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Jet Engines in Airline Service

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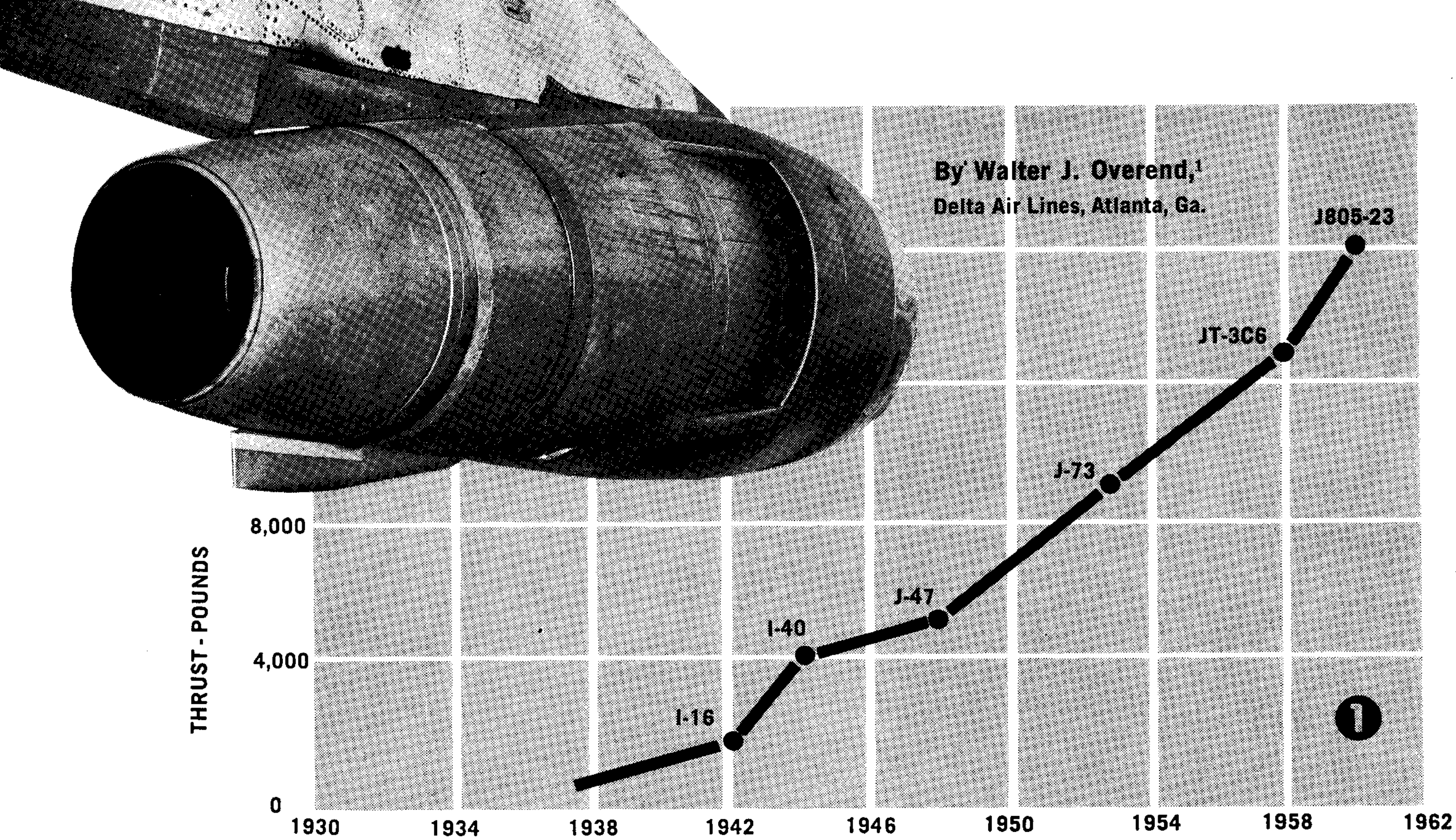

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JET ENGINES IN

In the aircraft industry, the evolution from the DC-3 to the DC-7 was a rather slow-paced progression. How then did we suddenly produce such aircraft as the DC-8 and the Convair 880?

Basically, the answer is a new type of power plant—the turbojet engine. Of course the power plant without the airframe is valueless, but the great power potential that became available with the turbojet engine brought about the essential matching balance between the airframe and engine. The change that took place in the commercial air transportation business a few years ago with the advent of the turbine engine was probably the biggest change ever made in any commercial industry in so short a time.

