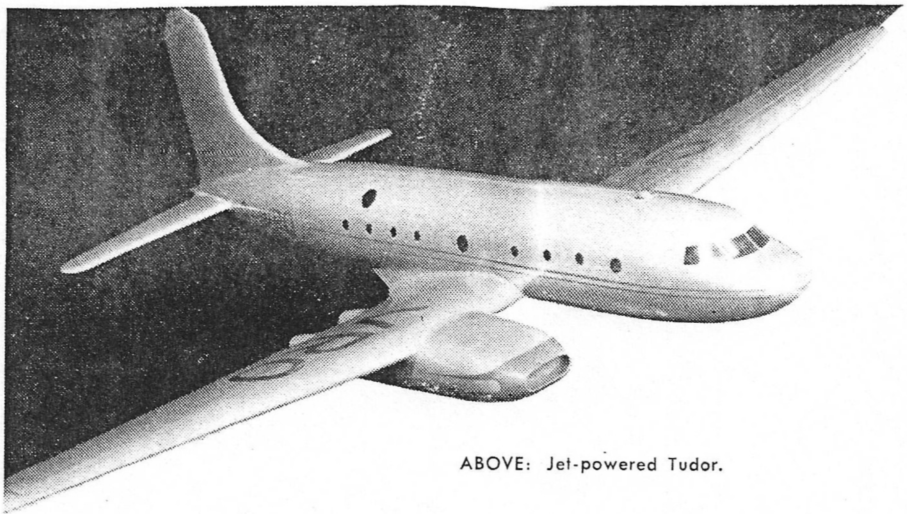


ABOVE: Jet-powered Tudor.

THE future of the jet transport has been the subject of considerable debate. However, a comparison of operating costs, servicing and maintenance, flight speed, passenger comfort and other jet-versus-piston engine features indicates that jet-powered flight is destined to establish its leadership within the next few years.

The Author

In the month of August, 1939, in a small town in Germany, an event took place which changed the course of aviation history.

The world's first jet propelled aircraft, a Heinkel HE 178, powered by a single Heinkel-Hirth HE-S3 gas turbine engine, was successfully flown at a speed of 250 mph.

Although this speed is now looked upon as being extremely slow in comparison with present near-sonic speeds and was, in fact, not particularly spectacular even in 1939, the flight proved a form of propulsion which has since revolutionized military aircraft, and which will undoubtedly become the accepted source of power for the future passenger transport aircraft.

The Picture in 1938—Technicians and engine designers had reached the stage where it appeared that there would be a limit, using conventional engines, to the speed at which an aircraft could ultimately fly.

It is well known that with the conventional reciprocating engine and airscrew combination, the airscrew efficiently reaches a peak at a speed somewhere in the neighborhood of 550 to 600 mph and from this point the efficiency drops off rapidly as the speed increases, with a consequent reduction in thrust-to-horsepower ratio. Thus, an increase in horsepower does not give a corresponding increase in thrust because of the inability of the airscrew to convert the extra power into thrust efficiently.

In the gas turbine engine we have a somewhat different set of conditions from those encountered with the piston engine.

By James C. Floyd, MIAeS

Asst. Designer, A. V. Roe Canada Ltd.

The author was educated at Manchester College of Technology in England. After a number of years with A. V. Roe & Co. Ltd. at Manchester, latterly as Chief Project Engineer at their Yeadon plant, he came to Canada in 1946 as Chief Technical Officer with the Canadian company. He is now Assistant Designer on the C-102 jet airliner project. He is an Associate Fellow of the Royal Aeronautical Society; Member of the Institute of Aeronautical Sciences; Member of the Aeronautical Research Sub-committee, National Research Council; and Vice-Chairman, Toronto Section, Institute of Aeronautical Sciences.

Jets vs Piston—Although it may be outside the scope of this brief article to describe the basic principles of the jet or gas turbine engine, a word or two about the main differences between it and the conventional engine should not be amiss.

