#408

The Avro C102 "Jetliner"

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For presentation at the
SAE ANNUAL MEETING
Book-Cadillac Hotel, Detroit, Michigan
January 9-13, 1950

SOCIETY of AUTOMOTIVE ENGINEERS, Inc., 29 West 39th Street, New York 18, N. Y.

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 honour of being the world's first jet transport to actually fly, which went to the British De Havilland 'Comet'.

The main purpose of this paper is to give a brief summary of the design and general problems, which were encountered in the development of the first prototype up to the present flight test stage.

Before proceeding with the main portion of the paper, however, and with apologies to the technical reader, the author would like to give a short account of the events which immediately preceded the first flight.

Introduction

On the 25th of July, the last stages of preparation for flight were nearing completion and the aircraft had reached the stage of final inspection and last minute test checking.

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 had to completely change the design of the aircraft to accommodate four engines of a different type.

Having reached the final inspection stage, we thought therefore that most of our bridges were crossed and all that we had to do was get our aircraft into the air. It just shows how optimistic you can get.

Two days later on July the 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 honour 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, which were not scheduled to be finished until some time towards the end of August. We were informed, however, by D. O. T. that we would have one runway on which to land, the 14-32 runway running north east and south west, with a bituminous surface, and we would also have a short piece of concrete runway on which to carry out our engine runs and taxi trials.

Then to confuse things still further, the temperature decided to take a hand in the proceedings, and for several days before the first flight was anticipated, it hovered between 90° and 100°F.

Final engine runs having been completed over the week end, the aircraft was wheeled out of the hangar on Monday August the 8th to start taxi trials. As a special favour, the temperature had gone up to 103°F, nevertheless, we carried out our taxi runs, braking tests, steering control tests, 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 normal reciprocating engines. We had a very short runway, due to the alterations to the rest of the runways, and the pilot was handling a completely new type of aircraft, the performance of which could only be predicted at that time.

We had calculated the distance required to take off and the decelerated stop after the hop, and from our calculations, there were only a few feet of runway left for pilot's error.

The aircraft taxied down to the north east end of the runway, wasting as little space as possible, the throttles were opened up, the aircraft accelerated, and at about 90 mph, the nose wheel came off the deck. A few seconds later, there were four loud and ominous reports, the nose wheel came down, and the aircraft decelerated to a stop, just 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 been easily able to keep the aircraft on the runway, and there was no damage to the wheels or brakes or any other portions of the aircraft.

The aircraft 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 at a hop.

On Wednesday morning, August the 10th, three more runs were made and a hop was attempted on the third run. This time, the two main wheels on the starboard side of the aircraft blew out, and the pilot again brought the aircraft to rest dead in the centre of the runway, and this time, with quite a bit of runway to spare.

The tires were quickly changed and a conference held to decide whether any more attempts at a hop would 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 rather take her up and 'have done with it', as he expressed 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 crosswind on the only available runway, and the fact that the temperature was around 103°F, the next time they went down on the runway, they would just keep on going, and so just after lunch on Wednesday, August the 10th, the Jetliner came down the runway, lifted off the deck after a relatively short run, and gracefully climbed up to about 500 ft. 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 where the ground crew were standing to let the boys have a look at the aircraft in the air. He then climbed away to 8,000 ft. and reported after a few minutes flying, that everything felt wonderful, and needless to say, everyone on the ground felt pretty good too.

After a flight of about one hour, during which time the aircraft was flying at altitudes up to around 13,000 ft., the aircraft was again seen, preparing for landing. By this time, the weather man had turned on a crosswind of 35 mph at approximately 50° to the runway, but the pilot made an extremely short landing, and taxied the aircraft down to the group of people waiting at the dispersal point.

There was a general slapping of backs and congratulations all round, the aircraft was wheeled back to the hangar, and the first flight of North America's first jet transport was all over.

Since that time, the aircraft has done approximately thirty flights, during which much valuable data has been accumulated, and the aircraft is now well on the way to completing the tests, which have to be carried out before the aircraft can be put up for C. A. A. approval.

It may be worth while mentioning one or two of the highlights of this test programme.

The most spectacular was probably the second flight, when after almost an hour in the air, it was found that it was not possible to extend the under-carriage, and it was discovered later that this was due to a fault in the main under carriage gear. After losing most of the hydraulic oil in the system, the pilot was forced to land with the nose wheel down, 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, but after three runs, the pilots brought the aircraft down on the grass verge at the end of the runway, and skidded to a stop approximately 50 ft. from the airport fencing.

The only damage sustained was four bent jet pipes and a caved-in plating in the rear of the fuselage, and the landing only served to highlight the safety of an aircraft which had no propellers to get in the way on an emergency such as this. The nacelles were repaired, and the aircraft was flying again in just over four weeks, having completed a test which no manufacturer would dare to carry out at this stage in the life of a prototype, unless by accident, as in this case.

There is no doubt that we got a lot of data from this test, and we also learned something from the tire bursting episode, as it was proved that the aircraft could be brought to rest easily with any tires burst, in any order.

Another series of tests probably worth mentioning are the engine cuts at take-off. An outboard engine was shut down at various speeds between 130 mph and 75 mph. It was found that with an outboard engine cut at 75 mph, it was still possible to take off and have plenty of rudder power to spare.

A lot of excellent data has also been accumulated on the low speed characteristics of the aircraft. These have proved that the low speed characteristics are just as good on a high speed aircraft, if it is designed properly, as on the present conventional low speed type of aircraft.

Before the jet transport had actually flown, there were many criticisms of this type of aircraft, and some of them were so bitter that one would almost think that they had been instigated by the manufacturers of propellers and their attendant controls.

One of the criticisms was, that the runways and ground personnel would probably get burned up when these aircraft were operating. It would have done the critics good to see the official flight of the Jetliner. On this day, the engines were started while the aircraft was standing next to the big marquee containing the refreshments. As the aircraft moved away, the people generally crowded in to get a good look, and some of the press photographers appeared to be almost trying to climb inside the jet pipe nozzles to photograph the flames around the turbine, and nobody even got their eye lashes singed.

Another point that has been grossly over-exaggerated is the takeoff and landing distance required with the jet airliner. The Jetliner has been repeatedly taken off and landed at weights up to 57,000 lb. T. O. gross weight during tests, in distances of around 1,000 to 1,500 ft. and in one case, landed at an average landing weight, less than 950 ft. from the approach end of the runway.

Numerous tests on relighting procedures in the air have been carried out, and engines have been shut down and restarted at various stages during test flights, and it has never been necessary to attempt more than one start on any engine. The results have been so good, that it is now felt that relighting in the air is not only feasible, but if carried out correctly is entirely without hazard.

Probably the most noticeable improvement inside the aircraft is the amazing lack of noise. The test equipment for automatic recorder on the Jetliner is about twenty feet aft of the cockpit, in the fuselage, and the observer sits at this station with the various instruments and cameras. It is possible to converse without using the aircraft inter-com. by just carrying out a normal conversation between the cockpit and the observer's station.

On one flight when a Lancaster aircraft was being flown along side the Jetliner to get some photographs for the press, the roar of the Merlin engines were quite apparent from inside the Jetliner. It was almost possible to tell without looking out of the windows just how close the Lancaster was at any time.

The lack of vibration is also very noticeable, and special vibrators have had to be fitted on the instrument panels to prevent instrument needles sticking. During the high speed runs which were recently made at 30,000 ft., at which time the aircraft reached speeds up to 500 mph, descent procedures were checked from 30,000 ft., and the aircraft was brought down at a rate of approximately 3,000 ft. a minute with the use of the dive flaps fitted on the aircraft. There was no sensation of rapid descent, and in fact, two of the observers had no idea that the aircraft was descending at all, and were surprised to find themselves at 20,000 ft. when they were of the opinion that they were taking readings at 30,000 ft.

The aircraft is at present being fitted with the necessary equipment to test the air conditioning and pressurizing system, carry out cruise control, and make a final assessment of the aerodynamics. To date, the test program has gone extremely well, and a large amount of data has been amassed in a relatively short time.

Without giving away any secrets, it can be said that up to the present time, there have been surprisingly few snags, and to quote from the pilot's official report, "The aircraft has behaved magnificently and is a very easy aircraft to fly".

The following portion of the paper gives a brief history of the project and covers some of the Technical problems encountered in the design.

CONCEPTION

During the latter part of 1945, some interest was shown by the airlines in both Canada and the United Kingdom in the remarkable progress then being made with the use of the turbojet engine in military aircraft. At the end of 1945, the Gloster Meteor was in regular squadron service with the R. A. F., and the U. S. Army Air Forces were also using jet fighters.

It was generally agreed that if the advantages of high speed and reduction of noise that the jet engine offered, could be combined with the requisite safety and economy essential in airline operation, there would be a ready market for the high speed jet powered transport.

In the spring of 1946, a detailed analysis was carried out at the newly formed Avro Canada Organization at Malton, around a provisional specification for a medium range inter-city turbojet transport. The specification was based upon the requirements of the Canadian domestic routes. The results of this analysis were sufficiently favourable to convince both the airlines and the Company that the idea of a medium range jet airliner was not only feasible, it was also 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.

DESIGN POLICY

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.

It was felt that the incorporation of too many design features which had not been satisfactorily demonstrated on previous aircraft would entail a considerable amount of laboratory testing, and at the same time, the development costs involved would be prohibitive. Nevertheless, enough original and novel design features were incorporated to make the project unusually interesting.

As the less conventional features will obviously be of the most interest, these will be covered in greater detail in this paper.

SPECIFICATION

The general specification around which the aircraft was designed was basically as follows:

(1) The aircraft was to be a turbojet powered short-to-medium range inter-city transport with a still air range of at least 1,200 miles.

(2) The payload was to be at least 10,000 lb., and accommodation for not less than 30 passengers was required.

(3) A cruising speed of over 400 mph at 30,000 ft. was specified without having to resort to the use of oxygen for the passengers or crew.

(4) The aircraft was to be designed to operate from airports with 4,000 ft. runways under Standard Atmosphere conditions and comply with the take-off conditions of the Civil Air Regulations. A decelerated stop length of 5,000 ft. was not to be exceeded under 'hot day' conditions following an engine failure.

(5) Controllability at low speeds was not to be sacrificed in any way, despite the high speed range required. The approach and stalling speeds were to be at least comparable with present transport aircraft.

