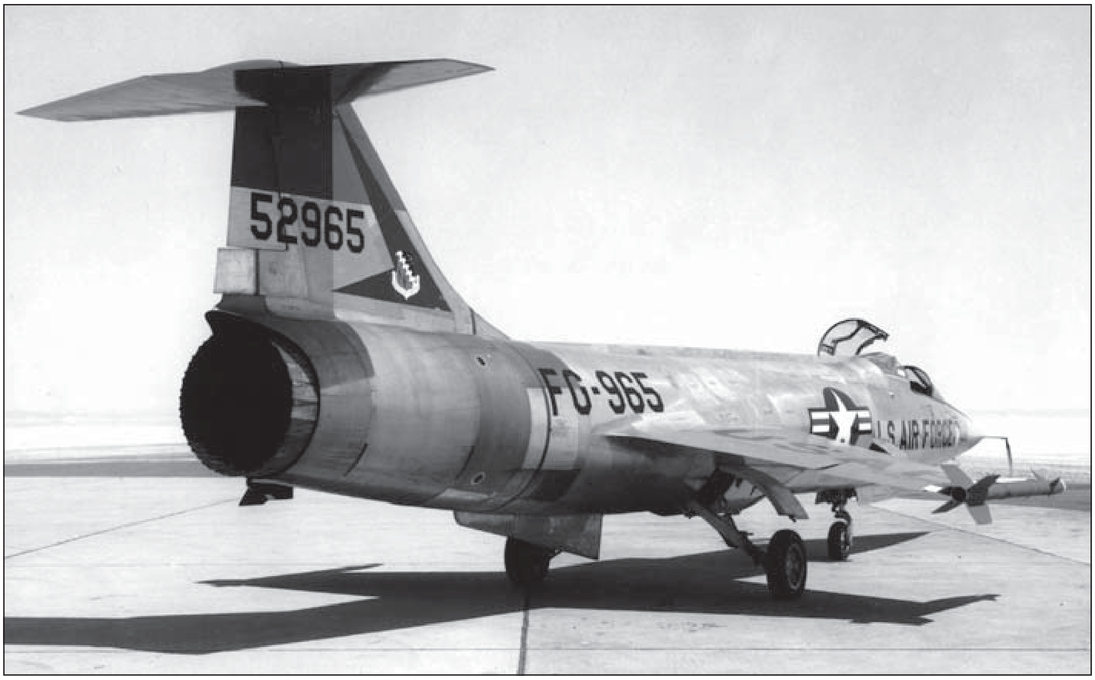
With a thickness/chord ratio of only 3.36 per cent and a maximum depth of 4.2 in at the root and 1.96 in at the tip, there was no space within the wing for fuel or landing gear, all of which had to be contained in the sleek, tubular fuselage. The landing gear had back-up manual retraction and anti-skid brakes. Braking was assisted by an 18-ft ring-slot parachute. Later, an arresting hook was added that partially extended automatically when the drag 'chute was deployed. Additional fuel could be carried in 170-gallon wingtip tanks or in two underwing 195-gallon tanks. The heat-treated steel ailerons were powered by ten cylindrical 'piccolo' hydraulic boosters, incorporated in a metal block within a wing depth of 1.1 in. None of the control systems required external fairings. The biconvex aerofoil had a butter-knife sharp leading edge, with a 0.016 in radius, that was covered with detachable wing-guards to avoid the very real danger of injury to groundcrew.

Most of the early Starfighter testing was conducted by Lockheed's Chief Test Pilot, Tony LeVier (left) and Chief Engineering Test Pilot Herman 'Fish' Salmon (*Lockheed*)

There was no 'carry through' structure joining the wings through the fuselage. The ribless wing structures were simply attached to five heavy-duty forgings that were tied into the tapered wing skins. To prevent twisting when flying controls were operated at high speeds, and to also provide adequate strength and rigidity, the wing skins were attached to a core structure manufactured from a single slab of aluminium. A similar but less rigid wing planform was used by the Douglas X-3 Stiletto experimental test aircraft that flew in 1952, although the X-3 lacked a suitably powerful engine to explore the high-speed potential of the wing.

