PT6 Turboprop for General Aviation

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The market and design studies that led to the PT6 engine are briefly reviewed, followed by a summary of the major development milestones leading to civil certification. The future growth of the engine is touched upon. The attractive operational characteristics of propeller turbines in general and the PT6 in particular are described including low temperature operation, life, power to weight ratio, payload/range, and direct operating cost. Aspects of engine installation peculiar to propeller turbines are reviewed and the ease of installation afforded by the PT6 configuration is described. It is concluded that propeller turbines in the lower power classes will find increasing application in the general aviation field.

Introduction

THE penetration of gas turbines into the general aviation field is now significant and confirmed. This relatively late adoption of a new powerplant is of course understandable. The first users of new powerplants are the military, where the high costs associated with new devices of all kinds are proper expenditures, if significant performance gains result. The second users of gas turbines are the commercial airlines, and in this application the gas turbine has demonstrated outstanding reliability and durability and has fully justified itself economically as well. The success of the turbine in the large commercial transports established the commercial turbines and hence paved the way for their introduction into the general aviation field. It is probably correct to take the introduction of the Grumman Gulfstream and the Lockheed Jetstar in 1959–1960 as being the beginning of general aviation use of turbine power. Subsequently, and with the recognition of the many operational advantages of turbines, the market has broadened with progressively smaller turbine aircraft appearing.

The first small twin turboprop powered airplane to be built in America was the Beechcraft King Air. The powerplant for this airplane is the Pratt and Whitney Aircraft 578 equivalent shaft horse power (eshp) PT6 turboprop. The development of this engine and the characteristics that make it so attractive for general aviation use are described in this paper.

Development of the PT6 Engine

Design studies that led to the PT6 engine were initiated in the spring of 1958. The aim was to select a powerplant that would find as broad as possible a market in the civil field but which would also be suitable for light military applications. Although there are increasing possibilities of substantial military business today, the majority of production orders are still for civil use. Consultations with numerous airframe manufacturers and studies of long range forecasts of aircraft requirements led to the selection of an engine in the 500-hp class with optional output shaft speeds of 6230 or 2200 rpm to suit helicopter or fixed-wing applications. The engine layout is rather unusual, and the reasons for the configuration have been described in detail in earlier papers.[1, 2] A cross section of the engine is shown in Fig. 1. An opposed shaft free turbine arrangement is employed with the air intake at the rear of the engine. The axial/centrifugal compressor is driven by a single-stage turbine, and a reverse flow annular combustion chamber is employed. The single-stage free power turbine drives a one- or two-stage reduction gear depending on desired output speed. Exhaust is through two ports on the horizontal centerline near the front of the engine.

Detailed design work on the engine began in January 1959, and the gas generator portion of the engine first ran in November 1959, less than eleven months later. Figure 2 shows the subsequent build-up in development running time and shows highlights of the development program. The first preliminary flight rating test (PFRT) to a U. S. Bureau of Naval Weapons approved schedule was completed in July 1961 on the turboshaft version of the engine at a rating of 450 shaft horse power (shp). Significant first flights in the Beech 18 flying test bed and Hiller Ten 99 helicopter also took place at about that time. Early in 1962 the decision was made to redirect development towards certification at 578 eshp for the turboprop engine and 550 shp for the turboshaft along with a substantial improve-

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Table 1 PT6 engine ratings

	Prototype A-4, eshp/esfc	Production A-6, eshp/esfc	A-18 now under development, eshp/esfc
Takeoff	480/0.70	578/0.65 (610/0.64)[a]	680/0.58
Max continuous and max climb	480/0.70	525/0.67 (545/0.66)[a]	606/0.59
Max cruise	400/0.73	495/0.68	554/0.60
Weight	250	270	295

[a] Nonflat-rated power.

Table 2 Multifuel capability

Fuel type	Approximate engine running hours
JP-4	7550
JP-5	5500
Aviation gasoline, 115/145 octane	700
Diesel fuel, 4 centistokes at 100°F	390
Automotive gasoline	60
Natural gas, rig test only	...

