6054 - Part 3

Avro C-102 "Jetliner"

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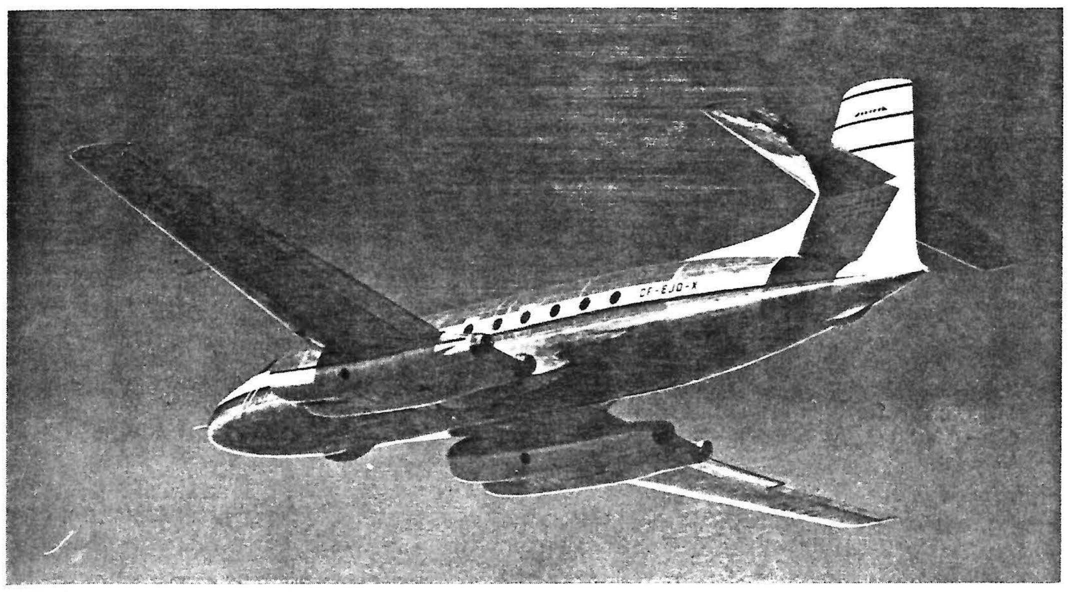


Fig. 1 : Trapezoidal wing plan, slim engine nacelles and high-set elevator unit are characteristic features of the Avro C-102 "Jetliner".

On August 10th, 1949, the Avro C-102 jet transport, now better known as the "Jetliner", made its first flight. This aircraft was the first civil jet transport to fly on the North American Continent and missed by only thirteen days the honor of being the world's first jet transport actually to fly. This honour went to the British de Havilland "Comet".

We had worked on the project for almost three years and had of course had numerous set-backs, the biggest of which was the inability of the engine manufacturers to supply the original twin engines, and we had to change the design of the aircraft completely to accommodate four engines of a different type.

When the prototype reached the final inspection stage on July 25th, 1949, we thought that most of our bridges were crossed and all we had to do was to get our aircraft into the air. It just shows how optimistic you can get. Two days later, on July 27th, it was announced over the radio that the de Havilland "Comet" had made its first flight. It was true that it had only hopped a few feet into the air, but we realized that we had missed by just a few days the distinction of being the first people in the world with a true jet transport.

Then, to make life still a little more complicated, the Department of Transport decided to tear up the runways at Malton and carry out extensive modifications. We were informed, however, that we would have one strip on which to land, the 14-32 runway running northeast and southwest, with a bituminous surface, and we could also have a short piece of concrete runway on which to carry out our engine runs and taxi trials.

Final engine runs having been completed over the week-end, the aircraft was wheeled out of the hangar on August 8th to start taxi trials. As a special favor, the temperature had gone up to 103° F, but we carried out our taxi runs, braking tests, and steering control tests nevertheless, and towards early evening decided that it might be possible to attempt a hop and take the aircraft a few feet off the ground.

It was not a very easy decision to make in view of the fact that we had to contend with what was probably the highest temperature of the whole year, and with engines which were very much more susceptible to temperature than reciprocating engines. We had a very short runway, and the pilot was handling a new type of aircraft with a performance which could only be predicted at the time. We had calculated the take-off distance and the decelerated stop after the hop, and from our calculations there were only a few feet of runway left for pilot error.

The "Jetliner" taxied down to the northeast end of the runway, the throttles were opened up, the aircraft accelerated, and at about 90 m.p.h. the nose wheel came off the deck. A few seconds later there were four loud and ominous reports, the nosewheel came down, the aircraft decelerated to a stop, a few feet from the far end of the runway. The pilot had realized that he just could not make it and had applied the brakes a little too early before the weight of the aircraft was on the wheels, the wheels had locked and all four tires had blown out. In spite of this, the pilot had easily been able to keep the aircraft on the runway, and there was no damage to the wheels or brakes or any portion of the aircraft.

The "Jetliner" was wheeled back into the hangar, the tires were changed, and the next day more taxi runs were carried out to enable the pilot to feel out the brakes before making another attempt. On Wednesday morning, August 10th, three more runs were made and a hop was attempted on the third run. The two main wheels on the starboard side promptly blew out, and the pilot again brought the aircraft to rest dead in the center of the runway, this time with quite a distance to spare. The tires were quickly changed and a conference held to decide whether any more attempts should be made, as it was getting a little expensive on the tires and also on the nerves of the pilot, co-pilot and flight engineer who had to sit in the aircraft wondering what was going to happen next.

The pilot decided that the next time he went down the runway he would take her up and "have done with it". The crew took time out for lunch and, after returning, decided that in spite of a small gale that was blowing with quite a stiff cross-wind and the fact that the temperature was again around 103°F they would just keep on going. So, just after lunch on August 10th, the "Jetliner" came down the runway, lifted off the deck after a relatively short run and gracefully climbed up to about 500 feet where the pilot tried out the controls.

