G-ARVF at Khartoum on 3rd March 1964

VC10–the "big jet" that can use small airfields

by G. W. Webber,* B.Sc.(Eng.), A.C.G.I., A.F.R.Ae.S.

ON 29TH APRIL a VC10 was scheduled, at the time of going to press, to leave London Airport for Lagos with its first load of fare-paying passengers and thus begin its useful life with B.O.A.C. This date is the culminating moment of over seven years of design, development and test work to produce what is likely to be the last long-range subsonic jet airliner in the Western world.

It was in January 1958 that B.O.A.C. signed a contract for a fleet of VC10s and it is worth reviewing the basic VC10 features specified by B.O.A.C. which justified the order in addition to the fleet of Boeing 707s also on order at that time.

The prime requirement was the ability to operate with economic loads from airports on the Commonwealth routes with their hot, high and often relatively short runways. A high cruising speed, low-approach speed, low cabin noise level, a sophisticated autopilot and built-in provision for automatic landing were the other main specification requirements.

These main requirements were responsible for establishing the distinctive configuration of the VC10. Outstanding airfield performance and low-approach speed call for extensive high-lift devices, and a wing which is free from engine installations is a logical solution. An uncluttered wing is also desirable from the high-speed cruise point of view. Having removed the engines from the wing the logical site for them is at the rear of the aircraft, behind the passenger cabin. This arrangement of course means that the tailplane cannot be accommodated in the conventional position, and a new location had to be chosen. The chosen position at the top of the fin has a number of aerodynamic advantages. Since the fin is highly swept back, the greatest possible tail lever arm is achieved, and the loss in tailplane effectiveness due to downwash behind the wing is minimised; both these factors help to reduce the size of tailplane required. Also, since the fin is bounded at the top by the tailplane and at the bottom by the fuselage, and to some degree the engine nacelles, a useful "end plate" effect is obtained which causes an increase in fin effectiveness.

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Design features

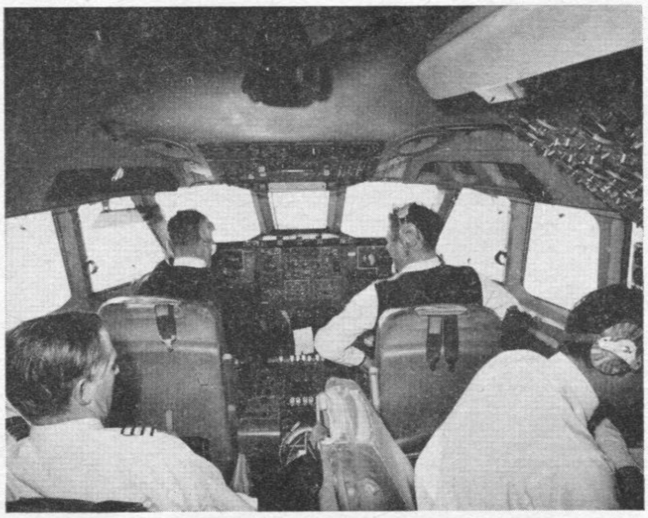
Fuselage.—The fuselage is a faired double bubble in section with a long parallel portion forming the passenger and freight accommodation. Many different passenger layouts are possible up to a maximum of 151 in the Standard VC10 and 180 in the Super VC10. Much attention has been given to the design of the two freight bays to obtain easy access and loading.

The flight deck is exceptionally roomy and is designed to accommodate five crew members. The cockpit glazing gives an exceptional all-round view, as can be appreciated from the photograph.

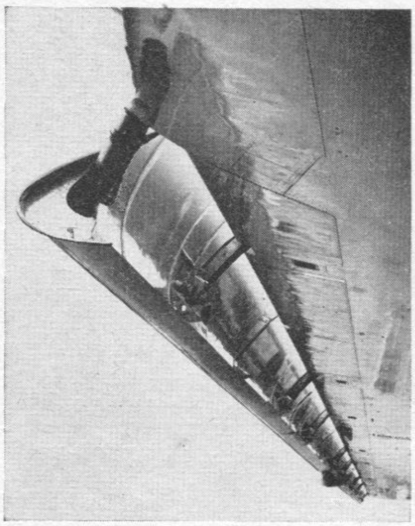
One feature of rear-engined layouts is that the wing has to be set well back on the fuselage to obtain longitudinal balance, and as a result a large proportion of the passengers have an unrestricted downward view.