(6) Special attention was to be given to serviceability and maintenance problems to allow for maximum utilization and operational regularity.

(7) The aerodynamic and structural requirements of the Civil Air Regulations were to be achieved.

(8) The cost of operation was to be comparable with or better than existing transports.

This then was the target. The figures in Table 1 will serve to show that it has not only been achieved, but that the aircraft as now designed is superior in all respects to the original specification.

TABLE 1

C-102 JET TRANSPORT

4 Derwent 5 Turbojet Engines Total Static Thrust at Sea Level I. C. A. N. Conditions	14,400 lb.
Gross Weight (Medium range version)	65,000 lb.
Gross Weight (Short range version)	60,000 lb.
Maximum landing weight	52,500 lb.
Still air range (Medium range version)	2,000 miles
Still air range (Short range version)	1,400 miles
Cruising speed at 30,000 ft. and 60,000 lb. gross weight	450 + mph
Payload	12,700 lb.
Number of passengers	40 - 60
Payload for 1,000 mile range with full A. T. A. allowances at 65,000 lb. T. O. gross weight	10,500 lb.
Payload for 500 mile range with full A. T. A. allowances at 60,000 lb. T. O. gross weight	12,000 lb.
4 Engine take-off over 50 ft. obstacle at 60,000 lb. I. C. A. N. conditions sea level	3,100 ft.
3 Engine take-off with above conditions	3,525 ft.

Distance to Accelerate to Critical Engine Failure Speed and Stop-ft. (C. A. R. 04B.1221):

60,000 lb. Gross Weight at sea level

I. C. A. N. conditions	3,750
'Hot day'	4,200

Landing	Distance from Height of 50 ft. - ft.
Sea level (I. C. A. N.)	2,867
3,500 ft. (I. C. A. N.)	3,064

Stalling speed at landing weight of 50,000 lb. with flaps in landing position.	87 mph
Stalling speed at landing weight of 40,000 lb. with flaps in landing position.	78 mph

To achieve the above results, there were many difficult and new problems to be faced. As there were no aircraft of this type in service, there was obviously no experience or established data to fall back on for many of these special problems.

A summary of some of the major items, which had to be considered will serve to show the nature of some of these problems.

PRESSURIZING REQUIREMENTS

To obtain the optimum operating conditions with turbojet engines, it is necessary to fly as high as possible. The reduction in engine thrust between sea level, and say, 30,000 ft. is around 40%, while the drag is reduced to less than 25%, and as the thrust from the engine is approximately constant for all speeds, the variation being usually less than 5% between 200 and 500 mph, it can be seen that flying at altitude is far more important than with conventional aircraft.

In the interests of economy, it is also essential to climb the aircraft to the operating altitude as fast as possible, and to descend as rapidly as possible at the destination.

Since it would not be feasible to subject the passengers to the extremely rapid changes of pressure caused by a quick descent, the pressure in the cabin has to be kept as constant as possible at all times. Statistics indicate that average passengers when awake feel 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 ft. per minute.

Most conventional pressurized aircraft have the cabin pressurized to 8,000 ft. conditions at any altitude, 8,000 ft. being accepted as the altitude to which the average person can climb without feeling any discomfort either from lack of oxygen or reduced air pressure.

Assuming that this aircraft was pressurized to 8,000 ft. cabin conditions at 30,000 ft., however, it would take 40 minutes for the aircraft to descend at the recommended rate of 200 ft./min. This is obviously not feasible with a jet aircraft, as not only would all the advantage of speed be completely lost, but the fuel consumption of four turbojet engines operating for most of the time at low altitude would be prohibitive.

It was obviously necessary, therefore, to pressurize the cabin to as near sea level conditions as possible, right up to the cruising altitude to enable the aircraft to be brought down in the shortest possible time. The conditions achieved to date are as follows: a sea level cabin up to 21,250 ft., a 2,000 ft. cabin at 25,000 ft., and a 4,000 ft. cabin at 30,000 ft. The pressure differential to achieve this is 8.3 lb./sq.inch., and as a safety factor of 2 is used for pressurizing, the fuselage had to be designed to withstand a pressure of 16.6 lb./sq. inch. The structural problems involved with the use of these high pressures were to say the least, interesting.

As it is obviously not desirable to put large access holes and doors in the fuselage for servicing under these pressures, a great deal of ingenuity had to be used to cut down the number of external holes, and at the same time design for efficient servicing, and maintenance.

Rapid decompression due to a window blow-out etc. is always a problem in considering high altitude flying for passenger carrying aircraft. It is comforting to note, however, that in the opinion of the Aviation Medicine experts, the only real physiological discomfort up to 30,000 ft. is the lack of oxygen. Above 40,000 ft., the average individual is unable to obtain sufficient oxygen, even when breathing an atmosphere which consists entirely of oxygen, because of the decrease in total pressure in the lungs.

As the optimum operating altitude of the C-102 was set at 30,000 ft. bearing in mind the best flight path for average range, this problem was not considered to be too serious. Investigation is, however, going ahead on the basis of an automatic oxygen system which comes into operation, if a blow-out does occur, and which floods the cabin with oxygen vapour.

CHOICE OF ENGINES

Originally designed as a twin engined transport, the C-102 was designed to take two Rolls-Royce Avon engines.

In the fall of 1947, when it was realized that the Avon engines would not be available for the first prototype, it was decided that four Rolls-Royce Derwent engines would be used on the first aircraft.

The decision to do this was not taken lightly, as it involved a complete redesign of the centre section structure which was then somewhere near design completion. The sideways retracting undercarriage scheme had also to be completely scrapped.

It was necessary to srart from scratch on the nacelles, and the change in centre of gravity due to the addition of two extra engines necessitated a re-positioning of the wing in relation to the fuselage.

As the redesign work progressed, however, it became evident that the use of four engines was not only a very much better and safer arrangement, but the fact that the undercarriage would now be retracted fore and aft in the nacelles made the undercarriage unit and adjacent structure very much simpler in all respects. Also the use of engines which had been operating in military aircraft for over 100,000 operational hours was a very big point in eliminating one of the big unknowns, which would have had to be faced with the use of engines which were only in the development stage.

The use of four engines also made compliance with existing C. A. A. requirements very much easier, and the engine failure case less severe on the control surfaces.

The decision to use an underslung nacelle instead of the 'through-the-spar' arrangement necessary with the original engines, also simplifies the fitting of newer types of engines as they become available without any major structural alteration.

STRUCTURAL REQUIREMENTS

The high speed and relatively low wing loading resulted in the load factors being considerably higher than those at present used for transport aircraft. Reference to C. A. A. 04. 21411 shows that the gust factors vary directly with the speed and inversely with the wing loading.

The relatively large amount of fuel carried in the jet powered transport resulting in a low landing weight, and consequently, a low wing loading, together with the increased speed, all make for a higher gust factor.

The limit load factors for gust conditions can be seen in figure 2, and these have to be multiplied by a safety factor of 1.5.

The highest limit load factor is 4.5 at an empty weight of 34,000 lb. and a speed of 300 mph E. A. S.

The overall wing loads were also increased due to the absence of relieving loads from conventional outboard nacelles.

To compensate for the increased structural strength required, the high strength aluminum alloys 75ST and 24ST are used extensively to obtain the maximum strength-to-weight ratio.

The outer wings are also designed as fully stressed skin structures with heavy gauge skin 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 prevent tail flutter.

The windscreen structure is a high strength aluminum alloy casting, and the pressure bulkheads are situated at the front of the windscreen and at the rear of the passenger cabin.

The rest of the structure is along conventional lines, and so will not be dealt with in any great detail. The structure weight is approximately 27% of gross at 60,000 lb.

GENERAL AERODYNAMIC CONSIDERATIONS

Drag

The reduction of the parasitic portion of the total drag is most important with the turbojet powered aircraft. Reference to figure 3 will show that the ratio of fuel consumption to thrust does not increase very rapidly for speeds between 300 and 500 mph.

As the thrust is approximately constant for all speeds, it is apparent that the miles travelled per unit of fuel is increased in almost direct ratio to the aircraft speed. The aircraft then, has to be aerodynamically clean to cut the parasitic drag to a minimum.

In the design of the C-102, the greatest care has been taken to get a good external finish, and all external riveting is flush. The skins are preformed and stretched to provide the smoothest contour and practically all the radio antennae are flushed into the contour. The exceptions are the short radio compass sense antenna in the nose, and the conventional wire antenna for H. F. communication.

Wing Section

The choice of wing section is always of necessity a compromise and the peculiar conditions which had to be met, with a transport which was to be almost twice as fast as existing transports made this problem even a little more complex than usual.

It was obviously essential to cut down the drag to a minimum, and at the same time to obtain the highest possible C_{Lmax} for take-off and landing performance.

The structural problems with high gust factors and the large amount of fuel which had to be carried also influenced the wing design.

The section chosen to obtain the best all round characteristics was a relatively high cambered aerofoil, with a thickness at the root of 16.5% and 12% at the tip. The aircraft will be operating at a Mach number of less than .7 at 30,000 ft., and no compressibility problems are expected with this aerofoil at these speeds.

This aerofoil also has the advantage that the trailing edge angle is low, and the pressure recovery gradient is conservative, which makes the section less sensitive to manufacturing and junction interference.

Wing Plan Shape

A fairly low wing loading was used for better approach characteristics, and the plan shape which appeared to give the best compromise was one with an aspect ratio of 8.1 and a taper ratio of .5. As the basic characteristic having the greatest effect on stalling is the taper ratio, this was chosen very carefully. The straight centre section makes the fuselage-to-wing junction easier to manufacture and helps in the power plant installation as the engines are on the parallel portion.

It was considered that for an aircraft operating at a Mach number less than .7, sweep back would not be worth the extra weight which it would involve. The best arrangement appeared to be that having a straight rear spar, which gives a sweep back of approximately $4\frac{1}{2}^{\circ}$ at the quarter chord. Washout was considered, but did not seem to give any great promise, as although it gave slightly better stall characteristics, the effect of the extra induced drag at high speed was less favourable, and the manufacturing difficulties would also be very much greater.

Split-type flaps are fitted on the first set of wings for the first prototype. These will later be changed to the double-slotted type to cut down the landing, and approach speeds to the minimum. As these are of the area increasing type, there will be a larger centre of pressure movement than with the split flaps, and slightly greater elevator angles to trim may be required when these are fitted.