He did a circuit of the field and then asked for clearance to bring her over the spot

Fig. 2 : The "Jetliner" during the landing approach. Two Rolls-Royce "Derwent" gas turbines are paired in twin nacelles which also house the main landing gear.

* This paper was presented on January 9th 1950, at the Annual Meeting of the Society of Automotive Engineers in Detroit. It is reproduced herewith in summarized form by courtesy of the author, A.V. Roe Canada L d. and the S.A.E.

where the ground crew were standing to let the boys have a look at the aircraft in the air. He then climbed away to 8000 feet and shortly reported that everything was all right. Everyone on the ground felt pretty good, too. After a flight of about one hour, during which time altitudes around 13,000 feet were reached, the aircraft was again seen preparing for landing. There was a cross-wind of 35 m.p.h. at approximately 50 degrees to the runway, but the pilot made an extremely short landing and taxied the aircraft to the group of people waiting at the dispersal point. There was a general slapping of backs and congratulations all round : the first flight of North America's first jet transport was over.

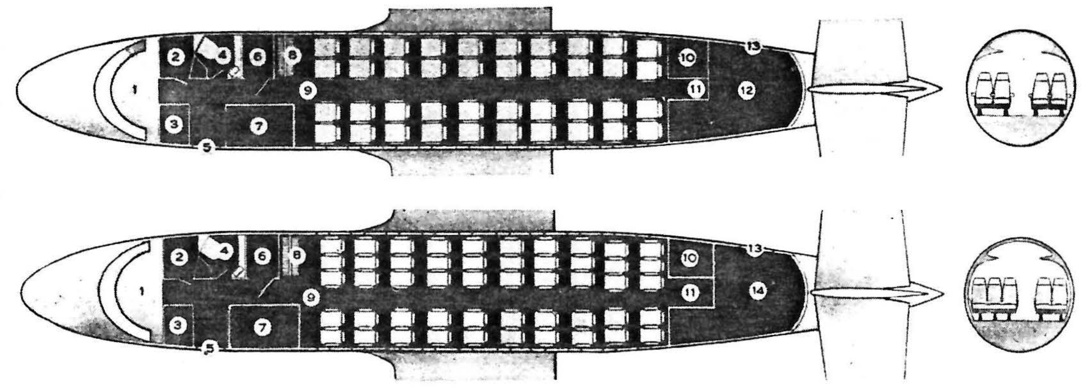


Fig. 3 : Layout projects for 40 and 50 passengers with coat racks near the entrance and galley in the tail.

1 Flight deck
2 Accessory compartment
3 Radio compartment
4 Washroom
5 Entrance door
6 Cargo hold (53.2 cu.ft.)
7 Cargo hold (121 cu.ft.)
8 Coat racks
9 Cabin
10 Galley
11 Air hostess station
12 Cargo hold (367 cu.ft.)
13 Cargo door

FLIGHT TESTING

The most spectacular was most probably the second flight. After almost an hour in the air it was found that it was not possible to extend the undercarriage, and it was discovered later that this was due to a fault in the main undercarriage gear. After losing most of the hydraulic oil in the system, the pilot was forced to land with the nose wheel down and the main gear up and no flaps. The fact that the flaps were up made the aircraft float, and the biggest problem was getting it down at all. After three runs the machine was brought down on the grass verge at the end of the runway and skidded to a stop approximately 50 feet from the airport fence.

The only damage sustained was four bent jet pipes and a caved-in plating in the rear of the fuselage. The landing served to highlight the safety of an aircraft which had no propellers to get in the way in an emergency such as this. The aircraft was flying again in just over four weeks. In a further series of tests some of the engines were cut at the take-off. It was found that with an outboard engine cut at 75 m.p.h. it was still possible to take off and to have plenty of rudder power to spare. Excellent data was also accumulated on the low speed characteristics of the aircraft. These have proved that low-speed characteristics are just as good on a high-speed aircraft, if it is designed properly, as on the present conventional low-speed types.

Before the "Jetliner" had actually flown, there were many criticisms of this type of aircraft. It was stated, for example, that runways and ground personnel would be burned if this category of aircraft were in operation. It would have done the critics good to see the official flight of the "Jetliner". The engines were started while the aircraft was standing next to the big marquee containing the refreshments. The people crowded in to get a good look and some of the press photographers almost tried to climb inside the jet pipe nozzles to photograph the flames around the turbine. Nobody even got their eyelashes singed. Another point that has been grossly exaggerated is the take-off and landing distance required by jet propelled transports. The "Jetliner" has repeatedly been taken off and landed at weights up to 57,000 lbs. gross weight in distances of around 1,000 to 1,500 feet.

Numerous tests on relighting procedures in the air have been carried out, and engines have been shut down and restarted during various stages of flight, and it has never been necessary to attempt more than one start on any engine. As a result, it is now felt that relighting in the air is not only feasible but entirely without hazard.

The most noticeable improvement inside the aircraft is the lack of noise. The test equipment for automatic recording on the "Jetliner" is about twenty feet aft of the cockpit in the fuselage. From his seat the observer can converse with the cockpit without using the aircraft inter-com. The lack of vibration is also very noticeable, and special vibrators have had to be fitted on the instrument panels to prevent instrument needles from sticking. During recent high-speed runs at 30,000 feet at velocities up to 500 m.p.h. the aircraft was brought down at about a rate of 3,000 feet/minute with the use of the dive flaps. There was no sensation of rapid descent, and two of the observers had no idea that the aircraft was going down at all and were surprised suddenly to find themselves at 20,000 feet.

Up to the present there have been surprisingly few snags and, to quote from the pilot's official report, "the aircraft has behaved magnificently and is easy to fly".

CONCEPTION

In the spring of 1946 a detailed market analysis was carried out by the newly formed Avro-Canada organization at Malton for a provisional specification for a medium range inter-city turbo-jet transport. The specification was based on the requirements of the Canadian domestic routes. The result of this analysis was sufficiently favourable to convince both the airlines and the company that the idea of a medium-range jet airliner was basically sound and should be proceeded with immediately. Preliminary design work was started in the summer of 1946 with an extremely small design staff which was gradually increased, and by the early part of 1947 the design was well under way.