The designers trialled various configurations before settling on a high 'T-tail' empennage arrangement. Extensive wind tunnel testing and free-flight investigation using 5-in rockets led to the conclusion that a T-tail minimised drag and provided the best stability and control across the broad speed and altitude envelope of the F-104. The placement of the horizontal stabiliser decreased interference drag and minimised trim change in the transonic and supersonic regimes. While most aircraft become nose-heavy as they transition to supersonic speed, the F-104 would experience only negligible trim changes, markedly improving manoeuvrability. The horizontal stabiliser acted as an end plate for the vertical tail, increasing the effectiveness of the relatively small tail while providing a positive dihedral effect. In fact the tail's dihedral effect proved too powerful, and after testing with Calspan's NT-33A variable stability aircraft, a ten-degree anhedral was applied to the Starfighter's wings to improve handling characteristics.

The Starfighter's handling was not without vice, however. One of the problems inherent in the overall design choices was that of pitch-up, as Lockheed test pilot G L 'Snake' Reaves explained;



YF-104A-1-LO 55-2965 with the USAF Flight Test Centre for AIM-9B missile tests. A straight wing provided more lift versus drag per square foot than a delta or swept wing, and appeared to give the lowest drag at Mach 2 and the lightest weight. A version swept at 26 degrees on its leading edge was decided upon after testing numerous configurations using 5-in high-velocity rockets with test wings bolted to them. For Johnson, these tests were crucial in selecting a suitable small wing that would avoid problems of flutter. The latter could not be effectively explored with wind-tunnel models without risking damage to the tunnel itself, so rocket tests were the answer. It was a pioneering wing format that was later seen, in modified form, in the Northrop F-5 and General Dynamics F-16 fighters (*USAF*)

'A fully developed pitch-up is best described as a non-repeatable stall manoeuvre that is inherent in aircraft with high tails. In the F-104 the choice of a thin, supersonic wing improved its resistance to stalling compared with a conventional subsonic wing. The supersonic wing continues to provide increasing lift at angles of attack [AoA] that would result in a stall for the subsonic wing. Total lift from the F-104 configuration does not decrease as the aircraft assumes extremely high AoA.'

At high AoA a large turbulent wake of air from the wing and fuselage covered the F-104's high horizontal stabiliser, causing the aircraft to lose its nose-down tendencies and become unstable in the pitch axis. Reaves and his test-pilot colleagues evolved techniques for recovery should this condition be allowed to occur, or even develop into a flat spin. Another test pilot, James 'Jake' Holliman, considered that the F-104 was 'beyond doubt the most pleasant handling piece of flying machinery that has taken the air since its grandfather, the F-80, launched the jet age [in the USA] back in 1944'. He also drew attention to the pitch-up issue, and the fact that 'the F-104 configuration continues to produce lift at AoA that would result in a fully-developed stall of a more conventional aircraft'.

To warn the pilot of a dangerously high AoA, an Automatic Pitch Control (APC) system was installed. When its indicator showed '5' on a dial in the cockpit the system would be activated, causing an automatic 'stick shaker' to vibrate the control column and emit a sinister 'machine gun' rattle. If the pilot still failed to react this was followed by an auto pitch control 'stick kicker' – a hydraulic ram that thrust the control column forwards, pushing the nose down. The system was installed at the USAF's insistence, partly due to serious pitch-up problems with the T-tailed McDonnell F-101 Voodoo and because it felt that all aircraft, including trainers, should have a 'shaker' warning system. Kelly Johnson preferred an aural warning system (similar to the one later included in the F-4 Phantom II), as the F-104 was actually quite difficult to get into a dangerous pitch-up situation if the pilot avoided high pitch rates.

At subsonic speeds the wing itself provided enough stall warning even for novice pilots. However, at supersonic speeds there was no warning of an impending stall via the usual aerodynamic signals of heavy buffet and a tendency to roll, so a warning system was indeed necessary. The F-104 Pilot's Manual prohibited pitch-up, not because it was inherently dangerous (the F-104 refused to spin in all but the most extreme conditions), but because the aircraft's gyrations after a stall could damage the airframe. When it pitched down the aircraft could swing violently sideways into the airflow and the tail would then flip it from a right to a left roll. This sudden reversal caused several cases of twisted fuselages during F-104 flight tests to explore spin characteristics.