Wing.—The cruising performance of the aircraft is determined largely by the wing design. The Mach number at which the drag begins to build up rapidly—because of regions of supersonic flow on the wing—and above which it is uneconomical to cruise, can be delayed by sweepback and by careful section design. On the VC10 the sweepback of the quarter chord line is 32.5 deg. and the optimum pressure distribution under cruising conditions for low drag is obtained by building in a twist and camber distribution which varies all the way from root to tip. The ratio of the maximum section thickness to the chord also varies, being greatest at the root. The cruising Mach number achieved on the VC10 varies from M=0.83 to M=0.86, depending on whether maximum range or minimum block time is required by the operator.

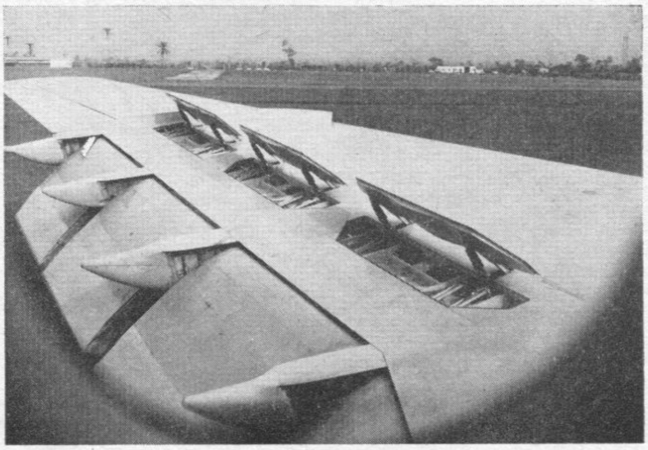
To obtain the outstanding airfield performance, a prime requirement, the VC10 has large Fowler flaps which move rearwards to the trailing edge of the wing and rotate through 45 deg. for landing, and



Flight deck of a Standard VC10. The flight engineer's station is at the bottom right



LEFT: *Leading-edge slats, each in four sections, extend over almost the whole of the wing span*



RIGHT: *The spoilers/air-brakes are used symmetrically for braking and asymmetrically for rolling*

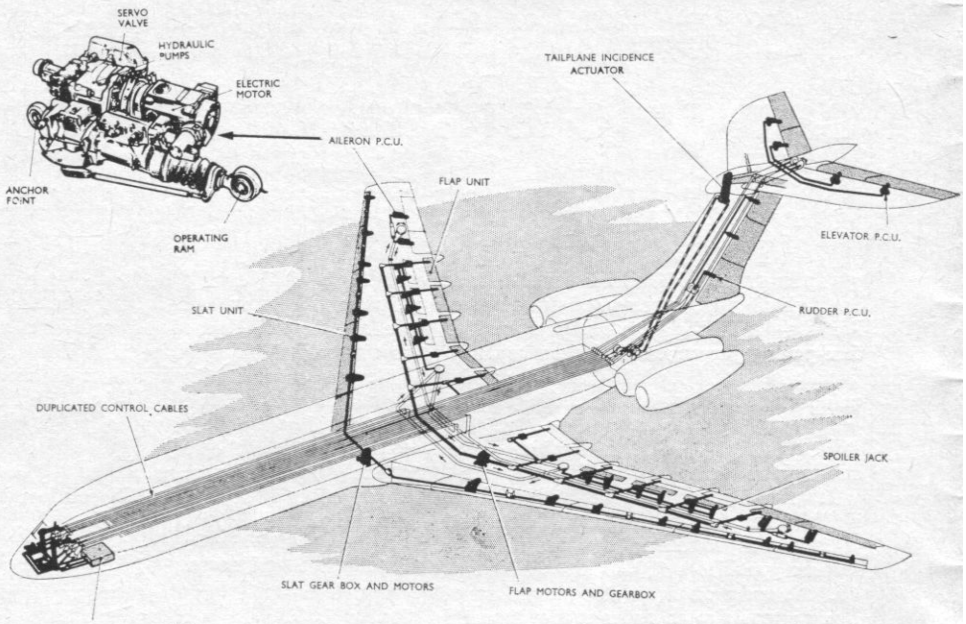
VC10 . . .

which work in conjunction with nearly full-span leading-edge slats. The combined effect of these high-lift devices and the take-off thrust of the Rolls-Royce Conway R.Co.42 engines enables the VC10 to operate into and out of difficult airfields using approach speeds that are of the same order as for the Viscount, and in fact lower than for the Vanguard.

