Fly-by-wire Jaguar
GRAHAM WARWIC K reports from BRITISH AEROSPACE, WARTO N

TOTAL reliance on electronic flight controls requires confidence in their fail-safe design. British Aerospace began studying fly-by-wire systems in the mid-1970s and set the maximum acceptable loss rate through flight-control failure at one aircraft in every ten million flying hours. The single-channel analogue autostabili-sers then in service had a failure rate of one in l.OOOhr, so any full-time fly-by-wdre system had to be multiplex.

The fly-iby-wire Jaguar testbed, now awaiting its first flight at British Aerospace Warton, has Britain's first full-time quadruplex, digital flight-control system. On paper, a quadruplex-redundant system offers a mean time between catastrophic failures of 250 million hours. In prac-tice it is much less, closer to BAe's target figure. Digital technology is essential to keep the four lanes in step and to reduce the scope for in-accuracy.

Had Jaguar been designed from the ground up around active controls, the aircraft would be 11 per cent smaller —a 9 per cent net saving in weight, and cost, when the bulk and com-plexity of the flynby-wire system is accounted for. Alternatively, for a constant airframe size, 9 per cent more performance could have been extracted from Jaguar by exploiting active controls.

The advantages of fly-by-wire come from oarefree manoeuvring and re-laxed stability. Artificially imposed safety margins prevent most aircraft from realising their full potential. By storing the boundaries of safe flight inside the active-control computers, an aircraft can be operated to the limit of its performance without risk of departure—pilot inputs are phased out as the limit is approached, pre-venting inadvertent overstepping of the boundary.
Similarly, electronic flight controls can simulate stability, allowing the

advantages of instability to be ex-ploited with safety. An aircraft is stable in pitch when the e.g. is for-ward of the aerodynamic centre and wing lift produces a nose-down pitch-ing moment, balanced by a downforce on the tailplane. An aircraft is un-stable in pitch when the e.g. is behind the aerodynamic centre and wing lift produces a nose-up moment which is balanced by an upload on the tail.

An immediate benefit of instability
is the removal of the tailplane down-force and an increase in overall lift. The unstable aircraft is more easily disturbed, and its pitch response is much improved. But if the disturb-ance is not cancelled out immediately, the aircraft will pitch up until it stalls. BAe likens controlling an un-stable fighter to steering a bicycle being pushed backwards at 60 miles

an hour.
As in the case of the bicycle, the control inputs required to keep an unstable aircraft on track are both tiny and rapid, and any uncorrected divergence soon becomes catastrophic. No pilot can react quickly enough, but high-speed computers can. BAe has taken the additional step of omitting any backup mechanical flight-control system. Such a system requires complex safety measures to restore stability in the event of a fly-by-wire failurej measures which re-duce the performance advantage of active controls.

At the heart of the flight-control system are four high-speed digital computers, developed by Marconi
Avionics drawing on its experience
with Tornado and YC-14 stability-
augmentation systems. Within each

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The Dassault-Breguet Mirage 2000 is the first European aircraft with full-time fly-by-wire flight controls. A failure rate of one in ten million hours is achieved by quadruplex redundancy on the pitch channel, triplex on the roll and yaw axes, and duplex on the automatic leading-edge slats. There is
a fifth, completely separate and simplified, electronic control channel which
allows the aircraft to be flown within a limited flight-envelope should the
primary system fail, say through battle damage. Mirage fly-by-wire is
analogue, and the aircraft is designed to be neutrally stable throughout
much of the flight regime.

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