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ALF502: plugging the turbofan gap

plus cutaway

GE-1017.001

ALF502: plugging the turbofan gap

RICHARD WHITAKER reports from CONNECTICUT Cutaway by FRANK MUNGER

AVCO LYCOMING is gradually increasing the production rate of its ALF502 light, high bypass-ratio turbofan, and has delivered 107 engines for its two applications—the BAe 146 feederliner and the Canadair Challenger business aircraft. Although Avco has won some notoriety over its difficulty in meeting 502 schedules, both versions are certificated and the company is reorganising its production to produce 12 engines a month by the summer.

The ALF502 is based on Avco's T55 core, more than 3,500 of which have been produced for the Chinook, Bell 214, and industrial and marine applications. The ALF502R-3 is take-off rated at 6,700lb for the BAe 146, and the ALF502L uses an extra intermediate-pressure compressor stage to increase the thrust to 7,500lb for the Challenger. This places the engine neatly between the Garrett ATF3, which produces just over 5,000lb, and the General Electric TF34, which clocks up 8,650lb.

T55 cores represent only 35 per cent of Avco's turbine activities. The T53 and LT101 account for 15 per cent each, and the M-1 tank engine takes up about 25 per cent of Avco's efforts. The rest of its activities include research. The addition of the ALF502 to the range has put a lot of pressure on Avco, both in development—especially of the gearbox—and in production.

To relieve things at Avco's Stratford, Connecticut, factory, the company has transferred all production of the LT101 series to Williamsport, Pennsylvania, home of Avco's piston-engine work. A new factory at Greer, South Carolina, should begin to produce ALF502 blades and discs in May. Finally, Avco has obtained second-source suppliers for many components, freeing its own machines for the more difficult parts. This approach gives Avco considerable flexibility, since it can dispense with some of the subcontractors when demand is not so great.

Avco has also increased the number of employees at Stratford from 2,700 in 1978 to more than 5,000—this is no easy task, since the numerous high-technology companies in the area tend to soak up the skilled labour. There is also the problem of taking employees away from local component subcontractors.

The main points about the ALF502 are that its high bypass-ratio gives good fuel consumption and low noise, and its modular construction makes for good maintainability. There are four modules—fan, accessory gearbox, gas producer, and combustor turbine. Each module is balanced before leaving the factory, so the modules are interchangeable directly. This means that a hot end, for example, can be removed and then replaced immediately by a hot end from stores without balancing.

Two men need 2·2hr to replace a combustor/turbine module, and 1·8hr to replace an accessory gearbox module. Both operations can be done without removing the engine. Fan and gas-producer module changes are done in the shop, but up to five opposite pairs of fan blades (out of 40 blades) may be replaced on the aircraft without balancing. Up to ten compressor blades may be replaced if their replacements are within weight limits. In fact, Avco claims that all maintenance can be done in the hangar, except for compressor dismantling, which needs complex balancing gear.