Engine installation.—The two double nacelles housing the engines, together with the section of the fuselage lying between them, form a lifting surface that has an area slightly greater than that of the tailplane and does in fact have a significant favourable effect on the stability of the aircraft. The two main design criteria which had to be satisfied with the installation were high intake efficiency and as low a drag as possible. The engines are stood off from the fuselage to be clear of the latter's boundary layer and splayed outwards slightly to line up with the local airflow direction, which tends to follow the fuselage contour. One virtue of mounting engines behind the wing is that changes of incidence at the engines throughout the speed range are reduced by wing downwash, whereas a wing-mounted engine suffers an amplification of incidence because of upwash effects in front of the wing (see diagram below). This makes it easier to maintain high intake efficiency throughout the speed range.

Many wind tunnel tests were carried out to establish the best cowling and pylon lines, position on the fuselage and inclination of the thrust line for minimum drag, before the production configuration was established; even so, flight results showed a need for certain changes. The design of the engine installation was in fact one of the most difficult problems to solve. The small moment arm from the centre line of the aircraft of even the outer engines makes the effect of a sudden engine failure very easy to handle, even at the most critical stage of the take-off—unlike a podded wing-mounted installation where this is always a difficult handling situation.

The outer engines on the Standard VC10 and all four engines on the Super VC10 are fitted with thrust reversers for use on landing. Hydraulic rams close eyelid-type deflectors across the jet pipe which deflect the jet through cascades, uncovered by the movement of the eyelids, in the upper and lower surfaces of the nacelles.

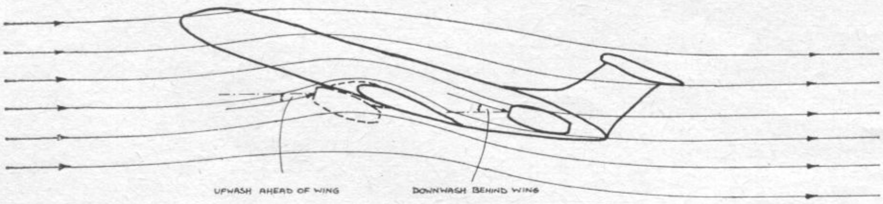


Arrangement of flying controls

Tail unit.—The fin and tailplane are both swept back for the same reason as the wing. It is important to ensure that the critical Mach number (that is, the Mach number at which regions of supersonic flow appear) is at least as high for the tail unit as for the wing, otherwise handling and stability problems can appear at cruising speed.

The tailplane "bullet" serves the double purpose of enclosing the mechanism involved in varying the setting of the tailplane for trimming the aircraft, and ensuring that the airflow does not break away in the junction between tailplane and fin. Its distinctive shape was evolved in wind tunnel tests and employs the principle of "area rule" often used for wing body junctions on transonic fighter aircraft. This can be seen in the waisting which

Flow-pattern diagram showing favourable downwash effect at a rear-mounted engine and unfavourable upwash effect for wing-mounted engine



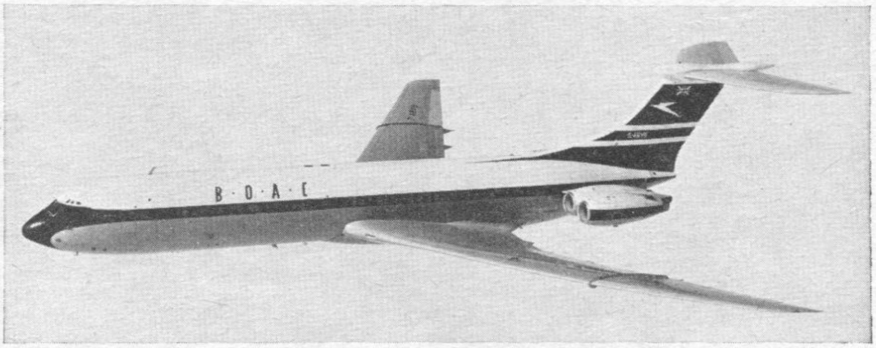
occurs in the centre portion of the bullet. The front portion of the bullet is fixed to the fin and the rear portion moves with the tailplane.

