RAF F-4M Phantom shadowing a Soviet Air Force Tu-95 Bear. The outer panels of the anhedral tailplane have stainless steel skins. This and other Phantom variants have a fixed inverted slot on the tailplane to counter the large nose-down pitching moment created by the drooped ailerons, which were themselves introduced for extra lift. (MoD)

moves into a less severe downwash field, allowing it to make a growing contribution to stability and so offset the pitch-up tendency. It also provides a strong pitch-down moment at high AOA, thereby minimising pitch overshoots into region in which a general breakdown of aerodynamic characteristics might be encountered. In addition, the low-mounted tailplane avoids any dead air from stalled portions of the wing at high AOA. For all of these reasons an aircraft with a low tail can be expected to operate at higher angles of attack before becoming longitudinally unstable. It is not surprising therefore that the low tail is almost universally adopted nowadays for combat aircraft.

There are some apparently slight though very significant variations on the theme of low-mounted tailplanes, as shown by the following examples:

McDonnell Douglas F-4 In order to avoid the structural and weight problems of a high horizontal tail, as used on previous McDonnell designs such as the F3H and F-101, extensive wind tunnel testing and analytical work was carried out to arrive at the unique tail configuration of the Phantom. The tailplane is mounted just high enough to stay out of the direct path of the jet exhaust. The inner portion is however subjected to exceptionally high temperatures, and so is made largely from titanium. Anhedral of 23° lowers the outer portion to ensure adequate longitudinal stability through the designed AOA range, to provide adequate directional stability up to the maximum designed

Mach number, and to counter the rolling moment of the outer wing panels in yawed flight. The high degree of anhedral was made possible in part by the ground clearance afforded by the overhanging aft fuselage.

BAe Harrier Pitch-up at high Mach number due to shock-induced flow separation was one of the primary aerodynamic concerns in the design decisions in the late 1950s. The tailplane was set as low as was consistent with keeping it out of the jet exhaust with the vectoring nozzles turned aft. At low AOA the Hawker P.1127 suffered from low pitch stability because the tailplane's contribution was so small. This was caused by the tail's close proximity to the exhaust, so that the local AOA was more a function of jet velocity than aircraft AOA. The rate of change of downwash with AOA was dominated by jet entrainment resulting in a minimal contribution to stability. Moreover, the stringent weight controls on the V/STOL design kept the tail small, contributing further to the problem.

Severe pitch-up arose in high-AOA and high-speed (i.e. high-g) flight. Despite improvements in wing geometry and local fixes, pitch-up limited manoeuvrability at high Mach number. Anhedral on the tailplane was investigated without success. Then it was discovered that favourable sidewash flows existed just outboard of the tips of the tailplane. Indeed, the only useful flow at high AOA lay beyond the tips of the original tailplane. The tailplane was therefore increased in span and given anhedral to take advantage of this flow, as shown in Fig 182.

The P.1127 itself featured a 0·6m increase in span and 18° anhedral was applied to the outboard portion. On the Kestrel, a service version designed for trials with the Tripartite Evaluation Squadron (with British, US and German personnel), the tailplane was reduced in area and the anhedral reduced to 15°, though now it extended to the root so that the tailplane tips were in the same position as they had been on the modified P.1127. The Kestrel was however still only marginally stable statically at low AOA and moderate Mach numbers despite a major effort to improve the static margin. The stability deteriorated further when underwing fuel tanks were carried.

The Kestrel tailplane was subsequently given another 0.6m increase in span. This put the additional area in the best position to take advantage of the favourable flows outboard of the jet exhaust. The Kestrel (the Harrier has the same tail) thus ended up with a tailplane whose span was 60% of the wing span. This provided an adequate level of

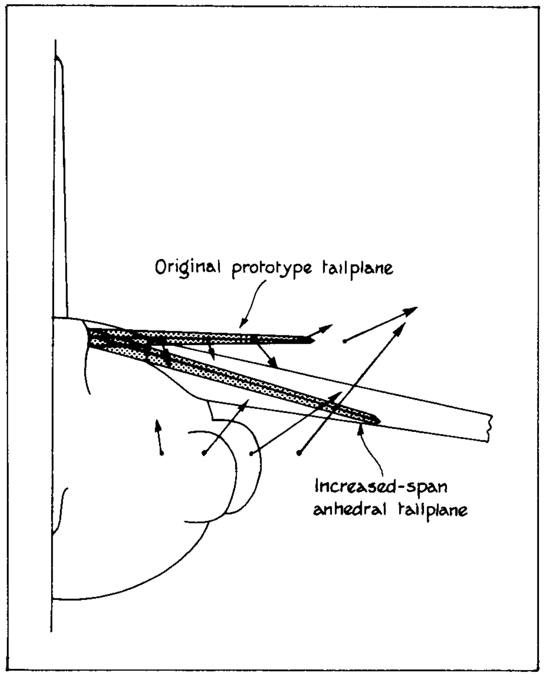

Fig 182 BAe Harrier tailplane down/sidewash patterns.[36]

stability but raised a structural problem encountered only on the ground. When the engine was running at high power with nozzles aft the tailplane began flapping, the motion being excited by the shearing at the edges of the jet exhausts. This was overcome by tying down both tailplane and aircraft during ground running. On Harrier ground runs the nozzles are deflected 10° down, which keeps the vibration and noise impingement on the tail to an acceptable level.