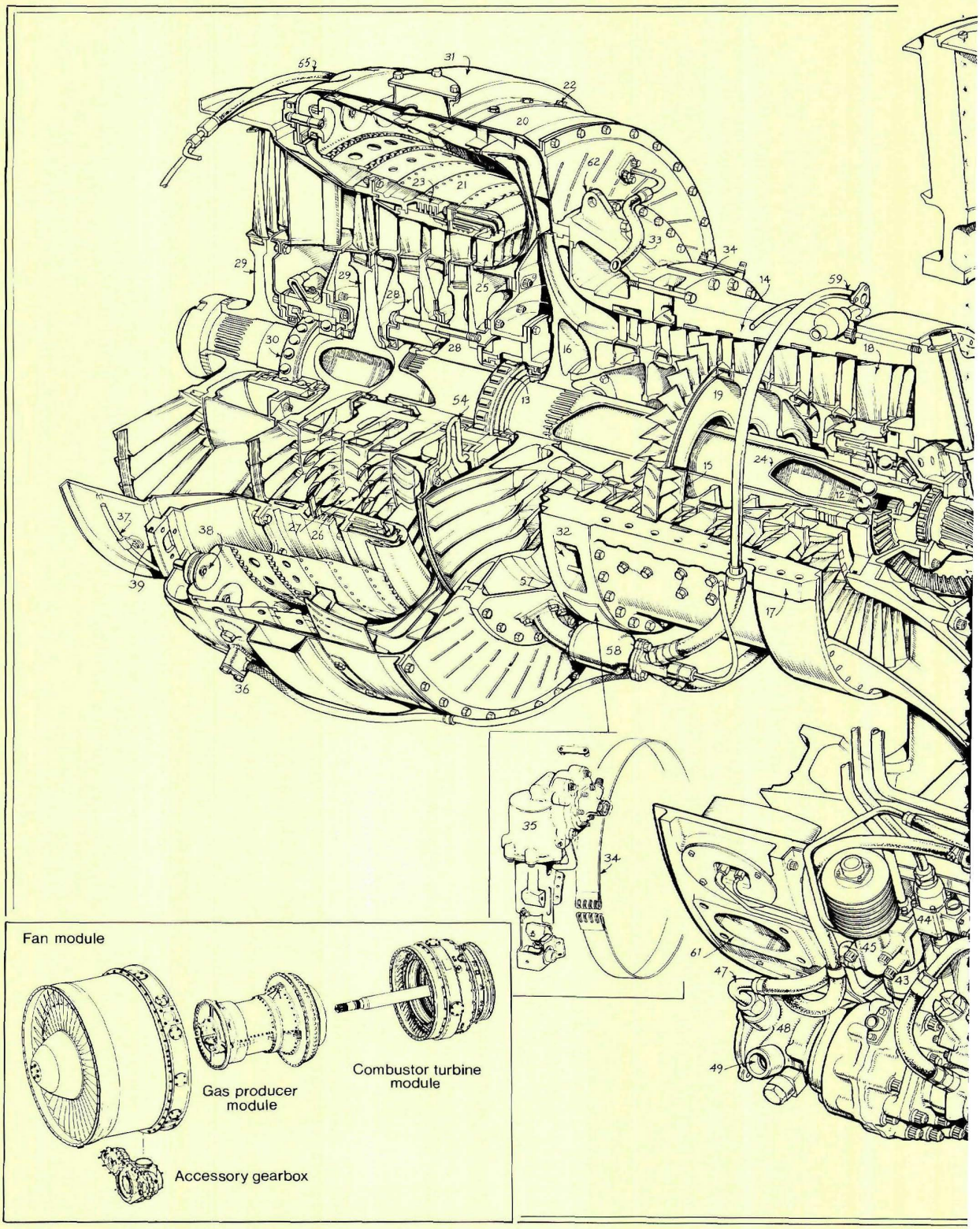
One factor in the ALF502's maintainability is that it is fairly small, so the modules are relatively lightweight, especially for an aircraft such as the 146, which might have been powered

ALF502 history

THE ALF502 is the commercial version of the YF102, which flew in a test-bed in 1972 and powered the Northrop A-9A contender for the US Air Force's AX competition, eventually won by the A-10. The first civil application for the turbofan was the ill-fated Dassault Falcon 30 30-seat transport. This made more than 100 flights in 1974-74, and was powered by the 6,500lb ALF502D flat-rated to 5,500lb.

Hawker Siddeley selected the 6,500lb ALF502H for its HS.146 in 1973, but the project was postponed for market reasons. The aircraft was resurrected by British Aerospace in 1978, and the BAe 146 now uses the ALF502R-3, which has a slightly higher rating, 6,700lb.

Meanwhile, Canadair had selected the 7,500lb ALF502L for its Challenger business aircraft, derived from Bill Lear's LearStar (hence the L designation). The Challenger made its maiden flight on November 8, 1978, and the BAe 146 flew for the first time on September 3, 1981. The ALF502L was certificated in February 1980, while the ALF502R received its FAA approval in January 1981. The only other aircraft to fly with this engine is Nasa's Quiet, Short Haul Research Aircraft, a modified Buffalo which still flies with the YF102s from the A-9A.