Control system

The VC10 is a fully power-controlled aircraft, with no manual reversion facility. To obtain a very high degree of safety in the event of possible malfunction of any of the elements of the control system, much use has been made of multiplication in the systems. The mechanical control circuits in the fuselage are for the most part duplicated and all the aerodynamic control surfaces are split into a number of independent sections, each with separate self-contained power-control units made by Boulton Paul. There are four elevator sections, four aileron sections, three rudder sections and six spoiler sections.

The design philosophy behind this arrangement is that failure of any single power control unit loses only a small proportion of the total control power about any axis and also that a misbehaving power-control unit can be easily counteracted by the remaining units while still leaving adequate power to carry on the control function. A faulty unit can be easily identified by the pilot or the flight engineer and isolated without affecting the remaining units. The sources of power which drive the power-control units are also duplicated, each supplying approximately half the units.

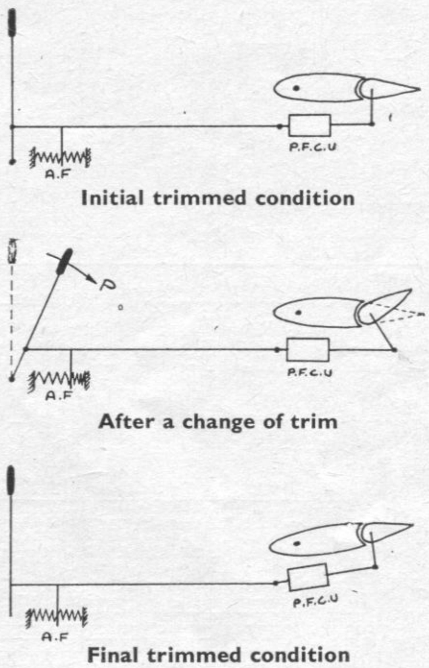
A further form of duplication employed is between hydraulically powered controls and electrically powered controls. Control in pitch can be effected either by the elevators, which are driven by electrically powered self-contained hydraulic units, or by the variable-incidence tailplane which is driven from the main hydraulic system. Similarly the aircraft can be controlled laterally by either the electrically powered ailerons or the hydraulically powered spoilers. Thus a complete failure of either the entire electrical system or the entire hydraulic system still leaves the pilot with ability to control the aircraft.



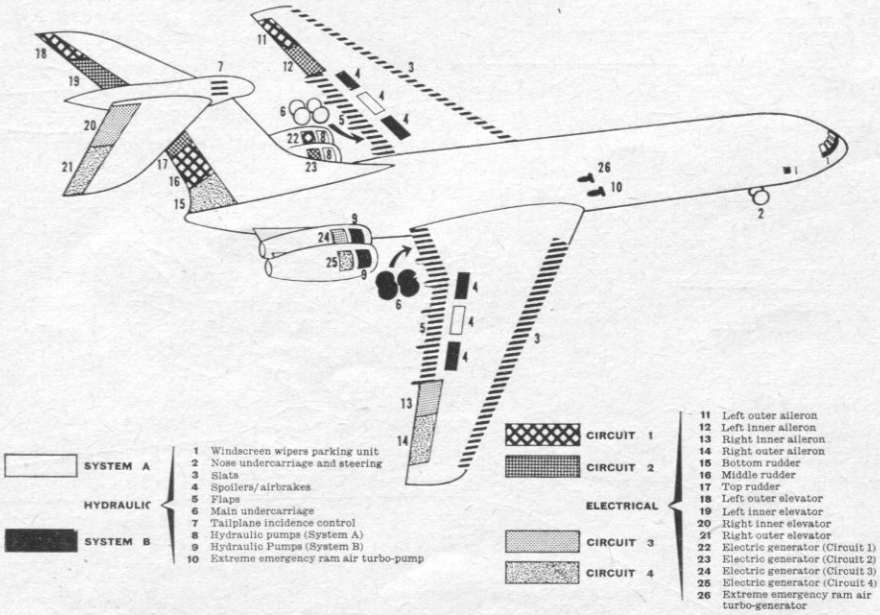
G-ARVB with revised wingtips and other drag "mods"

Even in the very remote case of simultaneous failure of all four engines, causing loss of the normal electric generating system and hydraulic pumps, a sufficient proportion of the electrically powered units is maintained operational by means of a drop-out ram air turbine housed in the fuselage centre section.