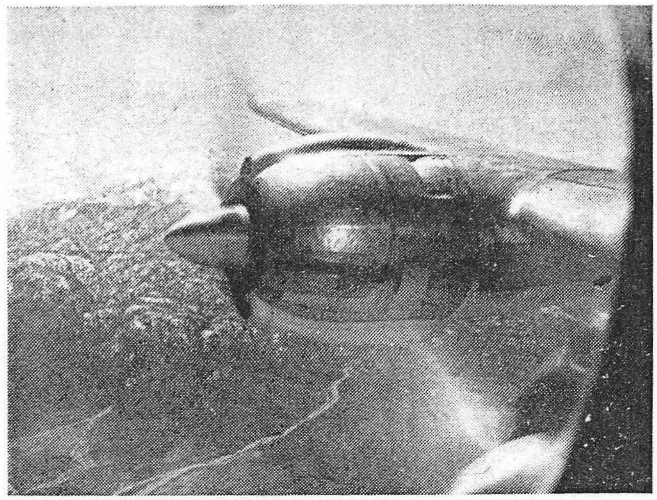
In both cases thrust is obtained from the reaction caused by a change of momentum locally in the air stream in the vicinity of the engine. In the conventional arrangement of reciprocating engine and airscrew, the airscrew does all the work of propulsion by accelerating the air adjacent to the blades. It is the reaction to this acceleration and consequent change of momentum which provides the forward thrust.

In the jet engine, energy is added in the form of heat energy by burning fuel in the airstream **inside** the engine. This causes the hot air or gases to expand and speed through the turbine at high velocity. It is the acceleration of the hot gases which increases the momentum and the thrust is merely the reaction on the engine obtained frim this continuous acceleration.

The rotating parts of a jet engine, namely the compressor and the turbine, are used to raise the pressure of the incoming air to give efficient burning in the combustion chambers and provide a high expansion ratio at the jet, and also to drive the engine auxiliary equipment and the aircraft accessories.

The most important difference, however, between the gas turbine and the conventional engine is the power rating. The conventional engine gives an approximately constant horsepower and the airscrew converts this into thrust, while the jet engine gives an approximately constant thrust and it depends on the speed of the aircraft as to what horsepower this is equivalent. The thrust from a jet engine is practically constant at all speeds for a given fuel consumption. Therefore, as horsepower is proportional to force times distance divided by time, the faster the aircraft travels, the more horsepower is obtained from the jet. The efficiency of the jet engine, therefore, actually increases with the increase in forward speed of the aircraft and takes away the maximum speed barriers which exist with the conventional engine airscrew combination.

Weight—The jet engine is also very much more efficient in power-to-weight ratio. During the last decade the goal of piston engine designers has been to achieve a basic engine weight to horsepower ratio of something less than one lb. per horsepower. Very few reciprocating engines have been developed with a ratio of less than .9 lb. per horsepower. To this engine weight has also to be added the weight of airscrews which is usually a considerable portion of the power plant weight.



Are these power plants to become outmoded? The author predicts that jet engines will succeed today's power units, such as this 2,200 hp Wright Cyclone. The picture was taken through a Constellation porthole.

Even in this relatively early stage of development of the jet engine, however, engine designers have achieved an equivalent basic engine weight to horsepower ratio of as low as .3 to .25 lb. per horsepower at high speeds.

It is true, as we shall see later, that this great saving in weight with the jet engine is somewhat offset by the extra weight of fuel used by the jet for a given range.

Use of Jets for Transports—The development of the jet powered military aircraft during and since World War II stimulated an interest in the use of the gas turbine engine for transport aircraft, but most airline operators viewed this situation with somewhat mixed feelings.

The advantages of speed in military aircraft were obvious and the increase in speed could be achieved without counting the cost, but it was argued that, as the jet engine consumed on the average two or three times as much fuel as the reciprocating engine for a given gross weight of aircraft and the speed was not likely to be increased by more than 50 to 60%, the jet transport would be ideal for the people who could afford to pay for the extra speed but would not be a commercial proposition.