Early History

In order to explore aspects of the power plant development, some historical facts must be reviewed. First, one cannot forget the fertile seeds that were planted by Whittle and those who worked with him, and the factors of World War II which allowed these seeds to grow and eventually bear fruit. For instance, the first Whittle engine flown delivered only 850 lb of thrust and weighed about 620 lb. These first flights took place in a small Gloster aircraft in England in 1941. Although the initial development had taken place some three or four years previously (Whittle applied for first patents in 1930), it was these early experiments which indicated the potential available. Actually, two years before the Gloster project, similar experiments brought the same realization in Germany.

Each country continued its developments through the war years to finally produce a fully operational jet-propelled combat aircraft just prior to the end of World War II. The German result had the edge in performance and numbers produced, for even as late as 1948 the German Me 262 was being tried at Wright Field against experimental Air Force jet fighters and doing a good job.

One way the German development got ahead of other countries was their selection of power plant. They concentrated most of their efforts on the axial-flow engine and gained a commanding lead at the end of the war. If it had not been for certain problems in obtaining fuel and in pilot training, this one aircraft could well have changed the outcome of the air conflict.

On the other hand, in England and the U. S., designers concentrated on the centrifugal compressor-type engine. Engines of this type powered both the first two airframes produced in this country, the Bell P-59 and the Lockheed P-80. This was a blind alley, for

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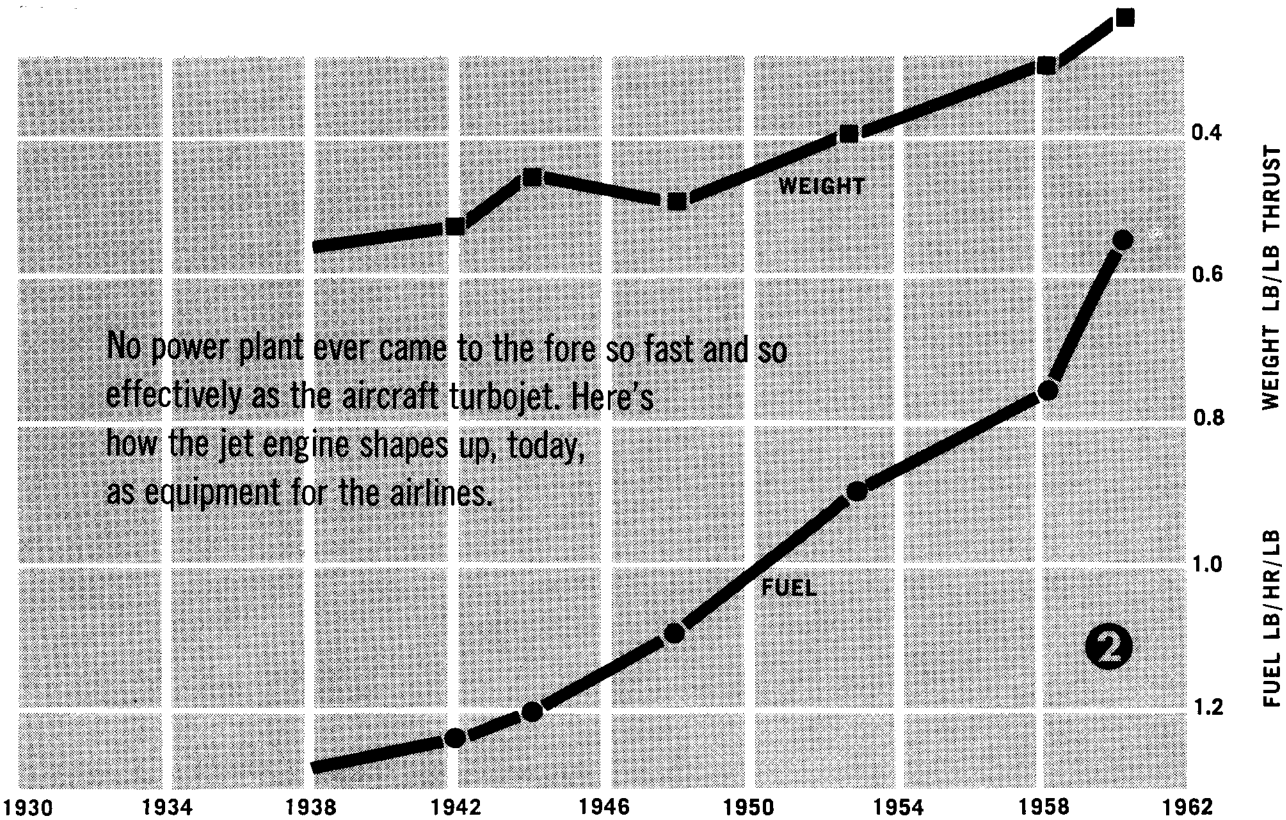


AIRLINE SERVICE

today all of the turbojet engines in commercial use are of the axial-flow type.