Table 3 Low-temperature lightup capability

Fuel type	Temperature	Remarks
JP-4	−35°F	Minimum ambient temperature encountered
JP-5	−24°F	Minimum ambient temperature encountered
Diesel fuel of 3.9 centistokes at 100°F	+11°F	...

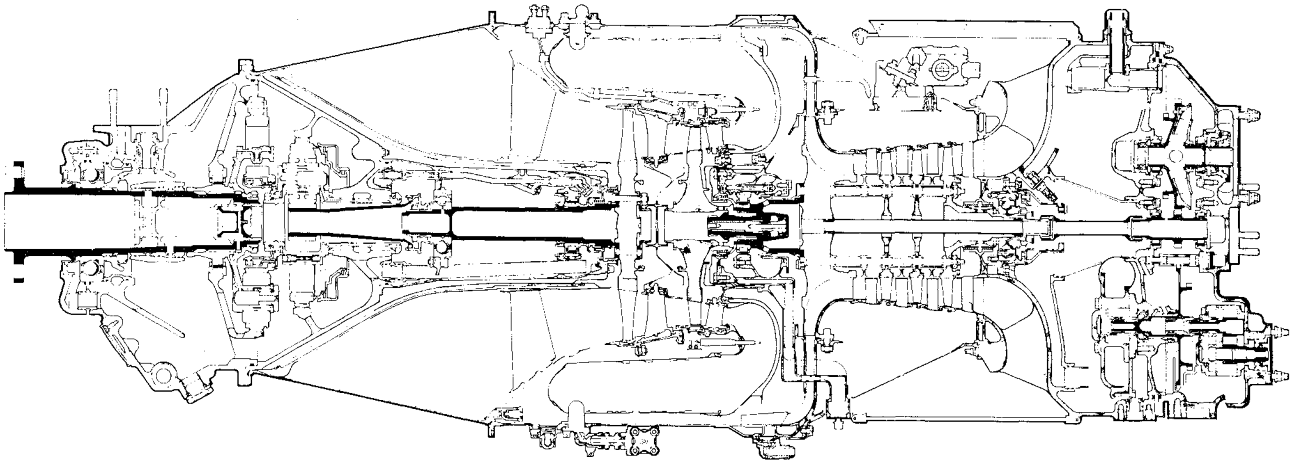

Fig. 1 Cross section of the PT6 turboprop engine.

ment in specific fuel consumption (sfc). This new performance target was bettered toward the end of 1962. During 1963 development running time built up at approximately 400 hr/month, and in June of that year an official Navy PFRT was completed at 580 shp.

Civil certificates for the turboprop version to the A-6 rating of 578 eshp were awarded by the Department of Transport of the Canadian government and the United States Federal Aviation Agency in late 1963. The PT6 is the only turboprop engine of North American design in its power class to hold a civil certificate. The official 150-hr block test was carried out in August 1963 and the many supplementary tests required including overtemperature, overspeed, vibratory stress surveys, low cycle fatigue, and altitude handling were completed in October 1963, as scheduled 18 months earlier. A total of over 11,000 development running hours had been completed at the time of certification in addition to over 1000 hr in various prototype installations. Flight time at certification was just under 800 hr.

Certification of the PT6B-9 is targeted for late 1964. Development testing aimed at systematic product improvement is continuing at approximately 450 hr/month. Aerodynamic and mechanical design improvements aimed at the next uprating step are being introduced into development engines and these will provide a 100-hp power increase and a 10% reduction in sfc relative to the A-6 and B-9 levels within the same envelope.

Table 1 summarizes the ratings of the prototype A-4, production A-6, and uprated A-18 turboprop engines. The latter represents 42% increase in power and 17% reduction in esfc relative to the prototype engine.