McDonnell Douglas F-18 Set at the mid-fuselage level, the tail could not have been lower because its sweepback would have caused tail scraping on take-off.

BAe Lightning, BAC TSR.2, MiG-25, F-14, F-15, Mirage F.1, Su-24, Tornado All of these aircraft were designed with high, shoulder-mounted wings and mid-fuselage-mounted tails. This combination keeps the tail outside the wing wake at low AOA and avoids flutter caused by aerodynamic interference between the two surfaces.

BAe Hawk (and other military trainer/strike aircraft) The low-wing layout typical of these types gives no opportunity to place the tail below the wing. The tail is accordingly mounted high on the fuselage at the base of the fin and, in the case of the Hawk, has 10° anhedral. This angle puts the tailplane tips outside the intense wing downwash at high AOA. The Hawk's wing, with only 26° of leading-edge sweep, is unlikely to suffer the rapid pitch-up typical of more highly swept designs. In addition, mounting the single-piece tail at the rear of the base of the fin makes good use of the volume there to house the tailplane actuators. A location on either side of the tailpipe would, by contrast, complicate the structure and could require external blisters.

Fore-and-aft position

The tailplane is generally placed as far aft as is practicable to maximise the tail moment arm. One restriction on this is engine noise-induced structural fatigue. Northrop has tackled this in the past by placing no structure aft of the exhaust nozzle exit plane. This means in practice that the tailplane trailing edge lies ahead of the steep part of the aft-fuselage boat-tail. This practice, as demonstrated by the F-5, was not as rigidly adhered to on the YF-17, but even this type contrasts markedly with the F-15, in which a good deal of structure overhangs the nozzle exit plane.

TAILPLANE SHAPE

In general a moderately swept, low-aspect-ratio, symmetric-section tailplane is used on high-speed aircraft, partly to give low zero-lift wave drag and partly to avoid the sudden stall associated with low sweep, high aspect ratios and thin symmetric sections. The actual planform and thickness/chord ratio tend to be determined by the need to incorporate a spigot, variations in hinge moment with Mach number, and aeroelastic considerations. Tailplane aspect ratio is invariably less than that of the parent wing.

Probably the most distinctive current tailplane is that of the F-15, which has a dogtooth or snagged leading edge. McDonnell Douglas discovered in wind-tunnel testing before the first aircraft flew that the proposed horizontal tail was more flutter-prone than early analytical studies had indicated. Reduction in aft-fuselage structural cross-sections for area-rule and base-drag reasons had resulted in a tail-support boom structure relatively short of bending and torsional stiffness. When this was combined with a simultaneous increase in size of the twin fins and deletion of the ventral strakes,

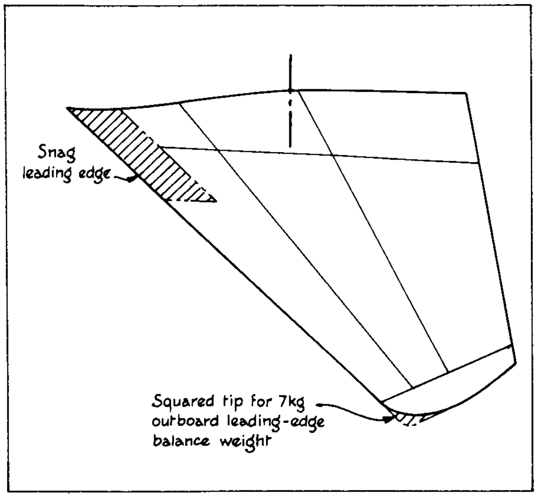

Fig 183 Alternative schemes for flutter avoidance on F-15 tailplane.[66]

both vertical and horizontal surfaces became flutter-critical. Wind-tunnel tests had shown that the flutter to be expected was of the explosive kind, giving little warning of its onset. Many models were destroyed in testing, in which tailplane tip deflections of a tip-chord length were reached within 3-5 oscillations. Applied to the full-scale aircraft, this corresponds to an interval of less than half a second between the first sign of flutter and structural failure. After a good deal of effort McDonnell Douglas found itself faced with the choice, shown in Fig 183, of either extending the tailplane tip and adding 7kg of leading-edge balance weight to increase the flutter speed by 11%, or "snagging" the leading edge of the stabilator to avoid the need for balance weights. Though both approaches offered an adequate flutter speed safety margin, the snag leading edge was lighter and had no negative effect on subsonic drag or stability/handling characteristics. Moreover, had a further increase in flutter speed proved necessary, balance weights could always have been added.

The tailplane's raked tip (Fig 183) was associated with these measures. The rake was applied normal to the tailplane's elastic axis, it having been shown that this would call for less weight to balance out the trailing-edge weight if leading-edge tip weights did prove necessary. The raked tip has no adverse aerodynamic effect and is lightly loaded, especially at supersonic speed, and was thus left on just in case!

The first three F-15s off the production line were too early to have the snag tail and were fitted with balance weights instead. Both tailplane halves are