The profile drag has been kept to a minimum by the use of thick skins required for wing stiffness, and complete flush riveting. Square tips are used, to give greater aileron effectiveness by carrying the surfaces out as far as possible, and for ease of manufacture of the tips themselves.

The dihedral on the outer plane is 6°, and the wing incidence is $2\frac{1}{2}^{\circ}$ throughout the span.

Fuselage Shape

The shape of the fuselage is the usual compromise between getting a profile which is aerodynamically clean and a structure which is easy to assemble, coupled with the standardization of interior fittings and structure for as long a length as possible. This has resulted in a parallel section of fuselage for approximately 60% of the total length with a carefully blended-in fore and after-body.

Special care was taken to get good lines around the nose canopy, and wind tunnel results showed that the critical Mach number around the canopy is about .73 i. e., higher than that for the wing.

A 00-21 series aerofoil section has been used for the after-body, which again showed very good pressure recovery characteristics in the wind tunnel. A circular cross-section is used throughout, as this is obviously the best section for the high pressure differential used on this aircraft.

The shape of the Dorsal fin was determined by the requirements for weather cock stability and helps to co-opt a portion of the rear fuselage as fin area.

Tailplane Vertical Position

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

Effect of Thrust on Trim

The jet nozzles are inclined at an angle of 7° to bring the line of action of the jets as close to the normal C. G. position as possible, and minimize the effect of change of trim between 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.

Wing Root Fillet

The unusual design of wing root fillet was incorporated to take care of the upwash from the fuselage. The normal component of the flow around a long nosed fuselage produces an upflow at the wing root, which may cause premature root stalling, and during wind tunnel tests, it was found that a long forward fillet of the right shape corrected this effect, see figure 14.

The fillet was tried out on a British aircraft by arrangement with Avro Canada and produced excellent results. The stalling speed was reduced by approximately 7 mph E. A. S. after incorporation of the fillet. There was no effect on the longitudinal stability.

FLIGHT PLAN

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. Figure 4 shows a recommended procedure, which allows for a standard 45 minute stacking and 120 mile flight to an alternative airport, plus allowance for instrument approach, landing and taxiing.

It will be seen that instead of the usual procedure of descending at the destination airport, taking a pass at the airport to check whether the landing is possible, and then proceeding to an alternative airport, the decision to descend or proceed to the alternative is made at some point during descent.

This point is shown on the flight plan at an altitude of 25,000 ft. and approximately 33 miles from the airport, and this is considered to be entirely reasonable with present ground aids and radio equipment.

Due to the high cruising speed, it is expected that the weather at the 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 an altitude of 25,000 ft., or could be carried out at any altitude on two engines, without any 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. For ranges under 200 miles, it is debatable whether it is worth while climbing to an altitude of 30,000 ft. for cruise.

It will be seen that 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 33 miles. Normal cruise at the operating altitude covers approximately 377 miles.

The fuel used for take-off, climb to 30,000 ft., cruise, descent and approach for a range of 500 miles is approximately 9,210 pounds, while the fuel allowances carried for flight to alternative, stacking, and descent at alternative airport amount to approximately 5,125 pounds, or just over 1/3 of the total fuel.

Descent is carried out at a speed of 200 miles an hour E. A. S. with the use of dive brakes to get a high rate of descent.

As the accessories, including the hydraulic pumps and electrical equipment for de-icing may be required during the 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.

There is very little penalty on rate of descent incurred by keeping the engines running at this r.p.m. Figure 3 shows the rate of descent, power-off compared with cruise r.p.m. and 7,000 r.p.m.

As shown, there is little difference between the power-off and half max. cruise engine speed curves. At this speed, the cabin blowers will also give their full ventilating output, and in any case, will be operating at a rapidly reducing back pressure during descent.

The average fuselage angle during descent is not more than 8°, which is considered to be reasonable from a passenger comfort standpoint.

DIRECT OPERATING COSTS

While it is not the purpose of this paper to join in the merry-go-round of comparisons of the conventional and jet-powered transports on a ton-mile per lb. of fuel basis, nevertheless, the operating costs had to be considered very carefully, and their consideration played an important part in the final design configuration of the aircraft.

The two important efficiency factors in the cost analysis are the cost per mile and the payload for a given range.

The cost per mile is obviously governed by speed, as many of the direct costs such as, crew salaries, depreciation, insurance, etc. are fixed hourly costs. Neglecting fuel consumption, if the blockspeed is increased from say 250 mph to 350 mph, the cost per mile would be decreased by approximately 30%. It can and has been shown elsewhere, that this decrease in cost due to speed more than compensates for the increase due to higher fuel consumption.

The effect of blockspeed can possibly be seen more clearly by considering the number of aircraft required for a given scheduling. The equation in its simple form is shown below.

$$N - \frac{D}{U \times V_b \times N_p}$$

where

- N - Number of aircraft required
- D - Traffic density in passenger miles per year
- U - Utilization in hours per year
- V_b - Blockspeed
- N_p - Passenger capacity of aircraft

For a given yearly utilization, traffic density and passenger capacity, it can be seen that if the blockspeed is doubled, the number of aircraft required is halved, and consequently, the earning power of each aircraft is considerably increased.

To take advantage of the higher blockspeeds, however, maintenance and turn-around time at the airport has to be cut down 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 to allow a rapid descent; the use of special accessories and radio compartments where practically all items that required frequent servicing are housed; and the employment of underwing pressure refueling 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 goes, the fuselage was laid out to give the best compromise between a full passenger version and combined passengers and cargo. Two typical layouts are the 40 passenger version with an additional 4,100 lb. of freight making a total payload of 12,500 lb., and the 50 passenger version with a payload of 10,500 lb. Payload Vs. range with all allowances is shown on figure 6.

While the final analysis of economy must be left to the individual airline, the results of a detailed analysis show that the direct operating costs compare very favourably with those of present transports, despite the relatively high fuel consumption of present jet engines, and the fact that the present allowances for stooge 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, and as the flight procedures are modified to cut down the stooge time, the picture will be even brighter.

CABIN LAYOUT

Although, the final seating arrangement and cabin layout will depend on the customer's choice, it appears to be fairly definite that the high density passenger version will be the one of greatest interest.

Two typical layouts are shown in figure 7. Accommodation for 40 or 50 passengers is shown with provision for their baggage on the left hand side of the cabin, adjacent to the front entrance door. The washroom is situated opposite this baggage compartment, and a small commissary and hostess station is situated at the rear of the passenger cabin.

The ten ft. diameter fuselage allows for wide seats, and a generous aisle with a head room of 82 inches. Seat pitching is at 38 inches.

Emergency exits are situated in the centre section and rear section above the wing, and a crew emergency exit is fitted in the ceiling of the crew compartment.

A permissible C. G. travel of approximately 23% of the mean chord or approximately 35 inches provides for flexibility of loading with the least number of restrictions.

Noise Level and Vibration

Noise level in the cabin is considerably reduced by the use of turbojets, and this, coupled by a complete lack of vibration, will add enormously to passenger comfort.

POWER PLANT

The four Derwent 5 engines are mounted in pairs in two under-slung nacelles, each nacelle being made up as a single integrated structure. The engines are toed-in toward the centre line by 5°, and set at approximately $11\frac{1}{2}$° to the horizontal in order to take the jet pipes under the main spars without cutting away any of the spar structure.

Tubular engine mounts are used, and these can be removed or replaced separately. The nacelle geometry is shown in figure 8. All nacelle air loads are taken back into the two engine mounts, which are attached to the centre section front spar.

Engine servicing and maintenance is made particularly easy by the low position of the nacelles. All engine adjustments can be made without the necessity of using service ramps or ladders, see figure 9.

Engine removal is carried out by detaching the services and gear drive at the break points, swinging the trunnion locating caps down, and dropping the engine on to the special trolley. The engine is then wheeled away sideways to make way for the replacement engine. With this unique arrangement, a complete engine change can be made in a very short time.

The jet pipes are parallel in plan and are supported on trunnions and links. Two spherical joints are incorporated to give flexibility to the pipes on expansion, and also for the withdrawal of the jet pipe for engine removal. Although, a relatively long jet pipe is used, it is estimated that less than 1% of thrust is sacrificed from the combined effects of length and shape of the pipe.

A sixteen inch nozzle is fitted and the jet emerges at 7° to the datum line of the aircraft, to bring the line of action of thrust as close to the C. G. as possible.

The jet pipe runs through a tunnel of stainless steel formed by fire-walls attached to the adjacent structure. The jet pipe itself is insulated, and is cooled by a flow of air passing through the firewall tunnel and induced by the extractor nozzle. The vena-contractor at the nozzle sucks the cooling air through the nacelle, after it enters through louvres at the forward end of the cowling.

Engine Accessories

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

Each inboard engine drives a cabin blower, a vacuum pump, and a Tachometer generator, and each outboard engine drives a 50 KW alternator, a 9 KW generator, an hydraulic pump, and a Tachometer generator.

The gearbox drives are connected with the engines by a system of drive shafts linked by means of flexible couplings, as shown in figure 10.

Derwent 5 Modified Engines

The C-102 engines are standard Rolls-Royce Derwent 5 engines but with a completely redesigned oil tank. The cast oil tank is sited at the front of the engine, underneath the forward gear drive. The engines are handed only by the oil tank filler and the gear take-off, see figure 11.

The change from starboard to port engines is made simply by interchanging the filler neck and blanking plate on the oil tank and swinging the gear take-off around in the opposite direction. The oil tank and system are integral parts of the engine.

Engine Suspension

The engine is supported by mounting trunnions at approximately the centre of gravity of the engine, and is steadied at the rear end by a shackle plate bolted to the top of the nozzle box.

Cowling

The upper part of the cowling is developed as a permanent structure provided with small access doors for engine slinging, and a larger door to permit access to the upper part of the accessory gearbox.

The lower half of the cowling consists of two large access doors hinged at the sides and a smaller door beneath the accessory gearbox swinging aft. All access doors are locked by means of flush-type quick release fasteners, and the two main curved doors can be quickly detached by swinging them out and unhooking the special hinge locators.

Fire Protection

With the engines installed, the nacelle is divided into two compartments on each side, and a third compartment housing the accessory gearbox. This split-up is achieved by means of special firewalls and bulkheads as shown in figure 8. Each nacelle has a vertical firewall forming a centre keel and isolating the two engines from each other.