Military Needs. Certainly all of the initial development of jet engines came about as a result of military needs. For instance, Fig. 1 shows the development of thrust available for take-off over a period of years.

It was not until after 1958 and the first commercial jets that any significant influence came from other than the military. Naturally, military interests were primarily concerned with highest possible thrusts with fuel consumption taking secondary importance. Also the aim was to have as small a weight penalty as possible with the thrust, and this was a major achievement of the jet engine. Fig. 2 shows this relationship as it progressed through the years.

Early Problems. During these formative years the military did not think that problems of high fuel consumption, particularly at low altitude, and the problem of engine acceleration from low rpm could ever be satisfactorily solved for the turbojet. The biggest commercial drawback at that time was the high fuel consumption.

From these early evaluations of the shortcomings came the trend to the turboprop. This engine had the necessary better performance in acceleration and better fuel consumption at low altitude.

However, the turboprop was only a stopgap solution. Better engine-control systems and metals able to withstand higher temperatures fairly well solved the acceleration problem.

High fuel consumption at low altitude is still apparent, but the fan engine has been a big step toward solving the problem.

So much for the early history of the turbojet. Much was left unmentioned. However, the intent was to pick out several salient features in history which led to the present commercial turbojet engine.

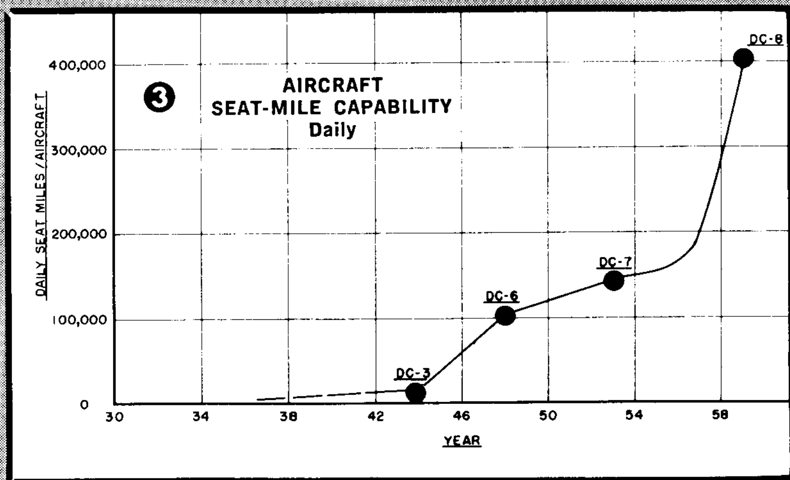
Jet Economics

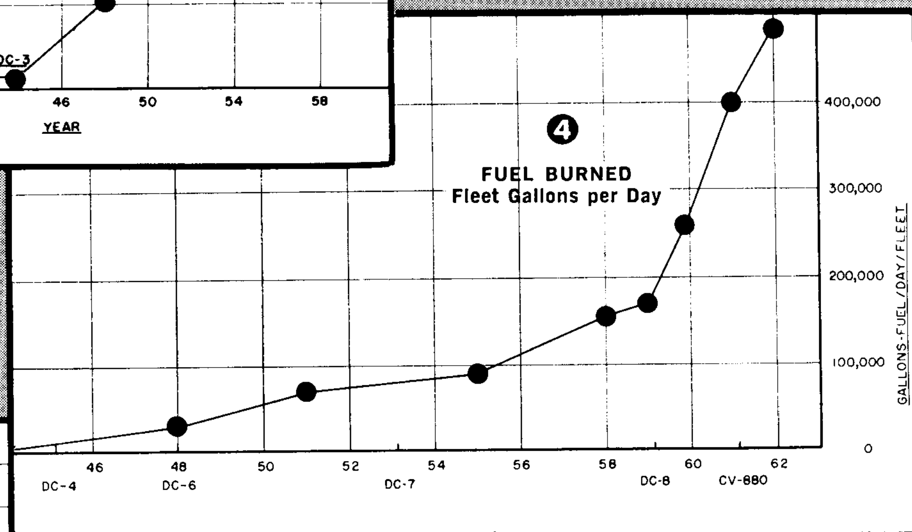
Looking back at the early efforts to build airframes, there were actually a couple of attempts to introduce the turbojet transport which were not successful. In mind is the early Canadian jet, the Avro C102, and the now successful Comet. On the other hand, had the engine economics looked reasonable at this early date, probably other problems could have been easily overcome.