Since the aircraft is fully powered, no natural aerodynamic "feel" is available to the pilot; this has to be supplied artificially. In keeping with the overall philosophy the artificial feel unit (supplied by H. M. Hobsons) is duplicated, each half being fed from one of the duplicated hydraulic systems. The feel unit contains means of trimming the aircraft in roll and yaw but longitudinal trim is obtained by means of the variable-incidence tailplane. The force experienced by the pilot is zero when the elevators are substantially in line with the tailplane. When the elevators are displaced, to change speed or because the configuration has been changed (*e.g.*, flaps extended), the aircraft is trimmed by rotating the tailplane in the appropriate direction to remove the need for the elevator angle, until the elevators are once more in line with the tailplane and the pilot's force is reduced to zero (see drawings above).



Method of trimming using variable-incidence tailplane (A.F. = artificial feel unit; P.F.C.U. = powered flying control unit); P = stick force applied by pilot). The stick and the elevator are always neutral for zero pilot stick force

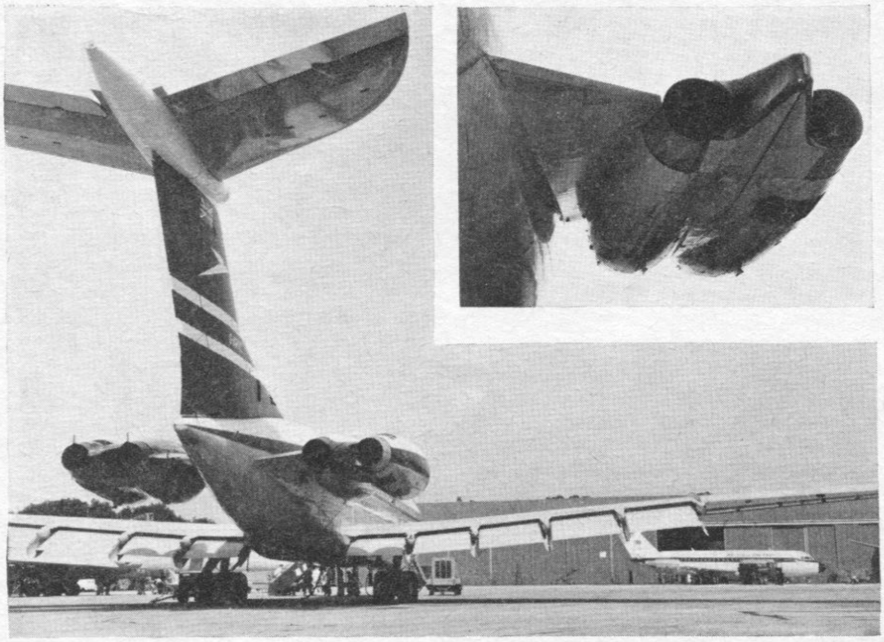


How the power to the flying controls and hydraulic services is distributed

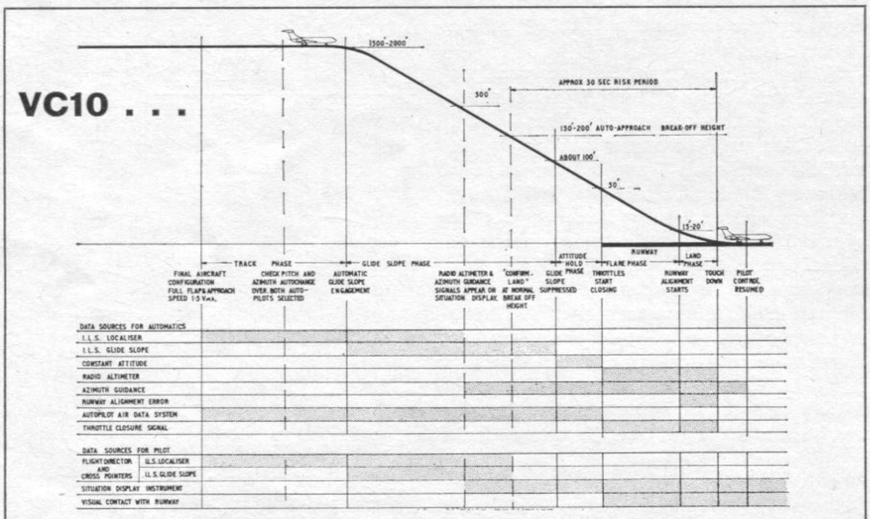
Automatic control

B.O.A.C. attached great importance to the automatic control system they required on the VC10, since they anticipated using the automatic system for about 95 per cent of the airborne time. Also they were particularly anxious to take advantage of the pioneering development work carried out by the Blind Landing Experimental Unit of the R.A.E. to increase the regularity and safety of their operations in bad weather conditions.

To achieve the necessary safety required for automatic landings, it became apparent



G-ARVC at Wisley during development trials. INSET: *Standard VC10 power-plant installation, incorporating "beaver-tail" and rearward pylon extension*



The VC10's automatic landing sequence

at an early stage that the same philosophy of multiplication of systems as used in the basic control systems would need to be applied also to the automatic systems. Further, to achieve continuous availability of automatic control during the *en route* flying required, it was clear that more than one complete system needed to be carried on the aircraft. Hence, the aircraft carries a completely duplicated autocontrol system with a number of advanced features not to be found on any other long-range aircraft.

The facilities available in the system include: pitch, roll and heading hold; yaw damping; pre-select heading; height, indicated airspeed or Mach number lock with datum adjustment; V.O.R. and I.L.S. coupling; automatic throttle control on approach; and provision for automatic landing. The actuation of the control surfaces by the autopilot is integrated with the power-control units, which gives a very light installation combined with precise control. The effects of violent autopilot malfunctions — sometimes called "run-aways"—which on most current aircraft installations can cause large disturbances to the aircraft if they occur, are prevented on the VC10 by a carefully designed monitoring system. The automatic landing system is under development and will be introduced in stages after the aircraft enters service and should be fully operational in about three to four years. The system has been developed by Elliott Automation and the basic system is based on elements of the well-proved Bendix PB20 autopilot.