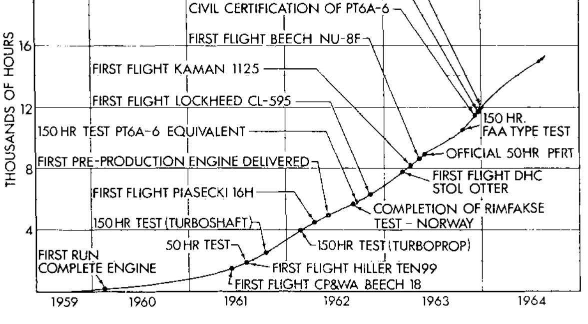

Fig. 2 PT6 engine development running time.

Operational Characteristics

Starting Capability and Flexibility as to Fuel

General aviation aircraft are required to operate under the widest of climatic conditions and in remote areas of the world. For some years also they will be required to operate side by side with reciprocating engined aircraft. The flexibility of the turbine engine as to fuel type and its ability to start under very low temperature conditions are, therefore, of considerable importance. The PT6 engine has done extensive running on all of the fuels shown in Table 2, the total number of hours being shown for each type. In all cases, condition of engine parts has been entirely satisfactory. On the basis of experience to date the engine is approved for use of aviation gasoline for up to 150 hr in any overhaul period. The ability to operate on diesel fuel is of particular importance for remote area operation where this fuel and approximate equivalents such as stove oil are generally stocked for use in construction machinery, trucks, and for heating purpose. Table 3 shows the low-temperature lightup capability that has been demonstrated. On the basis of the experience with JP-5, lightup

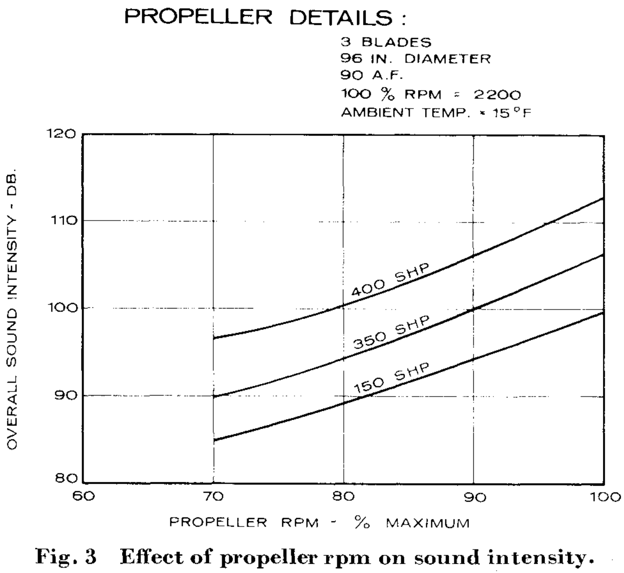

Fig. 3 Effect of propeller rpm on sound intensity.

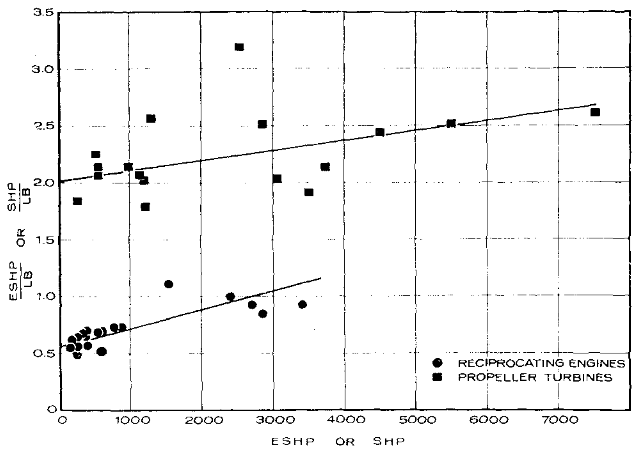

Fig. 4 Comparative power to weight ratio.

of JP-4 at temperatures below −65°F should be quite practical.