In order to reduce the number of untried features to a minimum, which was obviously desirable both from the point of view of safety and rapid development, the aircraft was designed on reasonably conventional lines. Too many design features which had not been satisfactorily proven on previous aircraft would have entailed a considerable amount of laboratory testing, and at the same time the development costs would have been prohibitive. Nevertheless, enough original design features were incorporated.

The aircraft was basically designed around the following general specification :

(1) Suitability for short-to-medium-range inter-city operation with a still-air range of at least 1,200 miles.
(2) Payload of at least 10,000 pounds.
(3) Cruising speed of over 400 m.p.h. at 30,000 feet, without necessity of oxygen for either passengers or crew.
(4) Operation from 4,000-foot runways under Standard Atmosphere conditions and in compliance with Civil Air Regulations take-off conditions; decelerated stop length of 5,000 feet, not to be exceeded under "hot day" conditions following an engine failure.
(5) Full controllability at low speeds; approach and stalling speeds at least comparable with existing transport aircraft.
(6) High degree of serviceability and easy maintenance.
(7) Compliance with aerodynamic and structural requirements of the Civil Air Regulations.
(8) Cost of operation comparable with or lower than existing transports.

The figures in the table serve to show that the target has not only been achieved but that the aircraft is superior to the original specifications.

AVRO C-102 JET TRANSPORT

(four Rolls-Royce "Detwent 5" Turbo-jet engines)

Span	97 ft. 1 in.
Length overall	82 ft. 9 in.
Wing area	1,1567 sq. ft.
Total static thrust at sea level	14,400 lbs.
Gross weight (medium range)	65,000 lbs.
Gross weight (short range)	60,000 lbs.
Maximum landing weight	52,500 lbs.
Still-air range (medium range)	2,000 miles
Still-air range (short range)	1,400 miles
Cruising speed at 30,000 ft. and 60,000 lbs. gross weight	450 m.p.h. -plus
Maximum payload	12,700 lbs.
Number of passengers	40-60
Payload for 1,000-mile range with full ATA allowances at 65,000 lbs. take-off gross weight	10,500 lbs.
Payload for 500-mile range with full ATA allowances at 60,000 lbs. take-off gross weight	12,000 lbs.
Four-engine take-off over 50 ft. obstacle at 60,000 lbs., under ICAN conditions at sea level	3,100 ft.
Three-engine take-off under above conditions	3,525 ft.
Distance to accelerate to critical engine failure speed and stop (CAR 04B.1221) at 60,000 lbs. gross weight at sea level :	
ICAN conditions	3,750 ft.
"Hot day" conditions	4,200 ft.
Landing distance from height of 50 ft.	
Sea level (ICAN)	2,867 ft.
3,500 ft. (ICAN)	3,064 ft.
Stalling speed at landing weight of 50,000 ft. with full flaps	87 m.p.h.
Stalling speed at landing weight of 40,000 lbs. with full flaps	78 m.p.h.

Most ... pressurized to 8,000-foot ... accepted ... this level being accepted ... average person can ...

... would be prohibitive.

It was necessary, therefore, to pressurize the cabin to as near sea level conditions as possible, to enable the aircraft to be brought down in the minimum of time. The condi-

The high speed ... loading resulted in the ... and a speed of 300 m.p.h. E.A.S., whereby a 1.5 structural safety factor is available. The overall wing loads were also increased due to the absence of relieving loads from conventional outboard nacelles.

... obtain optimum approach characteristics and the plan shape which appeared to give the best compromise was one with an aspect ratio of 8.31 and a taper ratio of .5. The latter is the basic characteristic which has the greatest effect on stalling. The straight centre section makes the fuselage-to-wing junction easier to manufacture and helps in the power plant installation.

... Mach .7, sweep-back would not have been worth the extra weight which it would involve. The best arrangement appeared to be a straight rear spar giving a sweep-back of approximately 4 ½° at the quarter-chord. Washout was not adopted. While it would have given slightly better stall characteristics, it also would have resulted in extra induced drag at high speeds.

Split-type flaps are fitted to the first prototype. These will later be changed to the double-slotted type to cut the landing and approach speeds to a minimum. Square tips are used to give greater aileron effectiveness. The dihedral on the outer plane is 6° and the wing incidence is 2 ½° throughout the span.

The shape of the fuselage is the usual compromise between an aerodynamically clean profile and a readily assembled structure, with standardized interior fittings over as great a length as possible. This has resulted in a parallel section of the fuselage for approximately 60 % of the total length with a carefully blended-in fore and aft section. Good lines around the nose canopy were especially important, since the

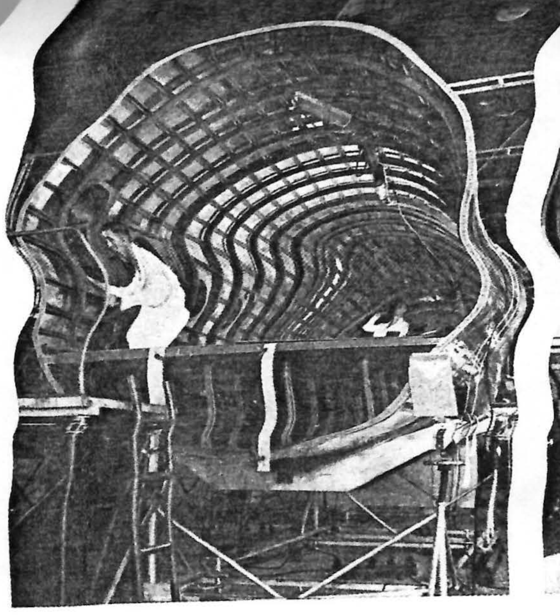


Fig. 4: Through sixty percent of its length the fuselage remains parallel ...