The engine has an integral intermediate firewall permanently attached and sited around the combustion chambers. This mates up with a permanent portion of firewall on the nacelle forming a complete firewall between the hot and cool portions of the engine.

The front portion, or zone 1, which also forms the plenum chamber contains the engine accessories and oil tank etc., while the rear portion or zone 2, contains all the hot portions of the engine, combustion chambers, turbine casing, and jet pipe. The intermediate firewall is to prevent the high pressure fuel from a burst pipe or joint being sprayed on to the hot side.

The rear portion of zone 2, extends in the shape of a tunnel back to the jet nozzle and is completely lined with stainless steel firewalling and sealed against ingress of fuel or oil.

Fire from a burst combustion chamber or perforated jet pipe would be confined within this zone out of reach of electrical and fuel lines or the aircraft structure.

The above system of firewalling also isolates all engine parts from the accessories and gearbox, which are in the space above the conical firewalls, shown on figure 8, as zone 3.

Edison resetting type fire-detectors are used and a methylbromide system of extinguishing is used for zones 1 and 2, while a CO_2 system is provided for the gearbox compartment, zone 3. A two-shot system is used and the warning lights, buttons, and selector switches are mounted on the ceiling fire-protection panel in the cockpit.

Thrust Augmentation

The thrust from a jet engine varies considerably with temperature and airport altitude, and on a hot day with a temperature of 110°F, the reduction in jet thrust can be as much as 16%. As this can be critical for take-off conditions, where a possible engine failure has to be taken into account, some means of thrust augmentation has to be used.

Various means of achieving the extra thrust were investigated, and 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 itself is relatively simple, and has few of the disadvantages of other forms of augmentation such as, after-burning where the long sheets of flame coming out of the tailcone are likely to cause alarm to the passengers. The percentage increase in thrust with rate of injection is shown in figure 12.

It can be seen from the graph, that under tropical conditions, to provide the static thrust which would be obtained for take-off under standard I. C. A. N. conditions, it is necessary to inject the mixture at a rate of 10 gals. per minute.

A tank is housed in each nacelle holding 66 gals. of water-methanol, which is sufficient to supply each engine with the required quantity for a period of three minutes.

Figure 13 shows the take-off distance for various gross weights and temperatures.

Nacelle Shape

The external and internal shape of the nacelles was chosen very carefully with a view to getting the best possible pressure recovery characteristics externally, and an efficient plenum intake which would give the best compromise between the ideal low and high speed conditions, see figure 8.

For take-off conditions where there is very little ram effect, there is a suction in the plenum chamber, and in order to prevent break-away around the intake walls, the wall angle was kept down to less than 10°. To achieve this, it was necessary to go to separate intakes for each engine, as with a common elliptical intake, the diffusion angle would have been excessive in a short nacelle, and any increase in nacelle length was disadvantageous, due to the destabilizing effects of a long wide nacelle.

The best intake curves were established in conjunction with the engine manufacturer's recommendations. For the outside shape, the lines between the inside lip of the intake radius and a point about 20% of the total nacelle length aft of the intakes were most critical both for drag rise and intake effeciency, see figure 14. Figure 15 shows how little the nacelles interfere with the top surface of the wing.

ENGINE DATA

A civil version of the standard Rolls-Royce Derwent 5 engine is used, and a brief summary of the performance is shown below.

	Engine Speed	Time Limit
Take-Off and climb	14,700	15 mins.
Maximum continuous power	14,100	Unrestricted
Idling on ground	Approximately 3,500	r. p. m.

Relighting in the air is possible and numerous relights have been carried out during flight tests.

As the economy of the C-102 has been worked out assuming that all engines are operating, however, relighting would not normally be employed. It can be seen by reference to figure 16, that each engine consumes less than 90 lb. of fuel in descent from 30,000 ft. at half max. cruise r. p. m. If the operator felt, however, that any stacking should be carried out at fairly low altitude, two engines could be closed down to conserve fuel.

FUEL SYSTEM

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. Immersed booster pumps are used.

The pilot can fully control the disposition of his fuel load, and 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 inoperative.

Manually controlled shut-off cocks to each engine are provided as a safety measure to shut off the fuel in the event of an emergency.

A signal light system is provided on the fuel system panel to enable the pilot to check instantaneously the condition of the fuel system.

Both overwing and underwing refueling is installed and the tanks can be refilled at the rate of 200 Imp. gals. per min. through each underwing refueling valve at a nozzle orifice pressure of approximately 5 p. s. i. A refueling manifold is used for each pair of tanks and a special built-in selector valve permits fueling or defueling of each tank individually.

A special float valve coupled with the underwing refueling system prevents the tank being damaged, by shutting off the fueling valve when the fuel reached a predetermined level in the tank.

Fuel Tanks

The sealing of the integral tanks was a problem which had to be studied very carefully, since the airlines had been having some trouble with certain types of integral tanks and a certain amount of prejudice had been built up against them.

After much investigation and testing, a system of sealing was derived which has given such excellent results on test that it appears to be a very great improvement on the existing methods of sealing.

Thiokol-based sealants are used and combinations of plasticizers and synthetic resins are added, making a permanently plastic seal, which has low shrinkage and good adhesion properties. The top and bottom wing skins and the spars are sealed before assembly, and the corners are then sealed after the wing is removed from the assembly jig.

No sealant is used between the faying surfaces. The finished tank is sprayed with a cyclohexanone solvent to bond the complete inner surface. The system lends itself to local repair as no slushing compounds are used.

Access to the wing is by large leading edge access doors and stress-bearing removable panels in the front spar, see figure 17.

FLYING CONTROLS

Double aerodynamically-unbalanced control surfaces have been used for both the rudder and elevator controls, see figure 18.

The intermediate or auxiliary surface on the rudders is used soley 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 slip stream, 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 tail plane is out of the flap wake during landing and, therefore, the tail efficiency is high which reduces the elevator angles required for normal trim. The auxiliary surface is only required for the flare-out, on landing with an extremely forward C. G. Piano hinges have been used on all tail surfaces, and this improves the effectiveness by sealing the gaps.

Narrow chord high aspect ratio surfaces are used, and these have the advantage that no aerodynamic balance is necessary. They also have lower drag, less danger of icing, better repeatability and low weight of mass balance.

The narrow chord elevator is also very much better from the point of view of susceptability to oscillatory instability. The usual cures for this are less aerodynamic blance, and a lower mass moment of inertia. These features are all incorporated in the double surface control.

Power operation of the tail surfaces on the first prototype is by a simple switch controlling a small electric motor and limit switches. The system is entirely separate from the electric and manual elevator trim.

An hydraulic assister is used for aileron power boost in the ratio of 5 to 1. This is a pure assist system, and in the event of an hydraulic or unit failure, the booster is thrown out and full manual control is retained with, of course, reduced power.

Push-pull type controls are used on all three main control systems, employing light alloy tube to eliminate differential expansion and contraction under extreme temperature changes. The tubes are supported in roller guide bearings using rubber covered ball bearing rollers.

PRESSURIZING

The air conditioning system is entirely automatic once the controls have been pre set by the pilot. Either supercharger is capable of delivering about 60 pounds of air per minute up to an altitude of 13,500 ft. Automatic control of the cabin pressure is maintained by the discharge valve set to provide sea level conditions up to 21,500 ft.

At 21,500 ft. the differential pressure remains constant, and at 25,000 ft., the cabin altitude is 2,000 ft. and 4,000 ft. at 30,000 ft. altitude.

The rate of pressure change in the cabin during the climb and descent is also automatically controlled.

Cabin Sealing

The fuselage had to be very carefully sealed to provide a pressure tight cabin and a method of sealing was used which has been well tried on other aircraft.

This consisted of applying special sealing compounds between the faying surfaces and skin joints. The remaining riveting such as, riveting stringers and capping strips to the skin were not sealed, as with the use of dimpled riveting, the rivets are tight enough to produce a satisfactory seal. Any leaking rivets are individually sealed by bushing with a special sealant.

Figure 19 shows the cabin insulation installed prior to fitting the wall panels.

COCKPIT LAYOUT

Having in mind the usual confusing array and disposition of instruments and controls in the average flight deck, a special attempt was made in the case of the C-102 to achieve a configuration that was both functionally good, and at the same time, gave the best servicing layout.

The extent to which this has been achieved can be seen in figure 20. The main instrument panel is divided into three sections. The centre panel carries all engine and fuel instruments. A small fuel system control panel is attached to the engine panel with the fuel diagram etched on, and this contains the switches and lights for the various booster pumps and cross-feed warning lights. All panels are hinged for easy access.

The engine instrument panel is very much simplified by the use of jet engines, as the only engine instruments are the R. P. M. indicators, jet pipe temperature gauges, burner pressure gauges, and oil pressure warning lights.

The two main instrument panels carry the normal flight instruments, and have been grouped to conform with the latest requirements for radio navigation and automatic landing aids.

In the ceiling, between and within easy reach of each pilot, is the main electrical panel carrying the engine starter switches, fire protection switches and buttons, and the main electrical control switches.

The pressurization control panel is on the left of the captain and the air conditioning, oxygen and de-icing control panels to the right of the first officer. Circuit breaker panels for both electrical and radio equipment are mounted on the aft deck bulkhead.

Both pilots' seats are fully adjustable and slide back for easy access. Cranked control columns are used to avoid obstruction to the pilots' knees, and a spectacle type of aileron hand wheel is used.

A lot of thought was put into the main control pedestal, which on the upper portion carries the engine throttles, undercarriage, flap, and automatic pilot controls, the emergency manual low pressure fuel cock levers, and fuel tank selectors.

The radio control panels are situated on the lower portion of the pedestal. The pedestal also carries all the manual trimmer controls, the manual autopilot disconnect lever, gust lock and parking brake levers, and the aileron power boost cut-out.

Direct vision windows which swing inwards are provided for landing under adverse weather conditions.

The rudder pedals are fully adjustable and are articulated to provide too brakes for equal or differential brake application.

The above cockpit layout was finalized only after many conferences with airline pilots and technicians and the final mock-up was carefully checked to get the best possible layout.