The average airline passenger is the person who is willing to pay a **small** addition to the cost of surface transportation in order to cut down the journey time from place to place and the airline operators have, in fact, been selling speed. All other things being equal then, it was felt that some passengers might be willing to pay even more for the super express service offered by the jet transport. It appeared, however, that it would not be possible to replace the existing types with jet powered aircraft and still give the average passenger the same value for his money.

Operating Cost Comparison—There were, however, one or two operators who got down to the job of carrying out a detailed comparison of the operating cost of the jet versus the conventional engined transport and they were somewhat surprised when they discovered that an efficiently-designed jet transport is not only faster, but, given the appropriate ground facilities, appreciably more economical to operate.

The main factor in this economy is the effect of speed on the direct operating costs which an airline has to consider. These costs include crew salaries, fuel cost, depreciation, insurance, maintenance, and all items of operational upkeep.

Speed plays an enormous part in these costs and the effect can best be shown by a comparison of two types of aircraft. One, the present-day medium-speed aircraft, and the other the future jet transport. It can be shown that the cost per hour for a given range and payload, whether the range be operated by a jet or reciprocating engined aircraft is, primarily, some constant, plus fuel and oil cost.

If we had two hypothetical aircraft of say, 40,000-50,000 lb. gross weight, both short-range twin-engine transports, one a medium speed 250-mile-an-hour aircraft with reciprocating engines, and the other a 400-mile-an-hour jet-engined aircraft, from statistics, it can be shown that the fixed direct operating cost per hour for the above aircraft is about $120 for each aircraft based on the American cost formulae being used at the present time.

This is due to the fact that most of the hourly costs are fixed, such as crew salaries, etc. and the rest, depreciation, insurance, etc. usually balance out between one aircraft and another. That is the reason that speed always pays in so far as the fixed costs are concerned, because the more miles you can cover in an hour the lower is the cost per mile.

We start off, then, with our fixed hourly costs for aircraft A and B. A being the jet powered high-speed aircraft, and B the reciprocating-engined medium-speed aircraft (both short-range-twin-engined transports with the same payload) operating under optimum conditions.

The fuel consumption for the reciprocating engine would be in the region of 70 gallons per hour per engine, i.e. 140 gallons per hour total. The fuel consumption for the jet engines would be approximately 250 gallons per hour per engine, i.e. 500 gallons per hour total. Thus, the jet engines consume about three-and-a-half times the amount of fuel consumed by the reciprocating engines.

Very litle oil is consumed in the jet engine; the actual consumption for most engines being in terms of approximately one pint per hour. For the reciprocating engine of say, 2,000 horsepower the oil consumption is in the region of six gallons per hour. For the purposes of this analysis, however, oil cost has been neglected.

(Continued on page 74)

Lighter, cheaper, faster, the gas turbine engine will win over the piston power plant during the next few years, but there must be co-operation in design, operation, traffic control.

Jet Transport Destiny

(Continued from page 27)

It should also be mentioned here that kerosene is definitely cheaper than gasoline even in large quantities and is likely to be for some considerable time. However, let us assume that the cost of kerosene used by the jet engines is the same as gasoline and is, say, 20c per gallon for both. The fuel cost will $28 per hour for the reciprocating-engined aircraft and $100 per hour for the jet.

As a very approximate figure, the block-to-block speed, taking into account climb and descent, etc., usually works out to about 70% of cruising speed on a short range, so that in one hour we would have travelled 400 x .70 = 280 miles in the jet transport, and 250 x .70 = 175 miles in the conventional aircraft.

Therefore, the cost per mile for A would be $\frac{220}{280}$ = $ .785 per mile, and the cost for B would be $\frac{148}{175}$ = $ .845 per mile. As mentioned previously, the payload is assumed to be the same in both cases and the cost per ton mile will therefore be proportionate to the above cost per mile.

Although the figures in the above comparison are very arbitrary they at least serve to show that despite the high fuel consumption of the jet, the extra speed can definitely decrease the cost per mile and this may be passed on to the passenger in cheaper transportation.

Other Advantages—The operators are now realizing also that there are many other advantages to the jet transport.