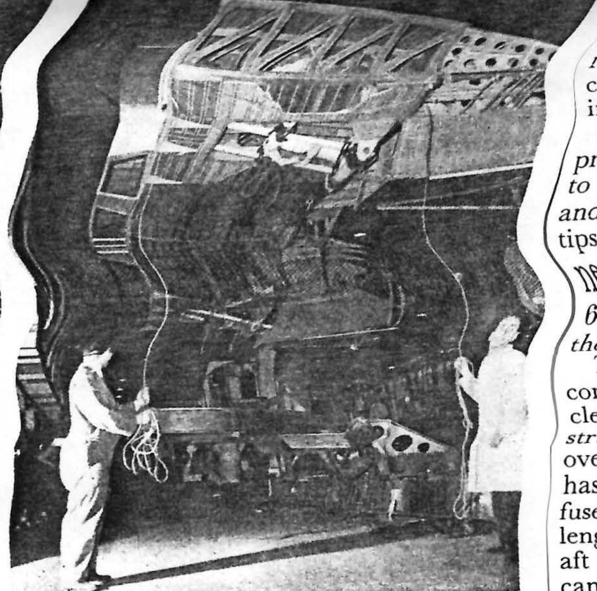


Fig. 5: The centre wing prior to installation of engines.

PRESSURIZING REQUIREMENTS

To obtain the optimum operating conditions with turbo-jet engines it is necessary to fly as high as possible. The reduction in engine thrust between sea level and, say, 30,000 feet is about 40 %, while the drag is reduced to less than 25 %. Since the thrust from the engine is approximately constant for all speeds (the variation being usually less than 5 % between 200 and 500 m.p.h.) it is evident that flying at altitudes is far more important than with conventional aircraft. In the interests of economy, it is also essential to climb the aircraft to operating altitude as fast as possible and to descend as rapidly as possible at the destination.

It would not be feasible to subject the passengers to the extremely rapid changes of pressure caused by a quick descent. The average passenger when awake feels no discomfort at equivalent rates of change in pressure up to 300 ft. per minute in descent, and when asleep may suffer slight discomfort at a rate of change of pressure somewhat below this. Most airlines therefore recommend an equivalent rate of descent in terms of pressure of not more than 200 to 300 feet per minute.

Most modern transports have the cabin pressurized to 8,000-foot conditions at any altitude, this level being accepted as the height to which the average person can climb without feeling any discomfort either from lack of oxygen or from reduced air pressure. Assuming that the "Jetliner" were pressurized to 8,000-foot cabin conditions at 30,000 ft., however, it would take forty minutes for the aircraft to descend at the recommended rate of 200 feet a minute. This would not be feasible, as all the advantage of speed be completely lost and the fuel consumption of four turbojet engines operating for most of the time at low altitudes would be prohibitive.

It was necessary, therefore, to pressurize the cabin to as near sea level conditions as possible, to enable the aircraft to be brought down in the minimum of time. The conditions achieved to date are as follows : a sea level cabin up to 21,250 feet; a 2,000-foot cabin at 25,000 feet; and a 4,000-foot cabin at 30,000 feet. The pressure differential to achieve this is 8.3 lb./sq.in., and as a safety factor of 2 is used for pressurizing, the fuselage has to be designed to withstand a pressure of 16.6 lb./sq. in. The structural problems involved in the use of these high pressures were, to say the least, interesting. A great deal of ingenuity had to be applied to cut down the number of external holes and at the same time design for efficient servicing and maintenance.

For the event of rapid decompression due to a window blow-out, etc., an investigation is now going ahead on the basis of an automatic oxygen system which comes into operation in the case of sudden decompression and which floods the cabin with oxygen vapor.

Although the final seating arrangement and cabin layout will depend upon the customer's choice, it appears to be fairly definite that the high density version accommodating 40 or 50 passengers will be the one of greatest interest. A ten-foot diameter of the fuselage allows for wide seats, and a generous aisle with head room of 82 inches is provided (Fig. 3).

STRUCTURAL REQUIREMENTS

The high speed and relatively low wing loading resulted in the load factors being considerably higher than those in use for present transport aircraft. Gust factors vary directly with the speed and inversely with the wing loading. The relatively large amount of fuel carried and used results in a low landing weight and consequently in a low wing loading. All this makes for a higher gust factor. The highest limit factor is 4.5 at an empty weight of 34,000 lbs. and a speed of 300 m.p.h. E.A.S., whereby a 1.5 structural safety factor is available. The overall wing loads were also increased due to the absence of relieving loads from conventional outboard nacelles.

Fig. 4 : Through sixty percent of its length the fuselage remains parallel (diameter 10 ft.; cabin head room, 6 ft. 10 in.).

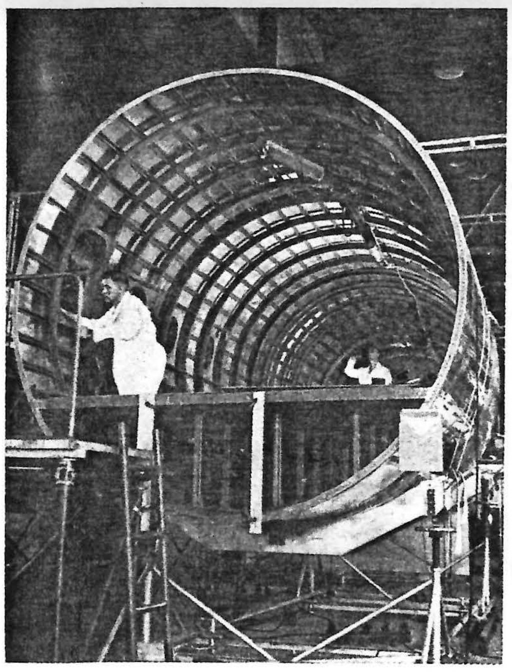
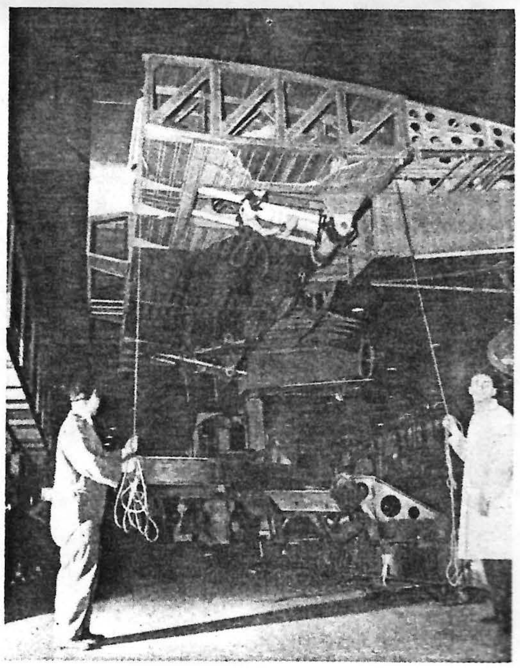