LANDING GEAR

The absence of propellers and the consequent short distance between the aircraft structure and the ground coupled with the fact that an under-slung nacelle configuration was used, resulted in an extremely short main landing gear, see figure 21. The actual distance between the undercarriage main pivot and wheel centres is less than 30 inches. This has resulted in the establishment of an extremely robust and simple design, and one 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 nose wheel is self-centering, fully castoring and incorporates shimming damping, see figure 22. The hydraulic steering unit incorporating a double piston control acts as a shimming damper when the steering is switched off. Steering is controlled by a wheel adjacent to the pilot.

The nose wheel is steerable through an arc of 70° each side, and the wheel cancaster through 360° for towing. Lever suspension is used on the nose gear.

Undercarriage retraction is electro-hydraulic and hydraulic brakes have been installed, controlled by the rudder pedal toe brakes. All wheels are to the American Tire and Rim Association specifications. The main undercarriage doors are operated by separate hydraulic jacks, and the nose wheel doors are operated mechanically by a trip mechanism fitted to the nose undercarriage.

Accidental ground retraction is prevented by a microswitch which comes into operation when more than 5% of the aircraft weight is on the wheels.

All undercarriage uplocks can be tripped manually in an emergency and extension will then take place by gravity and drag forces.

ACCESSORIES AND SYSTEMS

The position and layout of the various accessory units which have to be serviced regularly on the ground, or which need to be accessible in flight was given a lot of thought, as this is a point, which has aroused much criticism in the past by airline operators.

An accessories compartment was introduced behind the first officer's bulkhead on the starboard side to carry the main aircraft accessories, see figure 23. The heater, refrigerating turbine, main electrical accessories such as, inverters, relays etc., and the main electrical distribution panel are all housed in this compartment, which has its own fire extinguishing system.

All radio and electronic units are in a similar separate compartment on the port side behind the pilot's bulkhead, see figure 24.

The main hydraulic units are panelized, the panels being housed in the forward wing root fillet, with easy access at ground height to all ground connections, accumulators, valves etc. The emergency power pack is also contained on these panels.

Methyl-bromide engine fire protection bottles are housed in the nacelles at shoulder height and the engine starter relay panels are also in this vicinity.

The extremely low static position of the aircraft insures that practically all external servicing is done without steps or servicing ramps.

Ground pressure tests can also be carried out by connecting up the ground pressurizing equipment to a service panel inside the nose wheel well.

HYDRAULIC SYSTEM

The main hydraulic system is a high pressure system operating at a normal pressure of 1,800 pounds per sq. inch. The cut-out pressure is 2,200 p. s. i. and the relief valve pressure is 2,700 p. s. i.

The normal system power is provided by two constant pressure variable displacement pumps on the accessory gearbox in the nacelles. Either pumps will provide full hydraulic power for the complete system, and the use of two pumps is to provide duplication against failure.

The main services operated by the hydraulic system are the main and nose undercarriage gear, nose wheel steering unit, landing and dive flaps, main wheel brakes, main wheel doors, and aileron power booster. Complete duplication of the normal hydraulic system is provided by a 'power pack' consisting of an electrical motor and a pump.

A hand pump is provided in the accessories compartment which also can be used in an emergency. On the ground, the system can be operated by ground supply points located on the wing root fillet panels.

ELECTRICAL SYSTEM

The electrical system is basically a single grounded negative system for both D. C. and A. C. services.

There are in effect six separate systems providing power for the various services. The various systems are listed below:

28.5 volts - From two engine driven D. C. generators for lighting relay controls, radio and some instrumentation. The D. C. generator system is over-voltage protected.

115 volts - Three-phase 400 cycles from D. C. motor generators (inverters), for some flight instruments, engine instruments and some radio equipment.

26 volts - Three-phase 400 cycles from a transformer, connected across the 115 volt three-phase power supply for general instrumentation.

208 volts - Three-phase 400 to 700 cycles from two engine driven alternators for wing and empennage de-icing and galley.

600 volts - Three-phase 400 to 700 cycles, from a transformer connected across the 208 volt three-phase power supply for the 'Nesa' de-icing system.

Two 89 ampere hour batteries connected in series to supply 24 volts are used for ground testing and generator stabilization in flight.

DE-ICING SYSTEM

While dei-icing will not be fitted for the first flights of the first prototype, an electro-thermal de-icing system will be used for the wings and empennage. De-icing power is provided by two 50 KW., 208 volt three-phase 400-700 cycle alternators situated on the engine driven gearbox.

Windscreen de-icing is provided by special 'Nesa' glass windscreen panels, which consist of a vinyl core sandwiched by two thicknesses of semi-tempered glass. On the outside surface of the vinyl between the vinyl and the outside layer of glass is a conductive 'Nesa' coating which provides approximately 5-6 watts per sq. inch power input.

The windscreen de-icing is entirely automatic and the temperature is controlled to provide the quantity of heat required for anti-icing, and at the same time, keeping the vinyl layer at a temperature which gives it the best resistance to bird impact.

The three forward panes of the aircraft are designed in this manner, and the vinyl centre layer has the additional advantage, that in the event of a windscreen being shattered by any circumstances, the vinyl will still withstand at least twice the maximum differential pressure in the fuselage by blowing out in the form of a bubble.

Engine and intake de-icing is a special problem which at the moment is being investigated fully by the engine manufacturers and Avro Canada. There are several workable schemes. As it has not yet been decided definitely which system will be used for production aircraft, it is obviously not desirable to go into detail on the subject in this paper.

RADIO SYSTEM

All radio equipment is housed in the radio compartment on the starboard side of the front entrance door, and is completely enclosed by quick removable panels giving complete access to all units.

The electronic units are housed on sliding racks and use is made of special type connector boxes which automatically engage the pins when the units are pushed into position.

The radio and electronic compartment is ventilated by a separate blower. The basic radio system consists of the following:

(1) HF communication transmitter-receiver with provision for 20 channel equipment.

(2) VH communication transmitter-receiver.

(3) 18 channels plus guard channels.

(4) Dual automatic radio compasses with radio magnetic indicators.

(5) Isolation amplifier chassis including interphone amplifier, and a special loud speaker amplifier for the captain the first officer.

All the radio and navigation instruments are duplicated on the captain's and first officer's panels, and all control panels are located on the flight deck pedestal.

The entire radio pedestal assembly is removable as a unit by means of disconnecting plugs at floor level.

Microphone and headphone jacks are provided at the side panels, and separate loud speakers are provided for the captain and first officer.

Communication with the cabin attendant is by an interphone system. A sound hand set is connected to an outlet in the wheel wells and external servicing points.

All receiver audios are muted during interphone speaking periods with an interlock to prevent muting of either or both communication audios during communication periods.

Provision for Additional Facilities

Full provision is made for the following additional radio navigational equipment.

(1) Two VHF navigational receivers providing omni-directional range and localizer, both installations having separate controls and instruments for simultaneous operation. (Magnetic headings for each of the ODR sets derived from separate remote-indicating compass systems).

(2) Two glide-path receivers with channel selection automatically tied in with corresponding localizer receivers.

(3) An additional marker-beacon receiver to complete the duplication of radio navigational equipment.

Selection of the visual output of either of the two ILS combinations can be available to the captain by means of one switch. The autopilot automatic approach equipment would be paralleled with the captain's ILS indicator.

C O N C L U S I O N

It has obviously not been possible in this paper to give more than a bare outline of the work that is necessary in the design of a new aircraft.

An enormous amount of test work had to be carried out on the structure, and functioning of equipment, even before the aircraft first flew, and rigorous flight testing is now being carried out to assess control, stability and general performance.

There has been much discussion in the past on the relative merits of jet and reciprocating engined aircraft, and most of the criticisms of the jet have been made by people who have been made by people who have never had the experience of either working on a jet project or really getting down to the job of comparing the two types on a rational basis.

This stage has, however, passed and the main argument now is not if the jet transport will be used, but when will it be used.

The successful demonstration of the C-102 Jetliner in flight has brought that date a little nearer.

ACKNOWLEDGMENTS

I wish to express my thanks to A. V. Roe Canada Limited for their permission to give this paper, and also to the Rolls-Royce Company for permission to publish the engine data.

My appreciation is also due to Mr. R. M. Stuart, my Technical Assistant, for his assistance in the preparation of the art work and diagrams.

Author's Note:-

A certain amount of the above material was used in a paper I gave at the Annual Convention of the Engineering Institute of Canada at Quebec City in May 1949.

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LEADING DIMENSIONS

Wing Area	Cr: 1157 sq. ft.
Wing Span	98' 1"
Aspect Ratio	8.31
Aerofoil	NACA 230 Series
T/C Ratio at Root	16.5%
T/C Ratio at Tip	12%
Incidence of Datum Plane	$2\frac{1}{2}°$
Dihedral on Datum Plane	6°
Fuselage Length Overall	82' 9"
Fuselage Diameter	10'
Undercarriage	Tricycle

CAPTIONS

FIG. 1 - Frontispiece.

FIG. 2 - Gust Load Factor Vs. Equivalent Air Velocity for Various All-Up Weights.

FIG. 3 - Specific Fuel Consumption at Various Speeds.

FIG. 4 - Typical Flight Plan for 500 Miles.

FIG. 5 - Effect of Dive Flaps on Rate of Descent and Comparison of Rates with Power Off and Half Engine Speed.

FIG. 6 - C-102 Payload Vs. Range.

FIG. 7 - Forty and Fifty Passenger Versions.

FIG. 8 - Nacelle Data.

FIG. 9 - Engine Prior to Installation.

FIG. 10 - Engine Installation.

FIG. 11 - Engine Showing Oil Tank and Gearbox Drive.

FIG. 12 - Variation of Static Thrust with Water-Methanol Injection at 14,700 R. P. M.

FIG. 13 - Four Engine Take-Off Distance Vs. Temperature at Various Gross Weights.

FIG. 14 - Three-Quarter Front View of Nacelle.

FIG. 15 - Three-Quarter Top View Showing Aft Lines of Nacelle.

FIG. 16 - Fuel Consumed During Descent with All Engines at Half Speed.

FIG. 17 - Fuel Tank Access Panel in Front Spar.

FIG. 18 - Empennage Showing Double Surface Controls.

FIG. 19 - Cabin Insulation Installation.

FIG. 20 - Flight Deck.

FIG. 21 - Main Undercarriage.

FIG. 22 - Nose Undercarriage.

FIG. 23 - Accessory Compartment.

FIG. 24 - Radio Racks.