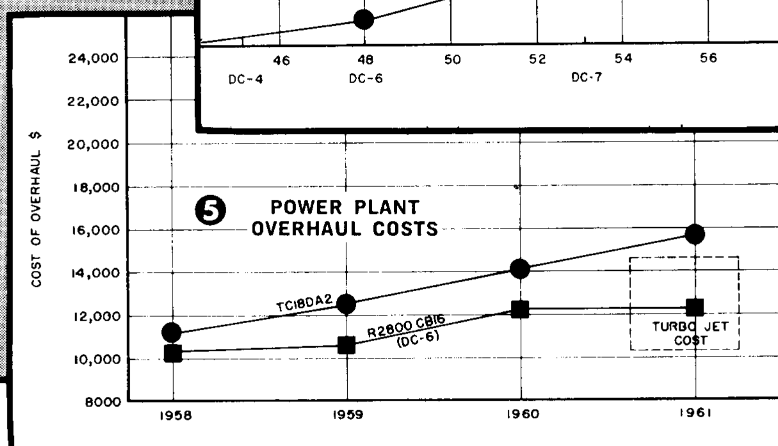
Economics was the major influence that ultimately made the decision in favor of the turbine engine. Despite advancements due to the war efforts, conventional piston engines and propellers had reached a limit. Hence the aircraft size, and therefore payload, were limited.

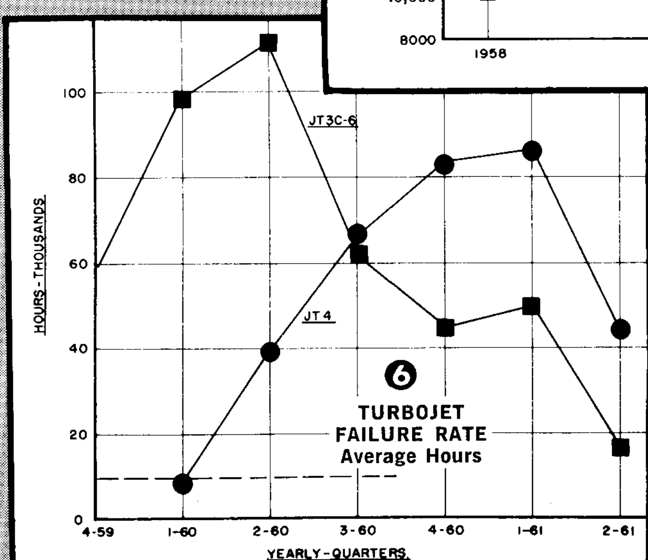
Aircraft seat-mile capability illustrates this point of economics, Fig. 3. The potential of the aircraft depends upon the seat-mile capability which in turn is