Fig. 5 : The centre wing prior to installation of engines.



To compensate for the increased structural strength required, high strength aluminium alloys were used extensively to obtain the maximum strength-weight ratio. The outer wings are also designed as fully stressed wing structures, with heavy gauge skins and stringers taking the place of the usual concentrated spar booms and providing a high degree of torsional stiffness. Extra heavy skins are used on the lower portion of the fin to give torsional rigidity and to prevent tail flutter. The structure weight is approximately 27% of gross, at 60,000 lbs., or about 16,200 lbs.

AERODYNAMIC CONSIDERATIONS

As the thrust is approximately constant for all speeds, the distance travelled per unit of fuel is increased in almost direct ratio to the aircraft speed. The aircraft therefore has to be aerodynamically clean to cut the parasitic drag to a minimum. In the C-102 the greatest care has been taken to obtain a good finish, and all external riveting is flush. Practically all the antennae are flushed into the contour, with the exception of the short radio compass sense antenna in the nose and the conventional wire antenna for HF communication.

The choice of wing section—always of necessity a compromise—was even a little more complex than usual. Drag had to be cut down to a minimum, and at the same time it was necessary to obtain the highest lift for take-off and landing. The NACA 230 Series which was chosen is a relatively strongly cambered aerofoil, with a thickness at the root of 16.5 % and at the tip of 12 %. The aircraft will be operating at a Mach number of less than .7 at 30,000 feet, and no compressibility problems are expected at these speeds.

A fairly low wing loading was used to obtain optimum approach characteristics, and the plan shape which appeared to give the best compromise was one with an aspect ratio of 8.31 and a taper ratio of .5 The latter is the basic characteristic which has the greatest effect on stalling. The straight centre section makes the fuselage-to-wing junction easier to manufacture and helps in the power plant installation.

For an aircraft operating at less than Mach .7, sweep-back would not have been worth the extra weight which it would involve. The best arrangement appeared to be a straight rear spar giving a sweep-back of approximately 4 ½° at the quarter-chord. Washout was not adopted. While it would have given slightly better stall characteristics, it also would have resulted in extra induced drag at high speeds.

Split-type flaps are fitted to the first prototype. These will later be changed to the double-slotted type to cut the landing and approach speeds to a minimum. Square tips are used to give greater aileron effectiveness. The dihedral on the outer plane is 6° and the wing incidence is 2 ½° throughout the span.

The shape of the fuselage is the usual compromise between an aerodynamically clean profile and a readily assembled structure, with standardized interior fittings over as great a length as possible. This has resulted in a parallel section of the fuselage for approximately 60 % of the total length with a carefully blended-in fore and aft section. Good lines around the nose canopy were especially important, since the

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critical Mach number in that region is 73., *i. e.*, higher than for the wing.

The tailplane is located high on the fin. Mounting it on the centre line of the fuselage would have placed it directly in the wake of the jets. While the temperature effects of the jet stream are not too serious by the time they get to the tail, the velocity effects are more marked. Had the tail been just out of the jet stream but fairly low down on the fin above the fuselage, there would have been a marked interference between the sharply tapered after body and tailplane.

The jet nozzles are inclined downward at an angle of 7° to bring the line of action of the jets as close to the normal centre of gravity position as possible and minimize the effect of change of trim for power-on and power-off. The jet stream has a cleaning-up effect around the trailing edge of the centre section wing. When the engines are opened up during a baulked landing, air is drawn into the jet stream over the adjacent wing surfaces due to the greatly increased velocity through the jet nozzles. This has the effect of reducing the stalling speed under these conditions.

An unusual design of wing root fillet was incorporated to take care of the up-wash from the fuselage. It was tried out on a British aircraft and produced excellent results. The stalling speed was reduced by approximately 7 m.p.h. and there was no effect on longitudinal stability (Fig. 6).

Double aerodynamically-unbalanced control surfaces have been used for both the rudder and elevator controls. The intermediate auxiliary surface of the rudder is used solely to trim out for an engine failure at low speeds. With the use of jet engines, high rudder angles are not normally necessary due to the absence of slipstream, which is the usual cause of swing at take-off. The engines are also close to the fuselage, which again reduces the rudder power required.

The tailplane is out of the flap wake during landings and, therefore, the tail efficiency is high. The auxiliary surface of the elevator is only required for the flare-out on landing with an extremely forward centre of gravity. Piano hinges have been used on all the tail surfaces, and this improves the effectiveness by sealing the gaps. Narrow-chord high-aspect ratio surfaces are employed, since they require no aerodynamic balance, have lower drag, offer less danger of icing, better repeatability and low weight of mass balance.