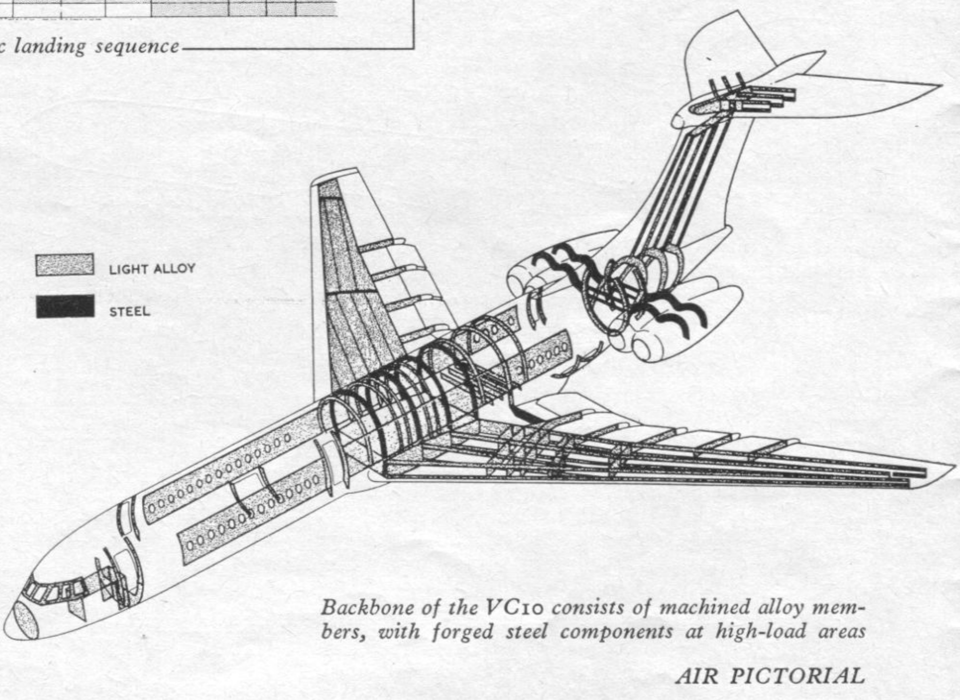
Structural philosophy

The VC10 structure is designed to a mixture of "fail safe" and "safe life" concepts—the two main ways of catering for fatigue. The "fail safe" philosophy is similar in concept to the multiplication principle applied to the control systems, whereby a number of "load paths" are provided in the structural component. If