Early pilots emphasised that despite its unusual configuration the Starfighter essentially behaved like a conventional aircraft, but it required careful, smooth handling and would not tolerate inattentive or 'ham-fisted' piloting. In service use the findings of these early tests continued to provide an effective guide to safe flying for F-104 pilots, but failure to observe them undoubtedly became a major cause of the aircraft's unenviable safety record with several foreign air forces. As 'Jake' Holliman commented, 'Treat her rough and you may have a miserable time. Be smooth and gentle and you're in for a very pleasant experience. "Pitch-up" doesn't mean "give-up" if you have sufficient altitude to wait it out'.

MACH 2 POWER

Basic to all the F-104's qualities was the General Electric J79 variable-stator, axial-flow engine. When the first XF-104 (53-7786) made its maiden flight, it and the second prototype had to use a Buick-manufactured Wright J65-B-3 – a licence-built British Armstrong Siddeley Sapphire. This engine had an afterburner installed later in the programme as the J65-W-6, but the first XF-104 had already gone supersonic in a dive with the non-afterburning J65-B-3. Development of the revolutionary X-24A or J79 (the first engine capable of Mach 2 flight) ran contemporaneously with that of the F-104 as General Electric engineers led by Neil Burgess and Gerhard Neumann worked on the problems of achieving rapid acceleration without compressor stalling, low fuel consumption and reliable performance throughout a wide speed range.

The engine commenced test runs in June 1954 and a J79-GE-3 was installed in the first of 15 YF-104As (59-2955), which undertook its maiden flight on 17 February 1956. YF-104As had substantial structural changes, including a 5 ft 9 in fuselage extension from the XF-104's 49 ft 2 in to accommodate more fuel, a forward-retracting nose undercarriage and a revised rear fuselage with a ventral fin to aid stability.

Major revisions to the air inlets to cope with the extra power of the J79 introduced half-cone centre-bodies to generate multiple shockwaves at supersonic speeds. Incoming air had to be slowed to below Mach 1 to avoid choking the engine, and some of it by-passed the J79 and was used to cool the afterburner. The intakes were optimised for Mach 1.7 (or Mach 2 in versions with the more powerful J79-GE-19 engine) and the aircraft generated its maximum excess thrust at that speed. The J79 maintained approximately the same speed once it was wound up. Prototype J79-GE-3s had an un-modulated afterburner system that essentially gave the pilot the choice of either Mach 1.1 in full military power or Mach 2.2 with afterburner. All production aircraft had modulated afterburners, however.

On 27 April 1956 the first YF-104A reached Mach 2.2 – effectively the maximum speed for the aircraft before air intake temperature limits were exceeded. Normally, F-104As could just about reach Mach 2, and Mach 2.2 could only be attained in cold conditions. Vital to the high-speed performance of the J79-GE-3 was the 'T2 reset', as Maj Gen Stan Hood (a pilot with fighter experience stretching from the F-80 to the F-16) explained;

'Air inlet air temperature determined whether T2 reset would cut in [at 100 degrees Centigrade]. It was like a second afterburner, and the engine would suddenly go to 103 per cent power. In a matter of a few seconds you were up to Mach 2 and beyond.'

High landing speed was another corollary of the small wing area, and this was ameliorated to some extent by the use of Attinello-type blown flaps from the YF-104A onwards. Bleed air from the engine's 17th compressor stage was blown across the flaps to provide boundary layer control (BLC) at increasing pressure through 55 slots in titanium ducts when flaps were lowered between 15 and 45 degrees, reducing landing speed by more than 30 knots. Pilots also had to be ready to pull the flaps back to 15 degrees if there was a malfunction in the flap-blowing to one wing, causing an immediate roll at a dangerous moment in the landing approach. Supplying sufficient airflow to the flap-blowing system required high engine power while landing. A dead-stick landing without flap-blowing was possible, but with a touch-down speed of 240 knots very accurate judgement was crucial.