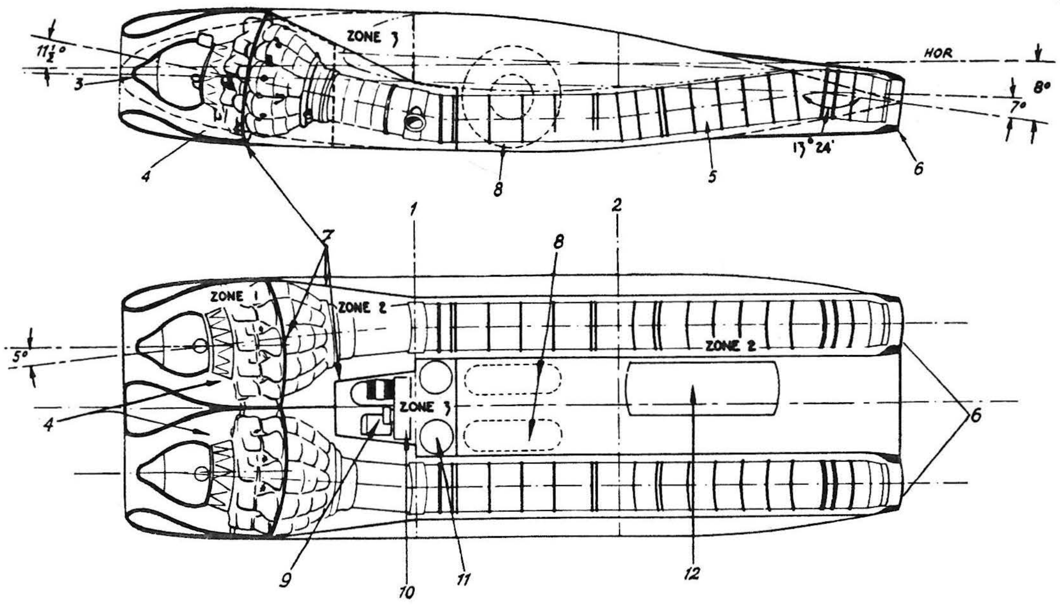


Fig. 7 : The longitudinal section of the engine nacelles resembles a NACA aerofoil; the nacelle plan form is rectangular.

1 Front spar
2 Rear spar
3 Nose bullet surrounding oil tank and accessories
4 Plenum chamber
5 Jet pipe
6 Extractor nozzle
7 Fire bulkhead
8 Main undercarriage wheel
9 Engine accessories
10 Accessory gearbox
11 Methyl bromide bottles
12 Water methanol tank

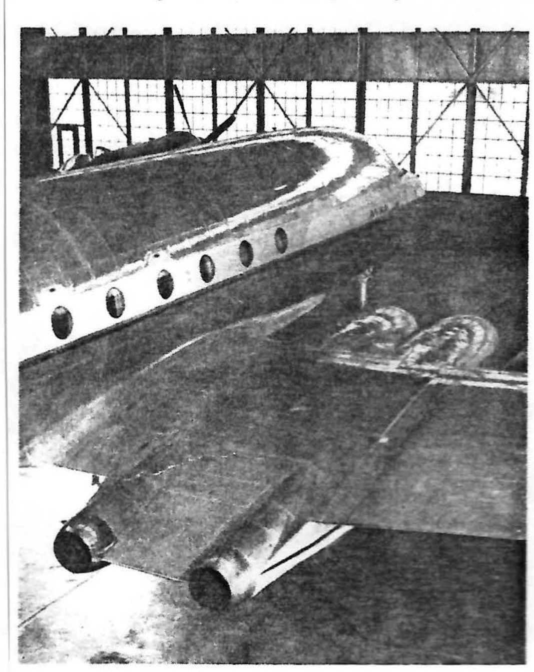
POWER PLANT

Originally the C-102 was designed to take two Rolls-Royce "Avon" engines. In the autumn of 1947, when it was realized that the "Avon" would not be available for the first prototype, it was decided to use four Rolls-Royce "*Derwent 5*" engines. This decision was not taken lightly, as it involved the complete redesign of the centre section structure. Similarly, the sideways retracting undercarriage scheme had also to be completely scrapped. The change in centre of gravity due to the addition of two extra engines necessitated a repositioning of the wing in relation to the fuselage.

As the redesign work progressed, however, it became evident that four engines were a very much better and safer arrangement and that the landing gear design was greatly simplified. Furthermore, the "Derwent" engine had flown in military aircraft for over 100,000 operational hours, which was a very important point in eliminating one of the big unknowns. The use of four engines also made compliance with existing airworthiness regulations much easier and the engine failure case less severe on the control surfaces. The decision to use underslung nacelles instead of the "through-the-spar" arrangement chosen for the original engines will also simplify the fitting of newer types of engine as they become available without any major structural alterations.

The four "Derwent 5" engines, standard Rolls-Royce units employing a completely redesigned oil tank, are mounted in pairs in two nacelles, with each nacelle forming a single integrated structure (Fig. 7-9). Engine servicing and maintenance is made particularly easy by the low position of the nacelles, and all adjustments can be made without using service ramps or ladders. Engine removal is carried out by detaching the services and gear drives at the break points, swinging the trunnion locating caps down and dropping the engine onto a special trolley. The engine is then wheeled away sideways to make room for the replacement engine. With this unique arrangement, a complete engine change can be made in a very short time.

Fig. 6 : A wing root fillet of unusual design reduces the upwash from the fuselage.



Although a relatively long jet pipe is used, it is estimated that less than 1 % of thrust is sacrificed through the combined effects of length and shape of the pipe. The pipes have a 16-inch nozzle and run through a tunnel of stainless steel formed by fire walls attached to the adjacent structure. The pipe itself is insulated and cooled by a flow of air passing through the fire wall tunnel and induced by the extractor nozzle.

All engine-driven main accessories are mounted on an accessory gear box located between the engines in each nacelle and attached to the wing front spar. The gear box contains two completely independent gearing systems, each driven by one engine.