a failure occurs in one load path, the remaining elements can still withstand a large proportion of the design load.

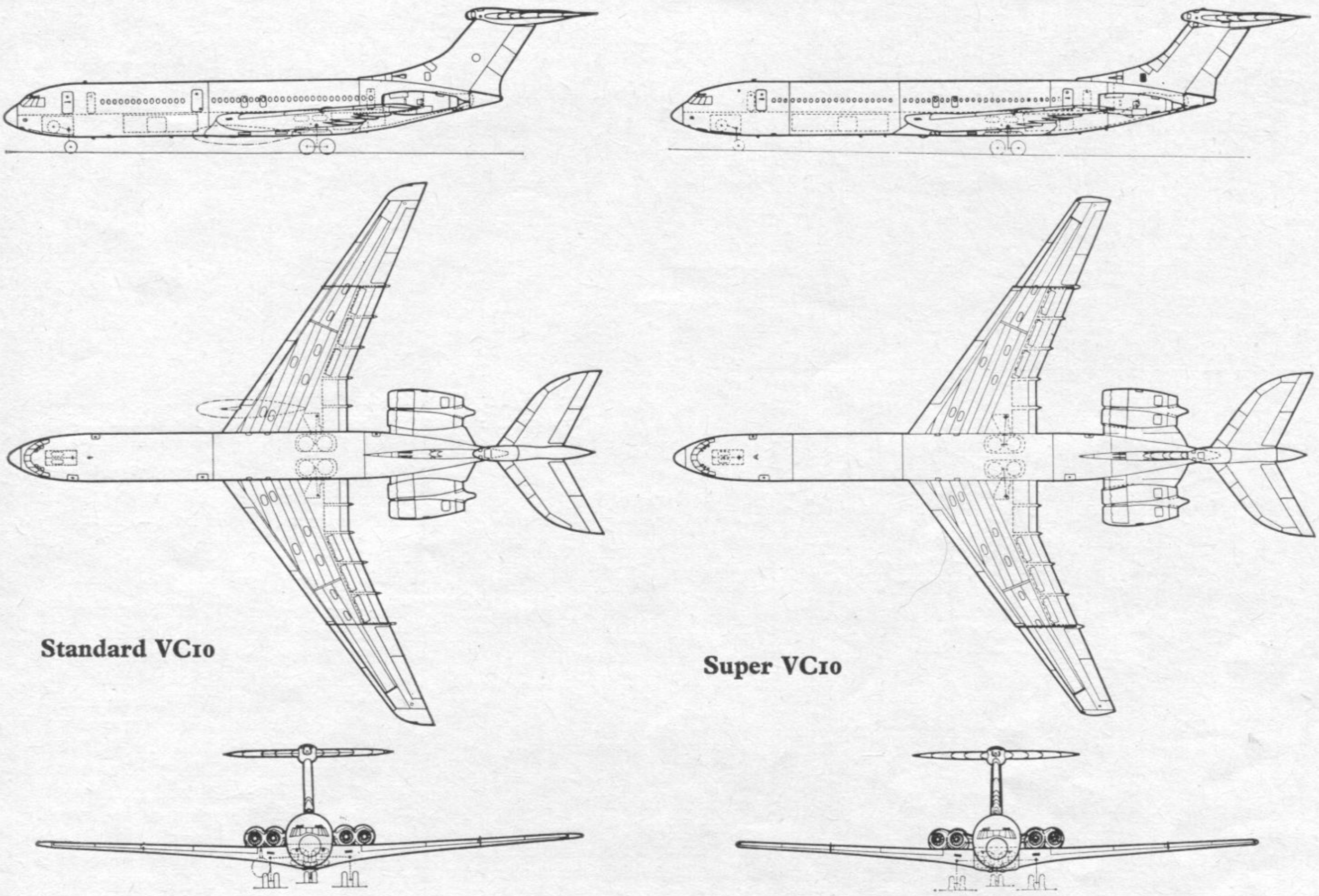
Where this philosophy cannot be applied conveniently, the structure is designed to low stress levels so that an unlimited number of load applications can be applied without causing fatigue—*i.e.*, "safe life".