Fan module
Gas producer module
Combustor turbine module
Accessory gearbox

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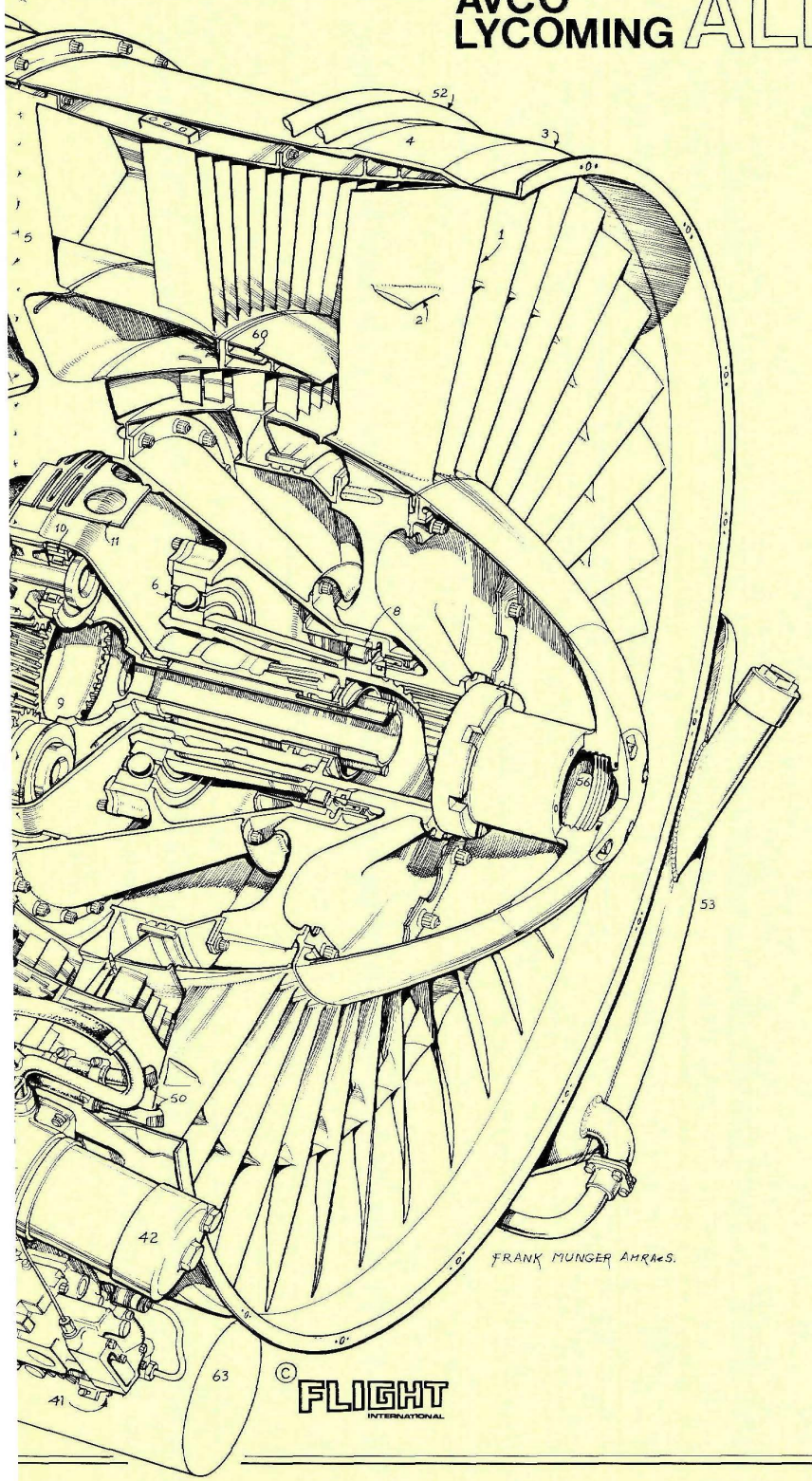
AVCO LYCOMING ALF 502R-3