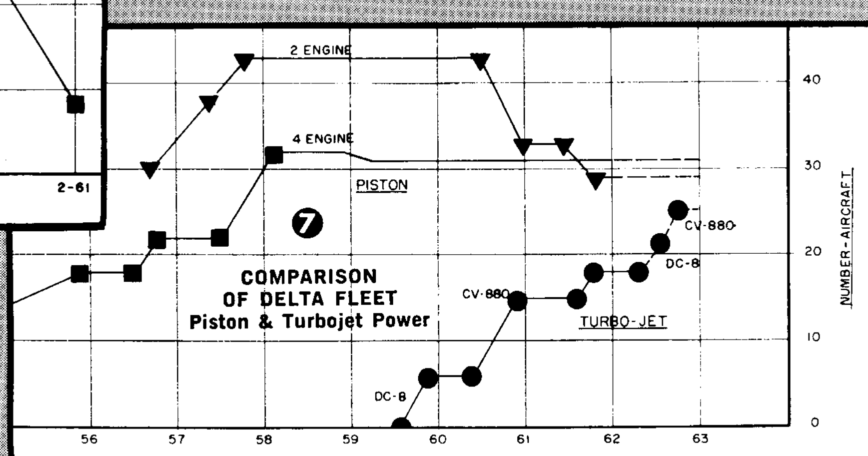
JET ENGINES IN AIRLINE SERVICE











ENGINE IDENTIFICATION

TC-18DA2	Wright turbo compound piston
R 3350	Wright piston
R 2800	Pratt & Whitney piston
R 2800 CB16	Pratt & Whitney piston
I-16	early GE jet
I-40	early GE jet
J-47	GE jet
J-73	GE jet
JT 3C6	Pratt & Whitney jet
JT 3D	Pratt & Whitney turbofan
JT 3D-1	Pratt & Whitney turbofan
JT 4	Pratt & Whitney jet
J 805-3	GE jet
J 805-3B	GE turbofan
J 805-23	GE turbofan

influenced by the trip distance, plus speed. Further, the aircraft utilization becomes a factor. As an example, taking Delta Air Line's route structure and utilization, this plot shows the greatest potential of the jet aircraft for carrying passengers. So suddenly we have an aircraft, the DC-8, seven or eight of which can provide the same daily seat-miles as produced by a fleet of 20 DC-7's.

The logical question at this juncture is, what about the cost of producing these seat-miles?

Fuel. First let's examine the amount of fuel burned. For Delta Air Lines the gallons of fuel per day per fleet increased rather gradually through the years as the route structure and the total number of aircraft increased. But as the DC-8 and then the CV-880 phased into operation the fuel burned climbed sharply to the figure of today, about 400,000 gal. By the end of 1962 the consumption can reach 500,000 gal per day, Fig. 4. Presently, with the DC-8 burning about 2000 gal per hr and the DC-7 somewhere around 500 gal, the fuel cost alone runs about twice as much for a DC-8 over a DC-7 (using kerosene costs of 10 cents and gasoline 20 cents). On the other hand, the DC-7 is only covering 263 miles in one hour while the DC-8 covers 433 (at Delta's trip lengths). At the same time, the DC-8 produces over one half more seats per mi than the DC-7. Thus the seat-mile fuel costs for the DC-8 are considerably less than that of the DC-7.

Overhaul. Even so, there has been quite a sizable increase in per mile costs. To be reduced, some other segment of the operation must be considered. Overhaul time for an engine is a big factor. The turbojet engine is rapidly catching up to their piston counterparts in this respect. It has taken some seven years at Delta Air Lines for the DC-7 piston power plant to reach 1700 hr between overhauls. The CJ805 jet reached a 1600-hr period in something less than a year and a half. The 2800 piston engine is now at a 2200-hr overhaul, but its operation period has been over ten years. Compare this with the Pratt & Whitney JT3C-6 jet, which is now at a 1500-hr overhaul period after two years. Other airlines have reached the 2000 hr plateau in only slightly longer operation time, with the same engine. Supplementing these hour rate figures with overhaul costs, it can be seen that an appreciable cost advantage can be reached as the turbine engine rapidly approaches the piston in overhaul time.

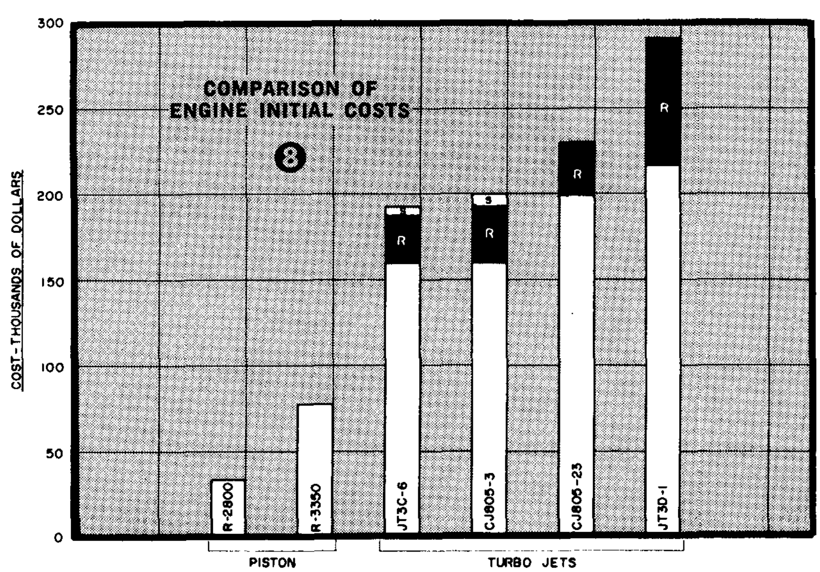
Fig. 5 shows a comparison in overhaul costs between piston engines and the turbojet engine used by Delta. The turbine costs are shown as an area only and are close to general estimates of overhaul costs as they stand today. The piston costs are those actually experienced by Delta Air Lines. Since Delta has not overhauled jet engines for a long enough period of time, direct comparison between costs is not considered valid; however, it can be seen the jet engine looks quite favorable and should be able to show distinct advantages as experience and knowledge progress.