FIG 1

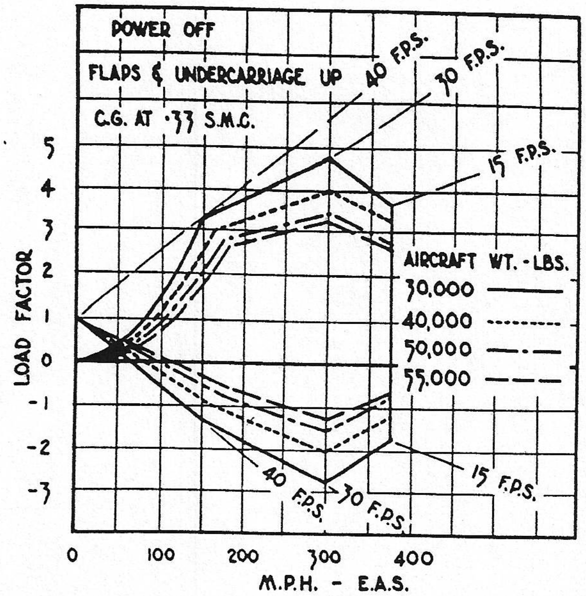


FIG 2

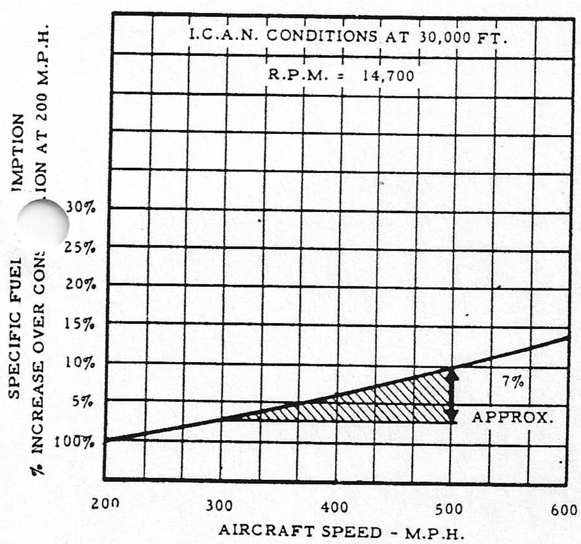


FIG. 3

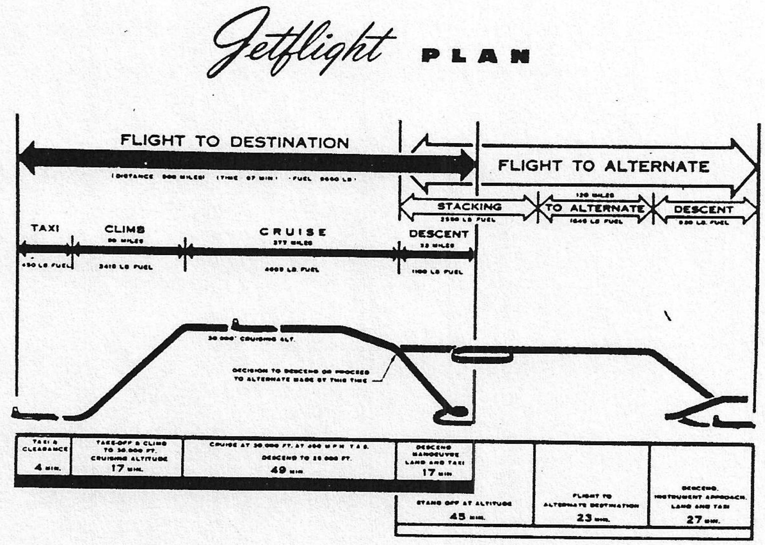
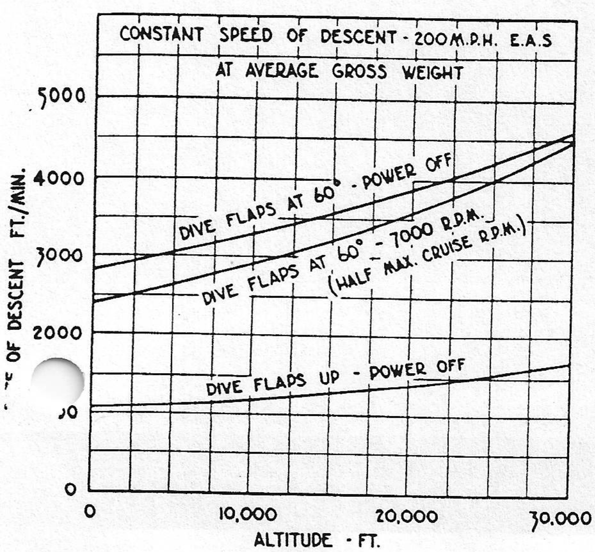
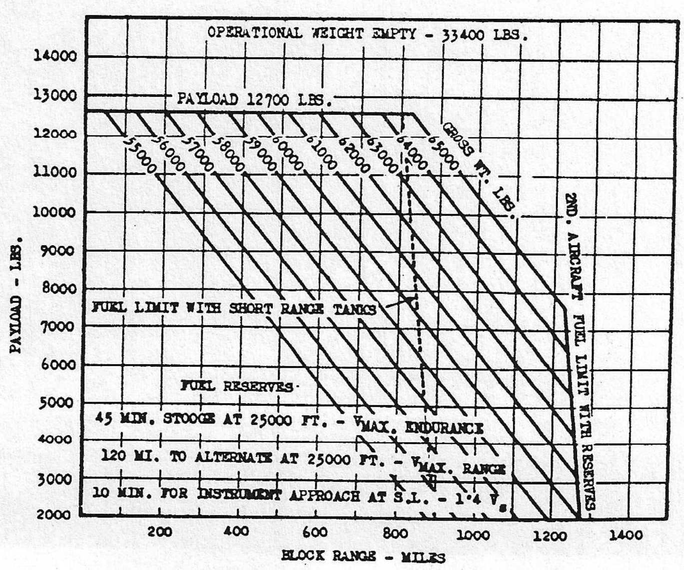


FIG. 4



← FIG 5

FIG. 6 →



J.C. FLOYD

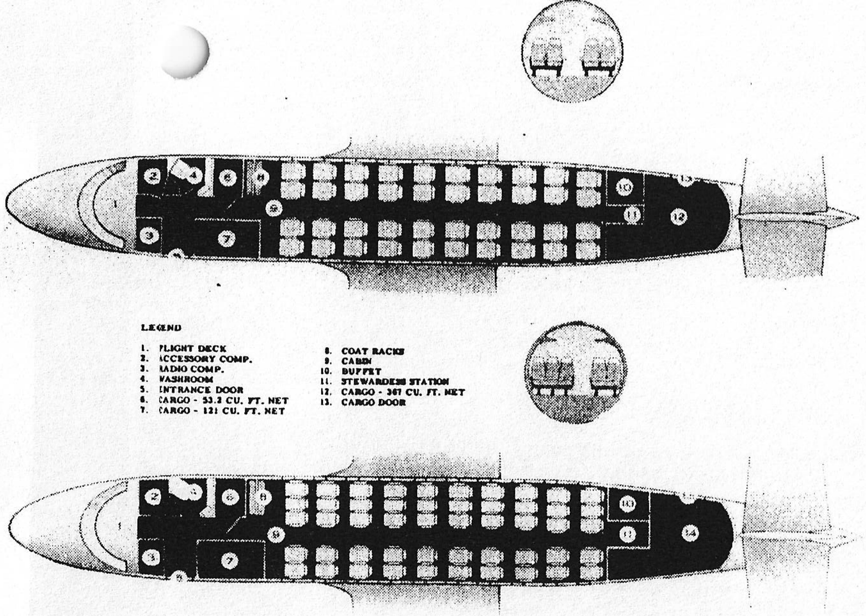


FIG. 7

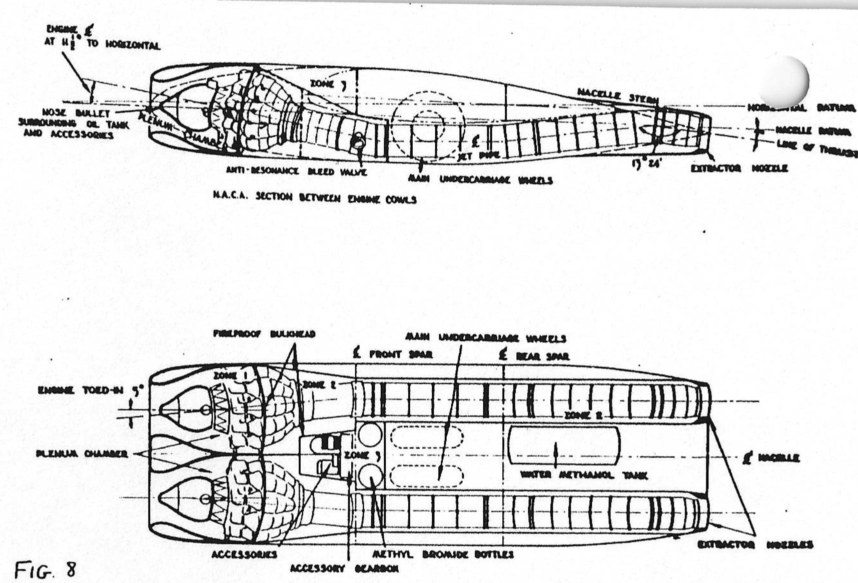
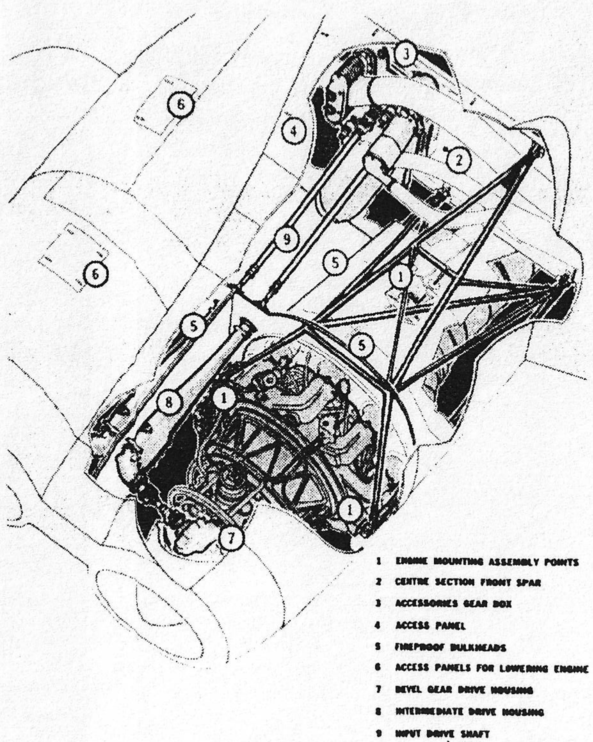