Key

1 Titanium fan unit
2 Fan blade snubbers
3 Steel fan casing (dia 41in)
4 Containment ring
5 Lightweight alloy main support frame
6 Fan thrust-bearing
7 LP shaft speed strobe
8 Fan shaft support bearing
9 2·3:1 reduction gear
10 Planetary gear roller bearing (seven planet gears)
11 Planetary gear-carrier retaining spring
12 HP compressor thrust bearing
13 HP compressor support roller bearing
14 Seven-stage axial compressor
15 Stator segments
16 Single-stage, two-piece titanium, centrifugal compressor
17 Lightweight alloy split compressor casing
18 Field-replaceable stainless steel blades
19 Wrought steel-alloy discs
20 High-temperature steel alloy diffuser case
21 Coated high-temperature steel combustion chamber
22 Combustion-chamber retaining bolts
23 Sealing rings
24 Steel LP shaft
25 Coated, air-cooled nozzle blades
26 Coated, air-cooled HP turbine blades
27 Coated stator blades
28 High temperature steel discs
29 High temperature steel LP turbine discs and blades
30 LP turbine thrust bearings
31 Bleed-air duct
32 Sixth stage bleed tapping, open for acceleration and low speed steady state
33 Compressor delivery to bleed-air control
34 Bleed-air control band
35 Bleed-air control band actuator (to reduced scale)
36 Igniter
37 Thermocouple harness
38 Fuel nozzle
39 Fuel manifold
40 Fuel control unit
41 Power control lever
42 Main fuel filter
43 In-line fuel filter
44 Fuel flow-meter
45 LP shaft overspeed shut-off valve
46 Fuel from oil/fuel heat-exchanger
47 Fuel to oil/fuel heat-exchanger
48 Fuel boost pump
49 Fuel inlet to pump
50 Intake pressure sensing air
51 Sensing air exhaust
52 Oil lines to oil/fuel heat exchanger
53 Oil tank
54 HP compressor bearing oil supply
55 Turbine bearing oil supply
56 Oil anti-iced spinner
57 De-icing bleed-air
58 De-icing air control valve
59 De-icing air duct to casing
60 De-icing air duct round intake lip
61 Front mounting pad (four places)
62 Rear mounting pad (three places)
63 Integrated drive and generator envelope

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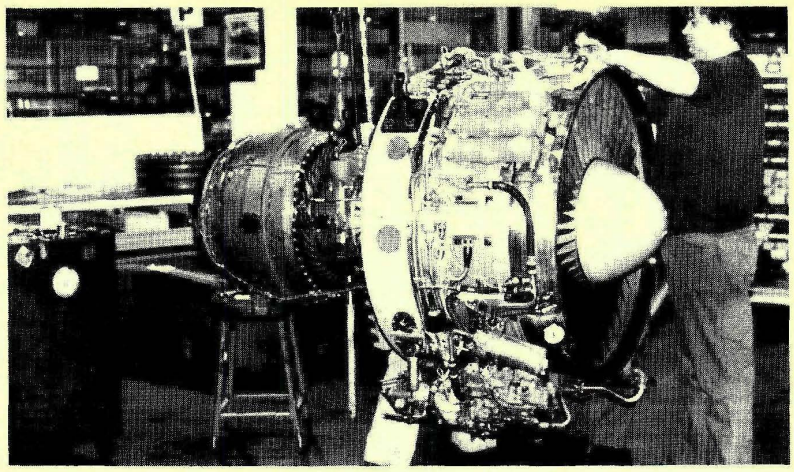

An Avco Lycoming technician assembles an ALF502L at Stratford. Maintainability is an important factor on the ALF502. Only three special tools are needed for module changes, and Avco claims the initial time between overhauls to be 4,000hr

by two engines of twice the thrust and more complexity. The fan is the heaviest module (497lb), the gas producer weighs 319lb, the combustor/turbine is 248lb, and the gearbox 41lb.