Failure Rate. Certainly a prime consideration of value in any power plant must be its failure rate. How does the engine stand up in operation? This information, Fig. 6, is taken directly from the FAA Powerplant Failure and Propeller Feathering Report and shows the phenomenal average hours per failure which the turbojet has attained through the few years of operation. The dip in the second quarter of 1961 can be attributed to age and failure of parts not normally expected. For the same time period shown in Fig. 6, the piston engines on the DC-7/7B's and DC-6B's were not able to exceed 10,000 hr per failure.

Other Points. As for the general industry's change-over from the piston engine aircraft to the jet, Delta's experience is a good example shown in Fig. 7. In other words, a typical airline has in some three years advanced to the point where the jet fleet nearly matches in numbers the previous size of the conventional four-engined or two-engined fleet. In this instance, Delta's piston fleet continues to carry passengers; whereas, in other airlines, many piston-powered aircraft have been converted to hauling cargo.

Commercial Design

In the early portions of this discussion, it was shown how the military requisites had complete dominance over the evolution of the turbojet engine—all turbine engines for that matter. After 1958, however, when the JT3-type Pratt & Whitney engine had gone into commercial service, the needs and the evaluated short-



This series of graphs shows why the jet engine is becoming the chief power plant of the commercial airlines. **Fig. 3** shows the sharp increase in seat-mile capacity that came with the jet-powered DC-8. Although fuel consumption has also risen steeply, **Fig. 4,** planes with jet engines can carry more people and go farther than their piston-engine counterparts. Thus the economics are in favor of the jet engine. Another factor for the jet is its lower overhaul cost, **Fig. 5.** The jet engine also has a low failure record, **Fig. 6.** For the same time period the piston engines were not able to exceed 10,000 hr per failure. Commercial airlines are well along in their change-over from piston engines. Delta Air Lines, **Fig. 7,** is a good example. **Fig. 8, right,** the initial cost of turbojets and piston engines. Note high cost of thrust reversing mechanisms **R,** and noise suppressors **S.** Fan jets, two bars on **far right,** do not need suppressors.

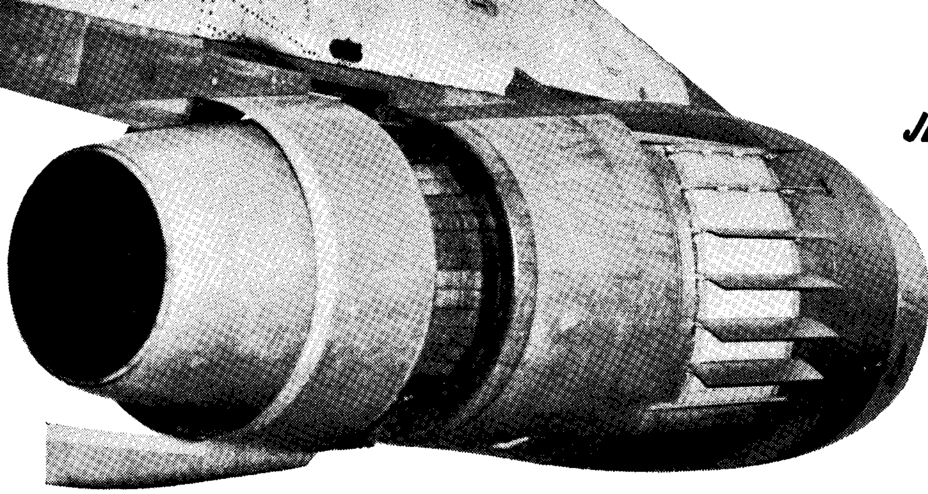


Fig. 9 Two separate actions are needed to reverse the thrust of this fore-fan jet engine. The rear exhaust cascade slips back allowing the main stream reversing buckets to deflect flow forward. Behind the fore fan, side gates come out into the fan flow on either side to deflect thrust. Picture on page 2, **top,** is the same engine before the reversers were activated.

comings of the engines by commercial operators begin to have stronger influence on the outcome of planning and design by the manufacturers.