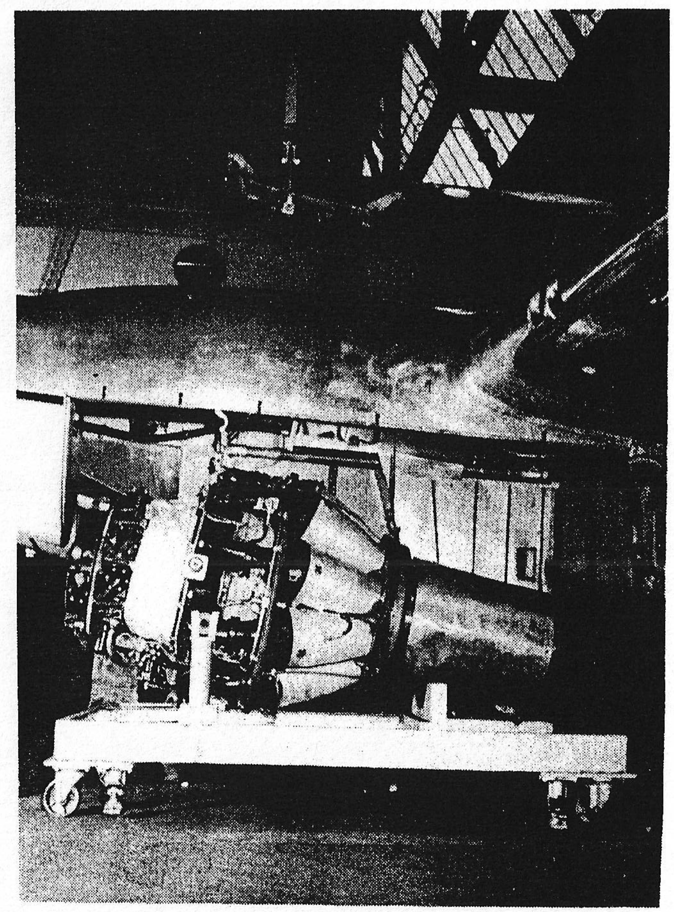
FIG. 8



← FIG 10

J C FLOYD

FIG 9 →



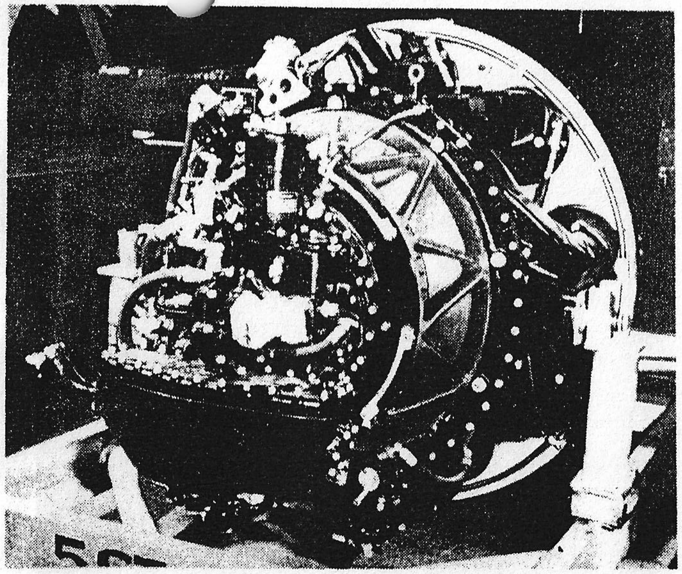


FIG 11

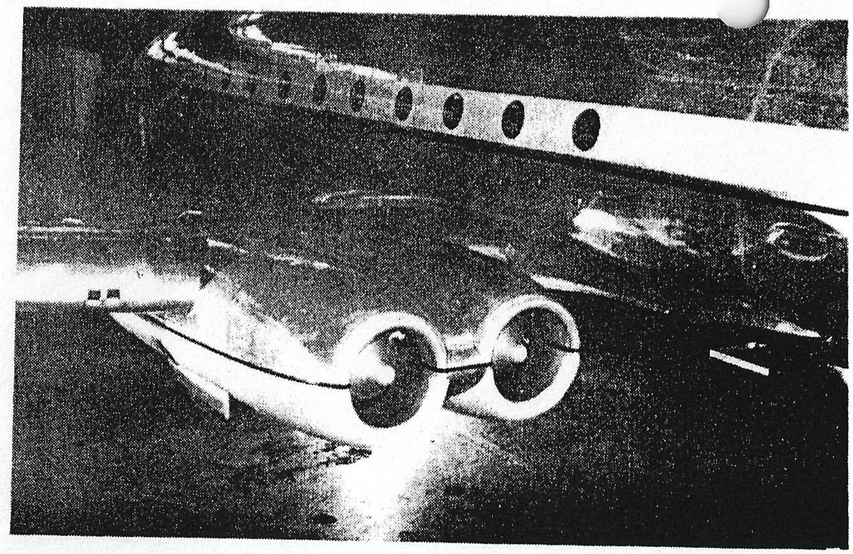


FIG. 14

FIG 12

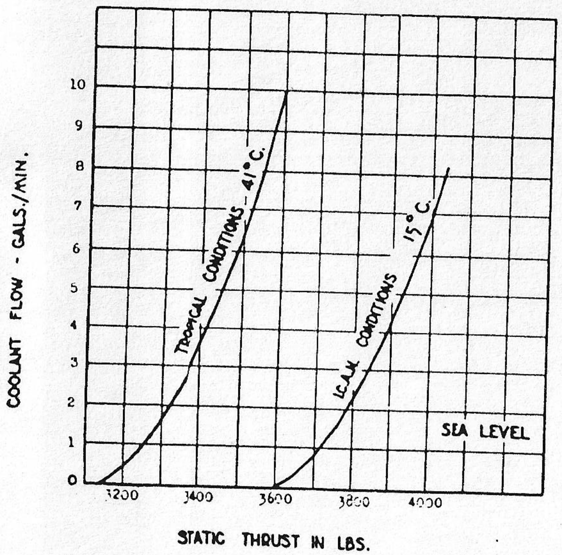


FIG 13

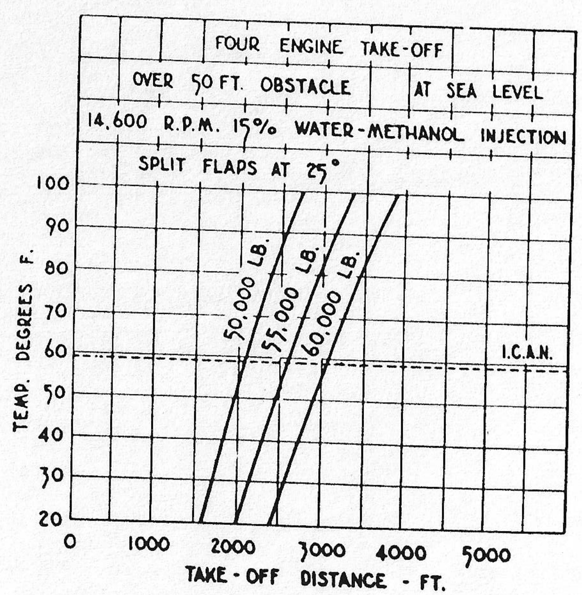
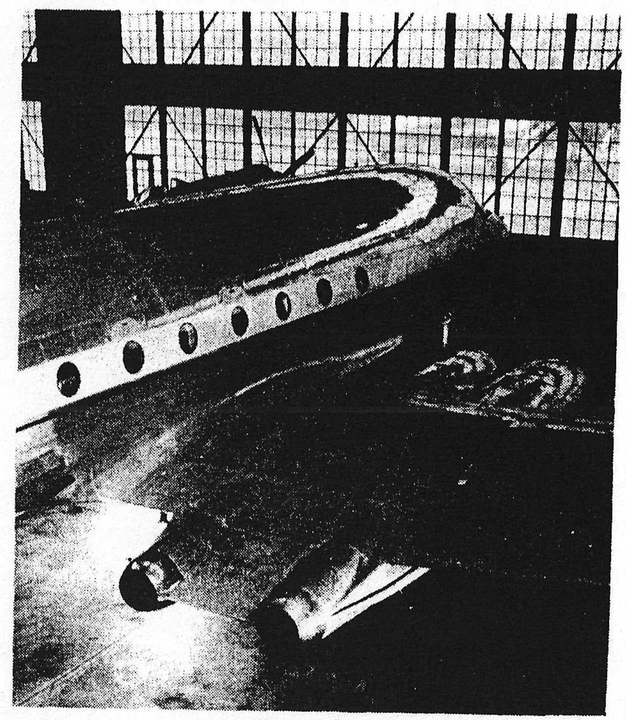