Although the T55 and ALF502 series have a similar core, it has been developed enormously since the mid-1950s, when the original engine developed 1,600 e.s.h.p. Now, the biggest T55 develops 4,750 e.s.h.p. The length and diameter has remained the same, the power increase coming from extra turbine stages, better turbine cooling, compressor improvements, and better materials. Avco tells *Flight* that there is still scope for increasing the core's power output.

The T55 has a centrifugal compressor, preceded by a seven-stage axial compressor. Avco's reasoning behind the centrifugal compressor lies mainly in the engine's helicopter applications —the arrangement is tougher, shorter, and does not need as many small axial blades. The annular reverse-flow combustor also helps to keep the engine short, and it shields the turbine, reducing noise. The combustor has a high mixing length, which reduces noise because the eddies can dissipate before reaching the turbine. A two-stage, high-pressure turbine with cooling drives the compressor, while the fan is driven by a two-stage low-pressure turbine. The two shafts contrarotate.

Most of the development work on the 502 has been connected with the fan. Avco decided on a geared fan arrangement, mainly because it saves two turbine stages, reducing core noise. (Stages would be needed to offset the lower shaft speed with no gears.) The three planetary gears give a 2·3:1 speed reduction. It was in this area that Avco had its most significant development problem—there were two gearbox failures in-house in 1979, both being caused by a resonant frequency problem. Avco has now cleared this up, largely by modifying the bearings. Nevertheless, the problem delayed the programme because it occurred just as the engine was entering production.

Compared with the T55, the 502 has an extra rear mounting for the fan, and a higher compressor pressure-ratio. The higher operating altitude for the turbofan requires more acceleration bleed-air, and this is governed by an extraction gallery surrounding the casing between the sixth and seventh compressor stages. The gallery controls the bleed air by moving in and out, and is connected to the main fuel control.

The BAe 146 engine, the ALF502R-3, has a single intermediate-pressure (IP) compressor stage just behind the fan. Here lies the main difference between the two versions of the 502, because the Challenger version has two IP stages, making the engine about 2in longer. The installation is different for the two versions, to cater for the 146's underwing position and Challenger's tail mounting.

Since the Challenger operates at higher altitudes—cruise altitude is 45,000ft, compared with the 146's 25,000ft or less—the 502L's fan blades are twisted at 15° rather than 12°. This gives a slight sea-level penalty but gives better altitude performance. There are also differences in the fuel controls to allow for the altitude difference. The 146 uses a Plessey electric starter, while Challenger has a Garrett pneumatic starter. Avco tells

Left *The BAe 146 is powered by four ALF-502s slung in underwing pods. The aircraft's wings are made by Avco's Aerostructures division*

ALF502 LEADING DATA

	ALF502L-2	ALF502R-3
Description	Two-shaft turbofan	
Take-off thrust (lb)	7,500	6,700
Bypass ratio	5·0	5·71
Overall pressure ratio	13·6	11·4
Cruise s.f.c. (lb/hr/lb)	0·424	0·411
Length (in)	58·6	56·8
Dry weight (lb)	1,298	1,270
Diameter (in)	41·7	41·7
Max airflow (lb/sec)	256	245
LP stages	Fan, 2 IP	Fan 1 IP
HP stages	7 axial, 1 centrifugal	
Turbine stages	2 HP, 2 LP	

Note: Avco is developing the ALF502L-3, rated at 7,800lb with a cruise s.f.c. of 0·413. A new version of the ALF502R will be rated at 6,970lb with a cruise s.f.c. of 0·400.

Flight that it could increase the thrust relatively easily by putting in a third IP compressor stage and increasing the turbine diameter.

Avco introduced several modifications to the engine in autumn 1979. Better compressor-stator sealing improved the efficiency and surge margin, and Avco redesigned the 28 fuel injectors. The nozzle diameters were increased to reduce their tendency to be blocked by contaminants, while the spray patterns were kept the same.