All F-104 versions had two flap settings. For take off, both leading and trailing edge flaps dropped to 15 degrees without BLC. For landing, the leading edge flaps dropped to 30 degrees and the trailing edge flaps to 45 degrees, with BLC applied progressively as the flaps extended past 15 degrees in the 'land' position. Pilots could also select the 'take off' (15 degrees) setting as 'manoeuvre flaps' at higher speeds to improve turn rate by about 1g. Pilots often used this facility, but with discretion to prevent undue loss of speed in combat with better-turning fighters.

The choice of a high-T tailplane out of 290 possible airframe configurations also raised the concern that no existing cartridge-driven ejection seat would be powerful enough to avoid impacting the tail at high speed up to Mach 2 without using a cartridge that would injure a pilot's back due to its extreme acceleration. Having rejected the idea of a self-contained escape capsule, the designers, therefore, and with some reservations, included a seat that fired downwards through a hatch (which formed the cockpit floor) once the cockpit had been de-pressurised, the control column retracted and the pilot's legs pulled back against the seat.

The first seats for the prototypes and the first 26 F-104As were Stanley B downward-ejection models with an M3 catapult initiator. These were replaced by the Stanley C and later C-1 with cables attached to 'spurs' on the pilot's boots to pull his feet back safely against the seat front, while knee guards rotated downwards for further protection.

By 1960 all F-104A/Bs and subsequent models up to the two-seat F-104D were fitted with the Lockheed C-2 (licensed from Stanley) with an XM-10 two-tube rocket-catapult – one of the earliest rocket-powered seats. This was powerful enough to enable upward ejection without injurious acceleration rates, and many F-104 pilots preferred it to the Martin-Baker Mk GQ7(A) seat fitted in the F-104G and F-104S. The C-2 suited taller pilots, and its headrest allowed better rearward visibility, although the Martin-Baker seat had advantages at lower speeds and altitudes. The C-2 could be employed at ground level with 90 knots forward speed, using a zero-delay lanyard to cause immediate seat separation and parachute deployment. Canopy jettison was also activated by the seat ejection handle.

The original downward-firing Stanley B ejection seat, connected to an ejectable lower fuselage hatch, offered simplicity and light weight, but it presented problems at altitudes below 1500 ft, where the pilot was supposed to eject with the aircraft inverted – albeit with a greater risk of back injury due to negative-g. High-altitude ejections were, in any case, rare. Seen here with the second XF-104 (53-7787), the seat had an exit route that obviously left little room for error (*Lockheed*)

Ease of maintenance was a priority for the Starfighter's designers at a time when maintenance man-hours were constantly rising for a generation of increasingly complex aircraft. In due course this made the F-104A more attractive to users such as Pakistan and Taiwan, who were familiar with fairly basic jets like the F-86 Sabre.

Lockheed stated that the radar could be removed in ten minutes, the M61 gun could be stripped in 30 minutes via a single panel and the original downward-launching ejection seat could be removed through the lower fuselage hatch, allowing full cockpit access to a maintainer standing on the ground. Most of the engine accessories could be reached through a single access door so that servicing could be undertaken without removing the engine – a requirement on many other fighters at the time. An engine could be changed in an hour by four men after disconnecting the rear fuselage.

The electronics were ahead of their time in being mostly modular and contained in a series of similar 'Jeep cans' that fitted into a shock-mounted electronics rack in a large bay behind the cockpit. They could be replaced in minutes, even in the 'quick check' area while preparing to take off on an interception mission, from spares stocks in vans near the end of the runway. Throughout the Starfighter's career, maintenance man hours per flight hour for the F-104A/C never exceeded ten hours, and this only rose to 15-20 with the more complex F-104G. This was a major factor in its selection by so many foreign air forces.

The main undercarriage, a light-weight liquid spring design by Dowty in the UK and licence-manufactured by H M Loud/Cleveland Pneumatic, needed little maintenance. It had a manual 'gravity operated' back-up for extension. One inconvenience in early aircraft was the need to keep the nose-wheel steering button on the control column pressed in while taxiing. Hydraulics were powered by two separate systems backed up by a ram-air turbine (RAT) that extended from the forward fuselage near the starboard air intake. The cockpit's logical, practical design was widely praised at a time when many fighters had cluttered, inefficient 'office space'.