FIG 15



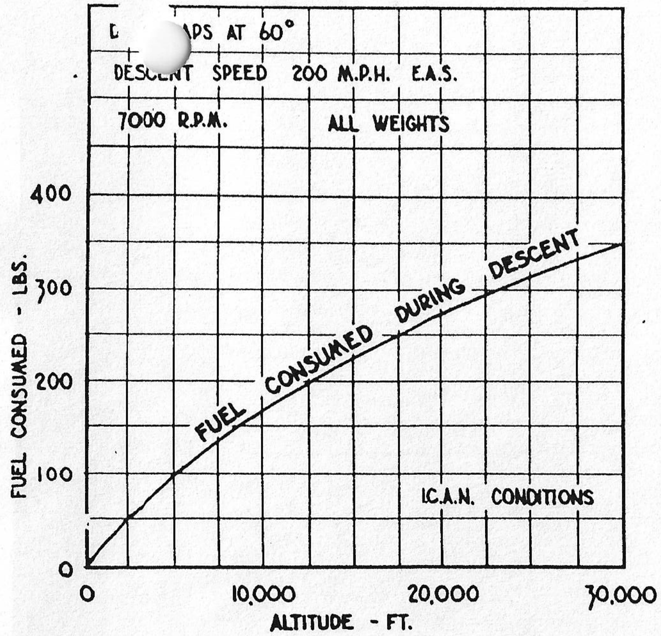


FIG. 16

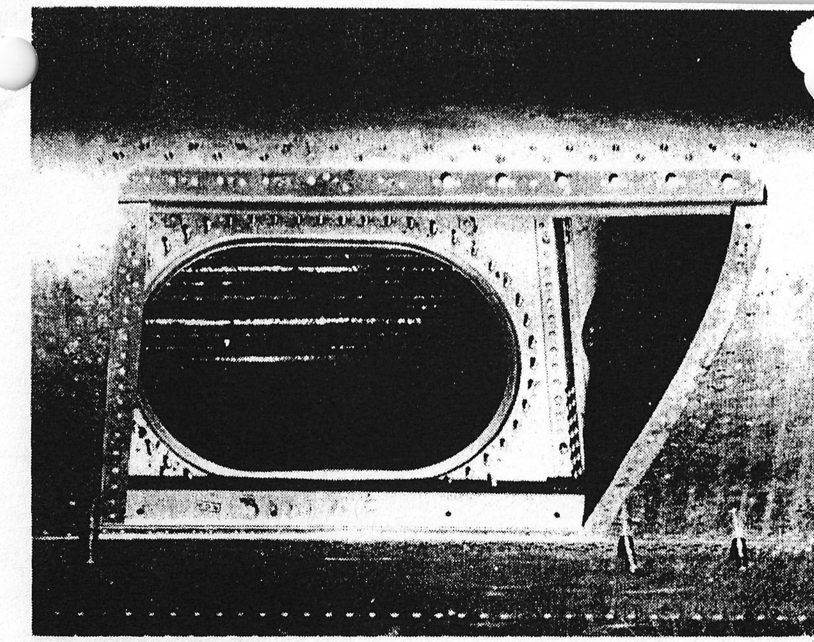


FIG. 17

FIG 18

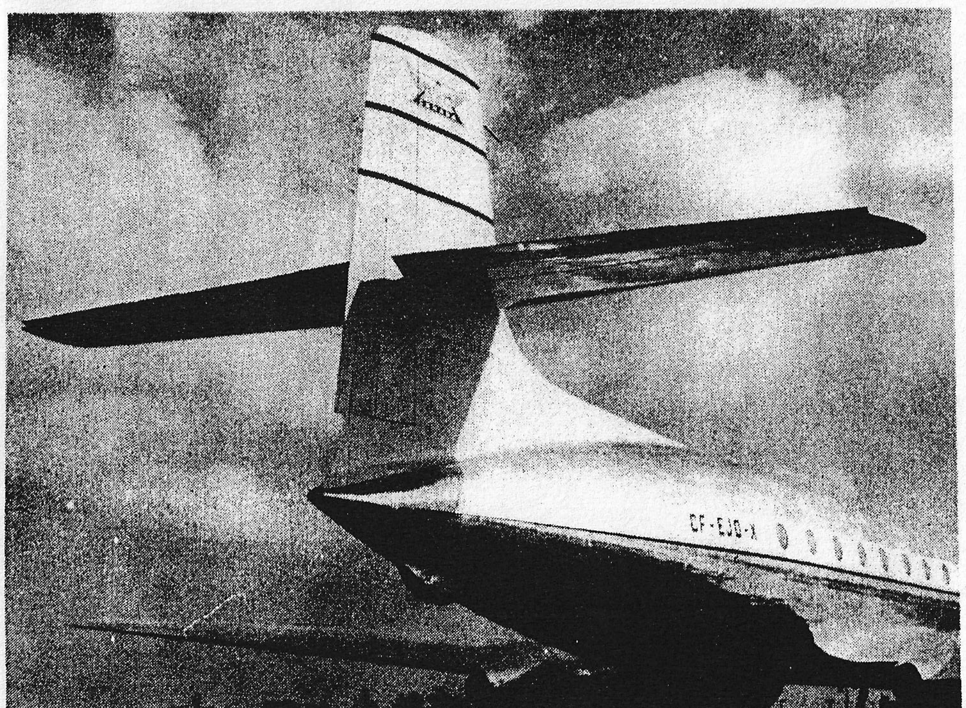
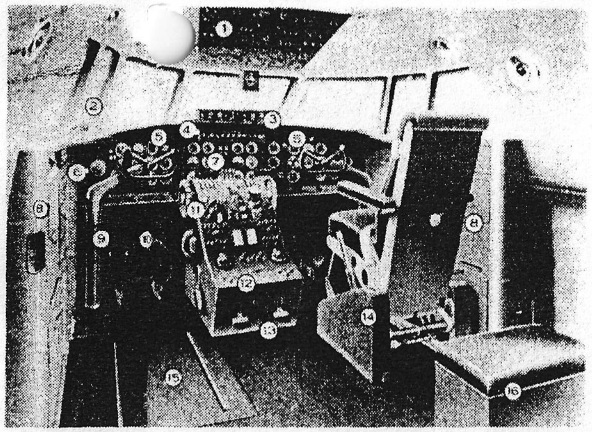


FIG 19



LEGEND 1 CEILING SWITCH PANEL 2 DIRECT-VISION WINDOW 3 RADIO COMPASSES CONTROL PANEL 4 FUEL SYSTEM PANEL 5 FLYING INSTRUMENTS PANEL 6 NOSE WHEEL STEERING HAND-WHEEL 7 ENGINE INSTRUMENTS PANEL 8 ANCILLARY CONTROL PANELS 9 CONTROL COLUMN 10 RUDDER PEDALS 11 AUTO-PILOT PANEL 12 RADIO CONTROLS 13 GUST LOCK AND PARKING BRAKE 14 FIRST OFFICER'S SEAT 15 CAPTAIN'S SEAT 16 FOLDING SEAT FOR OBSERVER

FIG. 20

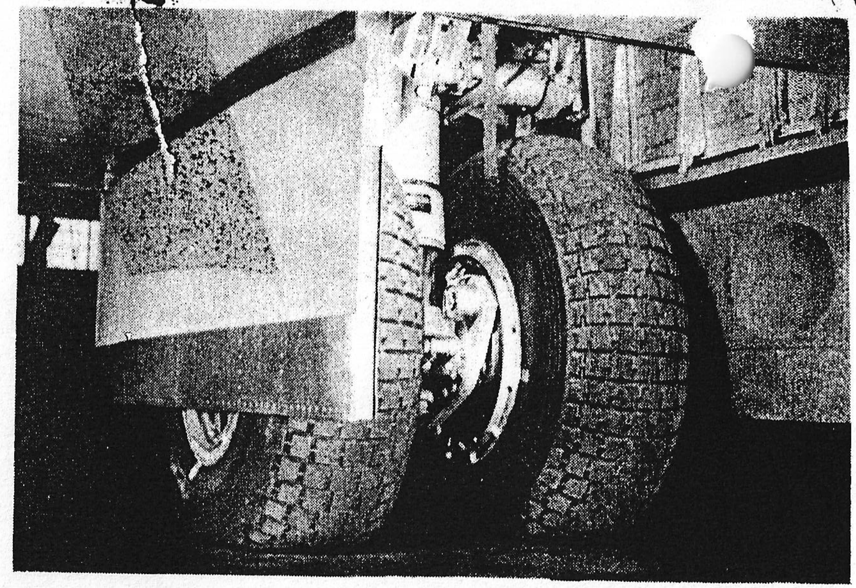


FIG. 21

FIG. 22

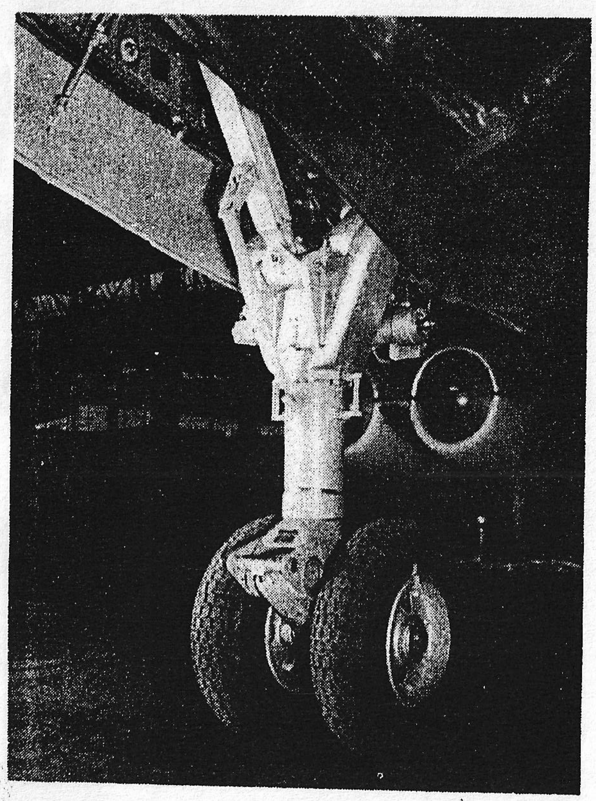


FIG. 23

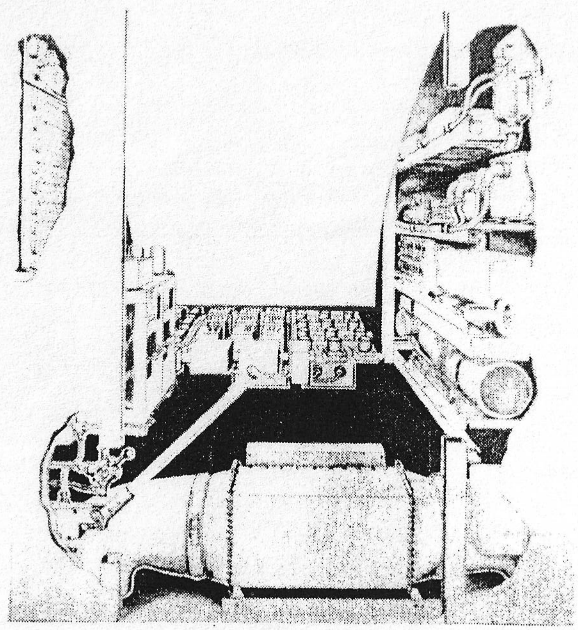


FIG. 24