The most recent change to the ALF502 is the introduction of the L-3, which is a package of modifications to the L-2, yielding a 4 per cent take-off thrust increase and a 2 per cent cruise specific fuel consumption (s.f.c.) improvement. The new version of the engine has reduced cooling airflow leakage in the HP turbine, tip-clearance control in the second-stage turbine, lower gearbox oil-flow in the cruise, and reduced LP compressor inter-stage bleed-air.

Avco has demonstrated the improvements in thrust and s.f.c., and a reduction of 17°C in the cruise turbine-entry temperature, on the test rig. Certification of the new variant is due in June. Avco tells *Flight* that a similar package of modifications will be certificated on the ALF502R-3 this year, and that this will yield the same thrust and s.f.c. improvements. The modifications can be retrofitted on to existing L-2s and R-3s in the field.

The ALF502s materials are fairly conventional, but a patented Avco high-temperature steel alloy is used in the turbine and nozzle. The fan, IP compressor, and centrifugal compressor are made of titanium, while the HP compressor is steel.

Both the 146 and the Challenger are quiet aircraft, as a result of attention to keeping down the 502's noise. The high bypass-ratio is an obvious reason for quietness. The variable inlet guide vanes of the T53 were dispensed with for the T55 and ALF502, partly for simplicity and lower cost, and partly to reduce noise—there are no wakes for the fan blades to impinge upon.

Avco decided on two rotor-chords as the spacing between the fan blades and stators, since this is enough to allow eddies to dissipate—reducing noise. Acoustic de-tuning was also accomplished by optimising the fan rotor/stator ratio—there are 40 fan blades and 85 stator vanes. The fan design was changed after running the initial design, which proved too noisy.

Avco's geared fan allows the turbine to run at 20,000 r.p.m., which is largely above the audio range, so turbine noise is low. Finally, the combustor is long—allowing eddy dissipation before the turbine—and wraps around the turbine, reducing noise.

The ALF502 will meet ICAO emission regulations which come into force in 1983, and which cover smoke, carbon monoxide, hydrocarbons, and nitrogen oxides. This is partly because of the moderate temperatures and pressures in the engine. The combustor efficiency is claimed to be high as a result of the airblast atomiser design. This means that there is less unburnt fuel to cause hydrocarbon emissions, which are often a problem, especially at idle-thrust.

The atomisers work by surrounding the fuel spray by two layers of air which blast into the can. There are two fuel orifices. During engine idle, fuel is sprayed from only one orifice, and when the thrust demand is increased the other orifice comes into play. This reduces the amount of unnecessary fuel sprayed during idle. Avco has optimised the flow divider schedule carefully to ensure maximum efficiency.

Canadair tells *Flight* that it holds orders for 138 Challengers, of which 127 will be powered by the ALF502. The remaining customers have chosen the more powerful General Electric CF34—the GE engine was also to have powered the larger Challenger E, but this project has been shelved. Canadair has now delivered 28 Challengers, and it has no complaints about the engine—service entry problems have been relatively small and easily solved. It is impossible to estimate how much of the delay in getting Challenger in service was due to engine delivery, and how much was due to the extensive redesign which Canadair performed on the original LearStar to obtain Challenger.

BAe 146 sales remain at 13, with 12 options. The announced customers are Air Wisconsin (four, plus four options), and Pacific Express (six plus eight). The aircraft will be certificated in August. BAe comments that it has never complained about the ALF502, and that the engine "has never been the pacing item" in the programme. There have been no engine removals in the 114hr which the first 146 has flown. Avco has delivered 19 engines to BAe, and engines are mounted on the third aircraft.

After a lengthy gestation and problems meeting deliveries because of the large volume of work at Stratford, Avco seems to be getting the situation sorted out. Our calculations indicate that 63 engines were delivered during 1981, and Avco expects to be producing 12 a month by summer.