Reversers and Suppressors. In fact, there were several areas of engine design and use which were solely confined to the commercial operator, and little or no work had been done in the military application. Chief items in this category are sound suppression and thrust reverser units. Understandably, the military application could not tolerate the performance losses resulting from attempting to reduce noise. And, for thrust reversing, in most cases military aircraft were intended to land with the payload expended. Hence, take-off runway requirements by far exceeded those for landing. Also, adaptations such as drag chutes achieved the same purpose of providing shorter runway lengths without involving power control devices.

But the commercial operator has had to have noise suppressors because his customers live off the end of the runway, and because he must, in the long run, operate from shorter runways, land with full payloads, and also have a safety factor backup wherever possible. With little or no development in the military, the full cost of these units was placed upon the airlines, and they have been quite high. Fig. 8 gives an idea of these costs as compared to actual engine costs. The wide disparity between initial piston type costs and those of turbojets also can be seen. In turn, the high percentage of total cost for reversers and suppressors is readily apparent on the turbine types and in particular the Pratt & Whitney fan.

Fan Engine. The commercial operator still was not satisfied with the amounts of fuel that had to be used, so it is quite natural that any change which could result in better fuel economies would be welcomed. A considerable advancement was made in this direction with the fan engine. (This newest effort in turbojets was first noted in Fig. 2 where the slope on the fuel specific curve changed.) In effect, the fan engine achieves its purpose by moving larger amounts of air at lower velocities, similar to a turboprop but without the propeller complication. As a result of this better economy, all of the newer four-engined jets now being produced are powered with some version of the fan engine.

An interesting point here is that no sound suppressors

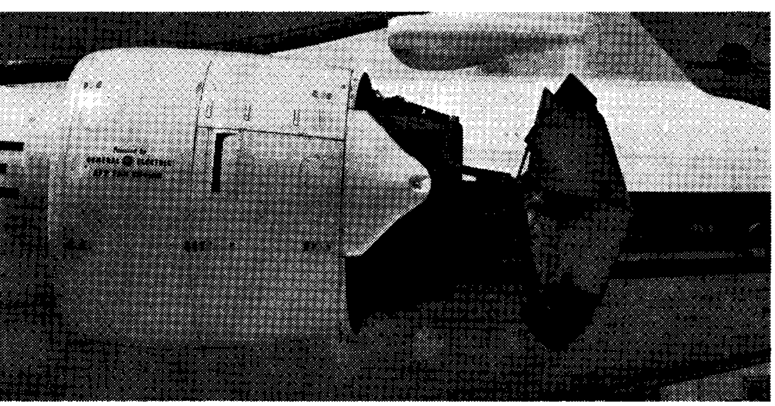


Fig. 10 One reversing mechanism handles the two flows from jet and aft fan at the same point. This calls for a bulky installation. However, it need not be as intricate as the fore fan, **Fig. 9,** where two separate operations have to be co-ordinated.

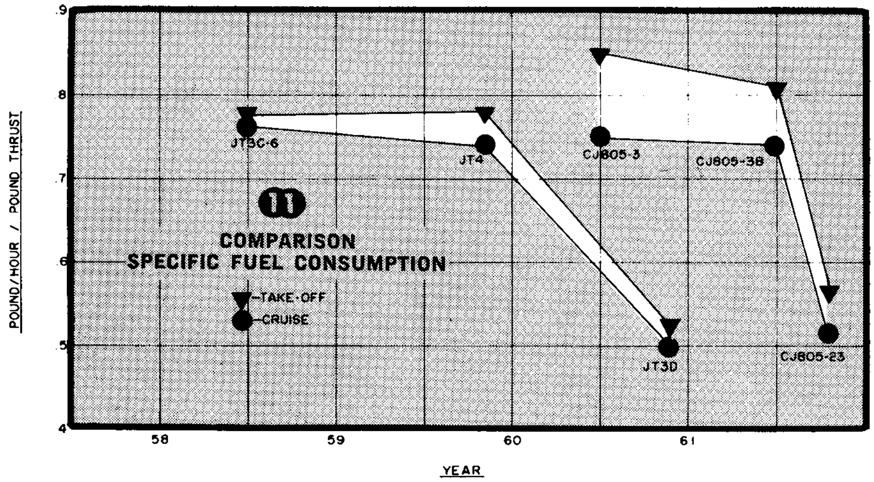


Fig. 11 Although the fan jet engine may have some undesirable characteristics, they are outweighed by its better fuel economies. The set of lines on the **right** indicate better fuel consumption of the fan jet. Those on the **left** indicate fuel consumption for some of the previous commercial turbojets.