For a given scheduling there will be fewer aircraft required due to the fact that each aircraft covers many more miles for the same utilization in hours. This will have an effect on the depreciation costs. Another factor which should be taken into account is the difference in airframe and instrument depreciation between the jet and the turbine airscrew or reciprocating-engined aircraft.

Depreciation is based on two major factors—(1) deterioration of materials, equipment, and instruments, due to fatigue, vibration, etc., and (2) obsolescence of type. With the pure jet the lack of low-frequency and airscrew vibration is a large factor in slower deterioration or disintegration and the pure jet transport is obviously less likely to become obsolete in a given time than present types of airscrew-driven aircraft.

This latter consideration is very important at the moment as most airlines are considering replacement of types and if replacement is carried out with reciprocating-engined aircraft the depreciation will have to be written off in a much shorter time when eventual replacement with jet transports is required.

Passenger comfort will be increased enormously by the reduction of noise with the jet types and, in this direction, even the man in the street will benefit as the world is likely to be a quieter place when the high-flying jet transports are in use.

Servicing and maintenance should be very much better because of the simplicity of adjustments on the jet engine as compared with the piston engine and the lack of airscrew means that the aircraft will sit much closer to the ground and most of the parts to be serviced can be reached without extra ground equipment.

An airline operator is always rather anxious about using new and untried methods. It can be said here that although there are actually no jet transports in service at the present time, there are military types which have been operating for many thousands of hours. One turbine engined type is now approaching the 100,000-hour operation mark, and there is reason to believe that another engine has already exceeded this figure. The experience obtained on these types has shown that the jet engine, due to its simplicity, is likely to be equally as reliable as, if not more reliable than any other type of engine in use today.

With increased speed there will be a better change of forecasting weather conditions from block to block with a consequent big reduction in fuel allowances and a corresponding increase in payload, and altogether, scheduling should be very much more predictable than at the present time.

If the optimum results are to be achieved, the designer, the operator, and airport management must all get together and work out the best solution to the many problems which will undoubtedly arise from the introduction of the jet transport to domestic airline operation.

Design Problems Involved—There are many problems to be faced by the designer of the jet transport. Good aerodynamic shape is essential to obtain the increased speed and the aircraft has to be operated at high latitude to obtain speed efficiently. As an example, the drag of an aircarft flying at 600 mph at 40,000 feet is less than that of an aircraft flying at 300 mph at sea level.

It is, therefore, essential to fly the aircraft as high as possible, and also, to cut down block-to-block time, it is important that the aircraft be able to climp to operating altitude as quickly as possible and to descend from the operating altitude to the airport for landing in the shortest possible time.

It would not be feasible, however, to subject the passengers to the extremely rapid changes of pressure caused by a quick descent. Thus, the pressure in the cabin has to be kept as constant as possible at all times. Statistics show 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 they may suffer slight discomfort at a rate of change of pressure somewhat below this. Some airlines, therefore, are recommending an equivalent rate of descent in terms of pressure of not more than 200 to 250 ft. per minute.

Assuming that our aircraft is flying unpressurized at say, 30,000 ft, it would take 150 minutes, i.e. two and one half hours to descend at the rate of 200 ft. per minute, whereas if we pressurize the cabin to, say 8,000 ft. it will only take 40 minutes to descend. If we can pressurize at 30,000 ft. to, say, sea level conditions, the pilot could come down just as quickly as the aircraft can be brought down safely.

To stimulate sea level conditions at 30,000 ft. the pressure inside the cabin would have to be approximately 10.3 psi. The safety factor for pressurizing is 2 which means that the designer would have to design the fuselage to withstand a pressure of 20.6 psi. The structural problems involved with these high differential pressures are extremely complex.

As it would obviously not be desirable to put large access holes and doors in the fuselage for servicing under these conditions, a lot of ingenuity has to be used to cut down the number of external holes and at the same time design for efficient servicing.

Also, with the high-speed aircraft, **controllability at low speeds** must still be maintained. The aircraft must be easy to fly and be stable at all speeds down to the natural approach speed for landing. The pilot must not be continually harassed by the need for trimming and correcting at a time when he must give his undivided attention to getting the aircraft down safely.