Because the thrust from a jet engine varies greatly with temperature and airport altitude—on a hot day with a temperature of 110°F the reduction in thrust can be as much as 16 %, which can be critical for take-off—some means of thrust augmentation had to be incorporated. It was finally decided that injection of a water-methanol mixture into the compressor inlet offered the best solution. The predominant effect of this is to increase the mass flow of air to the engine by increasing the air density at the compressor inlet. The injection system is relatively simple and has few of the disadvantages of other forms of augmentation, such as after-burning, in which the long sheets of flame issuing from the tail cone are likely to cause alarm to the passengers. Under tropical conditions water-methanol injection is necessary at the rate of ten gallons per minute per engine to provide the static thrust which should be obtained for take-off under standard ICAN conditions. A tank is housed in each nacelle holding 66 gals. of water-methanol, which is sufficient to supply each engine with the quantity required for three minutes.

The civil version of the standard Rolls-Royce "Derwent 5" can be operated at take-off and climbing power at 14,700 r.p.m. for a period of 15 minutes and at maximum continuous power at 14,100 r.p.m. for an unrestricted time. Idling speed on the ground is approximately 5,300 r.p.m.

Fuel is housed in four integral wing tanks located in the inboard portion of the outer wings, between the main spars. The total capacity of the tanks on the first prototype is 2,400 Imp. gals. The tank capacity can, however, be considerably increased. A cross-balance pipe is provided so that fuel from any tank is available to all engines in an emergency. In the event of failure of the booster pumps, the engines are capable of sufficient suction to enable them to operate with the booster pump out of action.

Both overwing and underwing refuelling is installed, and the tanks can be refilled at the rate of 200 Imp. gals. per min. through each underwing refuelling valve at a nozzle orifice pressure of approximately 5 p.s.i.

LANDING GEAR AND HYDRAULIC SYSTEM

The absence of propellers and the consequent short distance between the aircraft structure and the ground, coupled with the fact that an underslung nacelle configuration was used, resulted in an extremely short main landing gear (Fig. 10). The actual distance between the undercarriage main pivot and wheel centres is less than 30 inches. This has resulted in an extremely robust and simple design, which is believed to be lighter as a percentage of the gross weight than any existing transport undercarriage. Twin wheels are used on both the main and nose units, both retracting forward. The main undercarriage struts consist of a telescopic leg incorporating liquid springing. The nosewheel is steerable through an arc of 70 degrees each side, and the wheel casters through 360 degrees for towing.

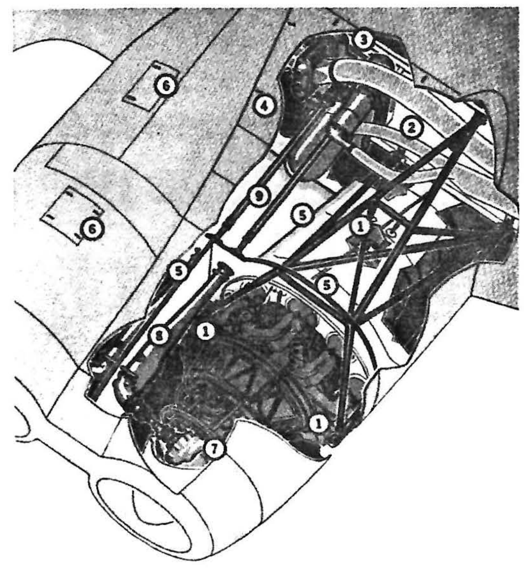


Fig. 9 : Engine installation diagram.

1 Engine mounting assembly points
2 Centre section front spar
3 Accessory gearbox
4 Access panel
5 Fire-proof bulkheads
6 Access panels for lowering engine
7 Bevel gear drive housing
8 Intermediate drive housing
9 In-put drive shaft

The main hydraulic system is of the high pressure type operating at a normal pressure of 1,800 p.s.i. Power is provided by two constant - pressure variable - displacement pumps on the accessory gearbox in the nacelles. Either pump will provide full hydraulic power for the complete system, and the use of two pumps is to provide duplication against failure. Main services operated by the hydraulic system are the main and nose undercarriage gear, nosewheel steering unit, landing and dive flaps, main wheel brakes, main wheel doors and aileron power booster. Accidental ground retraction of the wheels is prevented by a micro-switch which comes into operation when more than 5 per cent of the aircraft weight is on the wheels. Complete duplication of the normal hydraulic system is provided by a "power pack" consisting of an electrical motor and a pump.

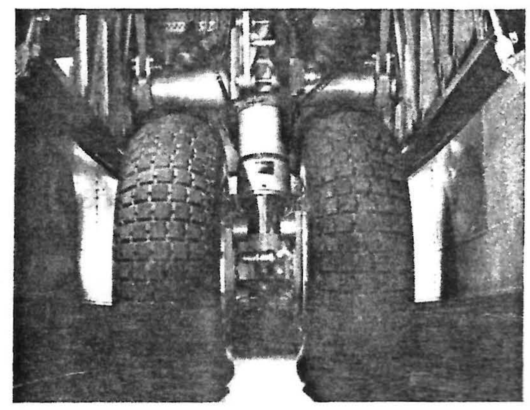


Fig. 10: Main wheels with liquid-sprung shock strut; the distance between the undercarriage main pivot and wheel centres is less than 30 inches.

Fig. 8 : Small distance above ground facilitates engine servicing.

FLIGHT PLAN AND OPERATING COSTS

Until the various flight plan procedures have been worked out between the airlines, the civil air authorities and airport control personnel, it is obviously not possible to give a definite flight plan. Fig. 11 shows a recommended procedure which allows for a standard 45-min. stacking period and 120-mile flight to an alternative airport, plus allowance for instrument approach, landing and taxing. The decision to descend or to proceed to the alternative must be made at an altitude of 25,000 ft. and approximateyl 34 miles from the airport.

Due to the high cruising speed, it is expected that the weather at destination will have been reasonably accurately established and will not have changed during the short flying time. If conditions are considered to be unfavourable for landing at the destination airport, the aircraft proceeds at its best endurance speed at an altitude of 25,000 ft. Any stacking required is carried out at 25,000 ft. or could be accomplished at any altitude on two engines without penalty in fuel consumption. When the aircraft is given the signal to land, the normal procedure of descent and instrument approach is then made at the alternative.