are necessary with the fan type of engine. The outer periphery, slower fan exhaust decreases the extremely high shear of the main exhaust stream decreasing sound levels to an acceptable value. But, at the same time, the reversing problems became much more difficult since now there are two streams of propulsive flow which must be turned. Looking at the DC-8 pod, Fig. 9, the side gates come out into the fan flow on either side of the engine, and then the rear exhaust cascade cover slips back, allowing the main stream reversing buckets to direct the flow through cascades and thus forward. The technical problems and the internal intricacy can be realized where each of these units must be co-ordinated to work together and, if any fails to go into position, adding power would only defeat the purpose.

The CJ805 aft-fan engine does not have this same two-stream co-ordination problem, but handles the two stream flows at one point which, in turn, causes a large and bulky installation. This is still not as intricate as the forward fan, Fig. 10.

In this respect, although the fan engines may have some undesirable characteristics, these are vastly outweighed by better fuel economies. Fig. 11 shows the actual change obtained in the fan engine as compared to the previous commercial turbojets. Here can be seen on the order of 35 per cent better fuel specifics. These figures relate to sea-level take-off and cruise conditions. Also, when comparing cost per lb of thrust, a considerable improvement is shown for the fan engine.

The C-6 engine, still in use by Delta on DC-8's, shows up well in this type of an examination because of its water-augmented take-off thrust. By the use of water, normal take-off thrust is increased by some 2000 lb which, if not available, would place the C-6 engine in the chart area of the CJ805. Again, on comparing cost per lb of thrust, however, water-augmented thrust is not entirely all beneficial. It entails handling problems, special loading, hauling and purification equipment, plus complication of aircraft systems which can cause delays and are expensive to maintain.

There are yet many areas in which the engine can still stand improvement. Better fuel specifics, higher overhaul times, longer life materials, and easier maintainability—all of these points will be expected of future power plants. And it is evident from the progress shown here, over a relatively short span of time, all of these things should come about.

Other Advantages. In the long run the turbojet engines have provided other advantages not covered thus far. The engine's construction allows it to keep delivering power even after it has received extensive damage. This is hardly true of reciprocating types.

Even though the performance standards for these newer turbine aircraft have been made more stringent, in most cases the aircraft exceed them by a greater margin than did the piston-powered fleets. Thus a higher safety factor.

The engine's ability to operate at high altitudes has been an outstanding asset to air transportation because of the greater airspace it has provided. Prior to 1958, and extensive use of jet aircraft, very few commercial flights were conducted above 25,000 ft. Now, with a limiting altitude somewhat above 40,000 ft on the jet aircraft, a completely new and unused portion of the sky has been made available. This is badly needed. And the phrase "above the weather" is a good one for jet flights because, in most cases, it is true, making an easier, more enjoyable ride for both crew and passengers.

For weather, the engine offers advantages in being less susceptible to ice—a difficult problem for reciprocating power plants. It is less susceptible to moisture and condensation in ignition systems and much more tolerant of fuel mixtures. In this regard, fuels of various grade and consistency can have undesirable effects on the jet engine in the long run; but, unlike the piston type, it will normally continue to deliver power with a wide range of petroleum products.

It is only fair to say a few words on systems and airframes improvements which, in combination with the power plant, are providing this outstanding transportation system. Flameproof hydraulic fluid, antiskid brakes, high-capacity cooling and pressurization systems, a-c electrical systems, power controls, high lift devices—all of these improvements have resulted from the essential balance so necessary between the airframe and engines.

Many aspects of turbojets and commercial air transportation have not been covered. But, it has been shown that it is certainly a field of commercial enterprise which is to be with us for some time to come. It developed in an extremely short period of time. It provides transportation which no other known field can hope to match. And general trends seem to indicate, in spite of the high initial cost factors, it will be able to match and exceed, economically, other modes of travel that have preceded it.