Therefore, no appreciable change of trim should be evident either when the flaps and undercarriage are lowered or when the engine throttles are closed down. It should be said here that the problem of controllability at low speeds should actually present no great difficulty with the jet transport as the increased speed is obtained by extra power from the engines and not by any aerodynamic trickery which is likely to upset the low-speed characteristics.

Engine Design Improvements—Because of the extremely rapid development of the pure jet engine during the war for military purposes, some compromise had to be made in the efficiency of the engine to get the simplicity which was essential for rapid production. Consequently, the cycle efficiencies of present-day turbine engines are very much lower than can ultimately be achieved.

The engine designers have, therefore, many problems to face in the further development of the turbine engine.

Fuel consumption must be cut down to a figure far below present consumption, which is in the region of 1 lb/lb.-thrust/hr. at sea level. This means that an engine developing 5,000 lb. thrust for cruising consumes some 600 or more gallons of fuel per hour (at sea level).

In this direction some means must be found of increasing the air-handling capacity of a given type of engine as the thrust is proportional to the amount of air going through the engine.

Some means of increasing the engine operating temperatures must also be found as it can be shown that for an increase in temperature of 50% at the turbine-inlet, the increase in thrust is approximately 50 to 60% while the increase in fuel consumption is something less than 10%.

Engine operating temperatures are the main limiting feature at the present time. but work is presently being carried out on porous materials, which will allow cooling liquid to be circulated through the hot parts of the engine. Other means of cooling are also being considered and the use of materials which are less susceptible to creep at high temperatures is being investigated.

There is every indication that the next few years will see the development of turbine engines which will consume (for a given thrust) less than half the amount of fuel consumed by present day turbine engines.

The Operational Story—From the operator's viewpoint the jet aircraft has to be used intelligently and the old cut-and-dried methods of piling up allowances for "stooge" and alternatives must be revised completely if the jet aircraft is to be used efficiently. With the higher speed and consequent better forecasting of weather conditions, many thousands of pounds of fuel can be saved on allowance.

One of the major fuel allowances catered for at the moment is the "stooge" which is another name for the airport control stacking the aircraft at various altitudes prior to giving the descent and landing signal Although the stacking only occurs to any extent at La Guardia and Chicago airports, practically all the operators put enough fuel in to be able to stooge around at a fairly low altitude for one hour. This extra fuel decreases the payload which can be carried by a very large amount.

Airport facilities must be modified to prevent this stacking where it exists. One does not see dozens of express trains waiting outside a station for the signal to enter, and the ground transportation services certainly could not be made to pay their way if we had a line of express coaches waiting to unload the passengers at the intercity stations.

Short Turn-around Needed

If jet travel is to be established as a major form of transport, airport facilities must be sufficient to allow the shortest possible time for aircraft turn-round. There must be facilities for pressure refueling to cut down fueling time and passenger embarkation and disembarkation must be speeded up. If speed is to be used to full advantage, the frequency of operation for a given journey must be increased in order to make the best use of the achievable annual ultilization in terms of flying hours.

Navigation and ground aids must be developed to ensure safe operation under all conditions of weather. There have been far-reaching developments in this direction in the past few years by the experiments carried out in England and the United States on high intensity lighting, etc. It is claimed that airport runways are visible even in thick fog at 2,000 ft.

One very great advantage of high-intensity lighting is that all the equipment is on the ground as there has been a tendency in the past to fill up the aircraft with so many complicated and heavy pieces of equipment to aid the landing that the operating efficiency was likely to be seriously jeopardized because of the high initial cost and the even higher loss of payload revenue. It is essential that landing aids be developed where practically all equipment required is on the ground and not carried around in the aircraft.

However, if jet travel is to achieve its destiny there must be co-operative effort by designers, operators, airport managements and traffic control to give this remarkable form of propulsion the chance it merits.

We should then see, with the use of the jet-propelled transport, an enormous increase in air travel. There is no doubt that jet travel will be faster, cheaper, safer and very much more confortable than anything which has been experienced in the past.