Over half the structure (55 per cent) is machined from solid billets. This gives better structural efficiency than fabricated components and also, when applied to skin panels on the fuselage and wing, gives a better external finish than riveted skin and stringer construction.

Most of the structure is aluminium



Backbone of the VC10 consists of machined alloy members, with forged steel components at high-load areas



LEFT: *Standard VC10 has Küchemann wingtips, "beaver tail" extensions, extended-aft engine pylons, provision for carrying spare engine (pod below starboard wing).* RIGHT: *Super VC10 has 13 ft. longer fuselage, original wingtips, 4 per cent forward extension on two inboard slat sections, integral fin fuel tank. Powerplant inclined 3° nose up*

alloy but some of the most highly loaded components, such as the fuselage centre-section frames, the engine beams, and the undercarriage supporting structure, are made of machined steel forgings.

Unlike most British aircraft manufacturers, Vickers-Armstrongs have always designed their own undercarriages and the VC10 is no exception. The trailing four-wheel bogie gear has given the aircraft very pleasant soft landing characteristics which should be popular with aircrew and passengers. Its shock-absorbing characteristics are in fact so effective that during early testing of the aircraft the pilots asked for special instrumentation to inform them when the wheels left or contacted the runway.

Performance

As is well known, the VC10 suffered a development problem concerned with its cruise economy during its early flight evaluation. The drag of the aircraft on the cruise was somewhat higher than estimated. This has now been solved by a wind tunnel and flight programme by means of which the sources of the drag were isolated and correcting modifications devised. Changes found to be beneficial were as follows:

1. The addition of Küchemann wingtips, which increased the total span by 6 ft.
2. The addition of a 4 per cent chord leading-edge extension over the inboard wing.
3. Minor changes to the rigging of the slat top surface trailing edge relative to the wing.
4. Inclining the engine nacelles 3 deg. nose up.
5. The addition of "beaver tail" extension fairings between the jet pipes of each pair of engines.
6. Rearward extension of the engine pylon fairings.

In addition, a few excrescences were cleaned up. The Standard VC10 does not have the same set of drag "mods" as the Super VC10. Items 1, 3, 5 and 6 are fitted to the Standard aircraft and Items 2, 3, 4, 5 and 6 are fitted to the Super VC10.

In all other aspects of performance and in particular the airfield performance, the aircraft comfortably met or exceeded its guarantees without design changes.

The handling characteristics of the VC10 have been praised by all pilots who have flown it to date, and its airline development and route-proving experience has been most encouraging from the point of view of utilisation and serviceability. Average daily utilisation achieved during the 850-hour period recently completed was 10½ hours, and total flying amassed to date is over 3,500 hours.

Specifications

	Standard VC10	Super VC10
Power Plant:		
Type	Rolls-Royce Conway R Co.42	Rolls-Royce Conway R Co.43D
Sea-level s.t.	21,000 lb.	22,500 lb.
Dimensions:		
Length	158 ft. 8 in.	171 ft. 8 in.
Height	39 ft. 6 in.	39 ft. 6 in.
Wing span	146 ft. 2 in.	140 ft. 2 in.
Wing area (gross)	2,853 sq. ft.	2,887 sq. ft.
Weights:		
Max. take-off wt.	312,000 lb.	335,000 lb.
Max. landing wt.	212,000 lb.	237,000 lb.
Max. payload	39,765 lb.	57,760 lb.
Cruising Speed	550–570 m.p.h.	550-570 m.p.h.
Range with full payload (with no reserves)	5,400 stat. miles	4,550 stat. miles

AIRCRAFT ON ORDER: B.O.A.C.—twelve Standard VC10s, and thirty Super VC10s (including eight mixed passenger/freight machines); British United Airways—two; Ghana Airways—three; R.A.F. Transport Command—eleven.