The flight plan as shown is applicable for all ranges above approximately 200 miles.

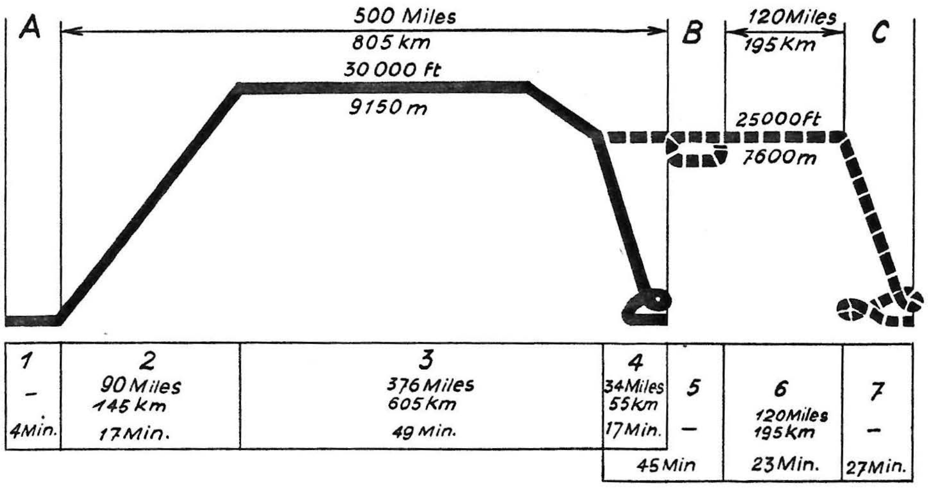


Fig. 11 : "Jetliner" flight plan for 500-mile route; landing at destination (B) or alternative (C).

1 Taxiing (450 lbs. fuel)
2 Climb to 30,000 ft. (3,415 lbs. fuel)
3 Cruising at 376 m.p.h. (4,695 lbs. fuel)
4 Descent and landing, taxiing at destination (1,100 lbs.
5 45 Minute stacking at destination (2,550 lbs. fuel)
6 Flight to alternative (1,645 lbs. fuel)
7 Descent, approach, landing and taxiing at alternative (extra consumption, 930 lbs. fuel)

For ranges under 200 miles it is debatable whether it is worth while climbing to an altitude of 30,000 ft. for cruising. For a range of 500 miles, the take-off and climb to 30,000 ft. covers a distance of 90 ground miles and the descent from 25,000 ft. approximately 34 miles. Normal cruise at the operating altitude therefore covers approximately 376 miles. The fuel used for take-off, climb to 30,000 ft., cruise, descent and approach for a range of 500 miles is approximately 9,670 lbs., while the fuel allowances carried for flight to alternative, stacking and descent amounts to 5,130 lbs., or just over one-third of the total fuel load.

Descent is carried out at 200 m.p.h. E.A.S. with the use of dive-brakes to obtain a high angle of descent. The engines are throttled down to 7,000 r.p.m., at which speed the accessories are designed to maintain the full output required for any of the services. The average fuselage angle during descent is not more than 8 degrees, which is considered to be reasonable from a passenger comfort point of view.

Finally, the *operating costs* had to be considered very carefully, and their consideration played an important part in the final design configuration of the aircraft. Of the two important efficiency factors in the cost analysis, namely, the cost per mile and the payload for a given range, the first is obviously governed by speed. Many of the direct costs, such as crew salaries, depreciation, insurance, etc., are fixed hourly costs. Neglecting fuel consumption, an increase in the block speed from approximately 250 m.p.h. to 350 m.p.h. would result in a decrease in the cost per mile of approximately 30 percent. It has been shown that this decrease in the cost due to speed more than compensates for the increase due to higher fuel consumption.

Fig. 12 : Inter-city jet services in the near future ? The "Jetliner" covered the Toronto-New Yorkroute (approximately Amsterdam-Basel) in about one hour's flying.

The effect of block speed can be seen more clearly by considering the number of aircraft required for a given schedule. If the block speed is doubled, the number of aircraft needed is halved and, consequently, the earning power of each aircraft is considerably increased.

To take advantage of the higher block speed, however, maintenance and turn-around time at the airport has to be cut to a minimum, and the optimum climb and descent procedure from operating altitude taken into account. The high degree of pressurization and the incorporation of dive-flaps, the use of special accessories and radio compartments where practically all items requiring frequent servicing are housed, and the employment of underwing pressure refuelling are only a few of the items which have been incorporated to increase the economic efficiency of the aircraft.

So far as the payload portion of the cost-per-ton-mile efficiency datum is concerned, the fuselage was laid out to give the best compromise between a full-passenger version and a combined passenger-and-cargo model. Two typical lay-outs are the forty-passenger version with an additional 4,100 lbs. of freight or a total payload of 12,500 lbs., and the fifty-passenger version with a payload of 10,500 lbs.

While the final analysis of economy must be left to the individual airlines, a detailed study shows that the direct operating costs of the "Jetliner" compare very favourably with those of present transports, despite the relatively high fuel consumption of available jet engines and the fact that the present allowances for stooging and flight to an alternative airport are severe on the jet transport. It is obvious that, as the specific fuel consumption for the jet engine improves, with the use of ceramic blade materials and higher compression ratios, etc., and as the flight procedures are modified to cut down the stooge time, the picture will become progressively even brighter.

There has been much discussion in the past on the relative merits of jet and piston-engined aircraft. Most of the criticisms of the jet have been made by people who have never had the experience of working on a jet project or getting down to the job of comparing the two types on a rational basis. This stage has passed, however, and the main argument now is not *if* the jet transport will be used but *when* it will be used. The successful demonstration of the "Jetliner" in flight has brought that date a little nearer.

5

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