Noise and Vibration

Noise level is of considerable importance, both from the point of view of the occupants of the aircraft and those living or working close to the aircraft. The jet engine noise problem is, of course, familiar to all. The propeller or shaft turbine, however, offers some relief, particularly if the design of the engine or installation is such that the compressor inlet is out of the line of sight, as is the case with the PT6 engine. A major portion of total noise, which does occur is due to the propeller, and low propeller tip Mach numbers can assist in minimizing the noise level. The free turbine engine with its flexibility as to output revolutions per minute allows reduced revolutions per minute to be selected for, say, cruise operation. Figure 3 illustrates the effect on noise of revolutions per minute at constant power levels. The free turbine, of course, idles at low propeller and gas generator revolutions per minute affording low noise level in that regime also. General vibration is greatly reduced by turbines, and this will result in substantially less maintenance of cowlings and similar parts as well as reduced passenger fatigue.

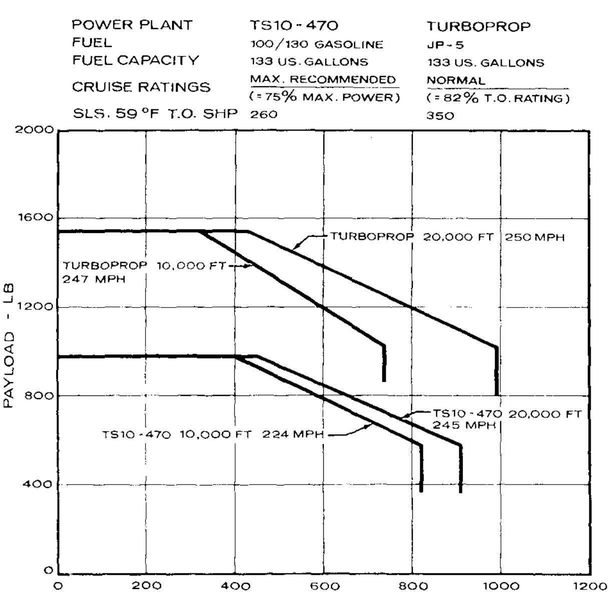

Fig. 5 Comparative payload range for executive twin.

Maintenance and Overhaul Life

Very long overhaul lives have already been achieved on large jet engines and propeller turbines; for example, the Pratt and Whitney Aircraft JT-4 engine has a time between overhauls (TBO) of 5000 hr. There is no fundamental technical reason why long TBO's cannot be achieved on the smaller turbine engines that will power the bulk of general aviation aircraft.

The systematic sampling of engines in service with a particular airline, which has been the basis for establishing the very long TBO's of the larger engines, is more difficult to carry out in the case of general aviation aircraft. This, coupled with lower average utilization, will probably result in a slower rate of progress than with the airline engines. Nevertheless, approval of a TBO of 1000 hr for the PT6 engine is expected by the end of 1965 with further extensions based on service experience and in-house testing.

Power to Weight Ratio

That the turbine engine has a power to weight advantage over reciprocating engines is well appreciated. The fact that this advantage is considerably greater in the smaller powerplants than in the larger units is illustrated in Fig. 4, which shows eshp per pound or shp per pound vs eshp or shp for turboprop and reciprocating engines based on data from Ref. 2. The large development effort being expended today on turbine engines should result in a widening of the margin shown and will make the turbine increasingly attractive in small power classes.

Payload/Range

When piston engines in an existing aircraft are replaced by appropriately sized turbine engines, considerable improvement in the payload/range characteristics can be obtained. In the example presented in Fig. 5, the characteristics of a typical light twin-engined aircraft powered by 260 hp supercharged piston engines are compared with its characteristics when powered by propeller turbine of 350 shp. The analysis is based on the same takeoff gross weight and fuel tankage. It will be noted that approximately 60% increase in payload is obtained at a given range. For a payload equal to the maximum piston engine value, the range is improved by 80% at 10,000 ft and 120% at 20,000 ft. The installation of higher powered turbine engines would yield an increasing speed advantage at the expense of payload/range.

Figure 6 compares the characteristics of an actual single-engined bush-type aircraft, the De Havilland Beaver, originally powered by a Pratt & Whitney Aircraft (PWA) 985 450 hp pis-

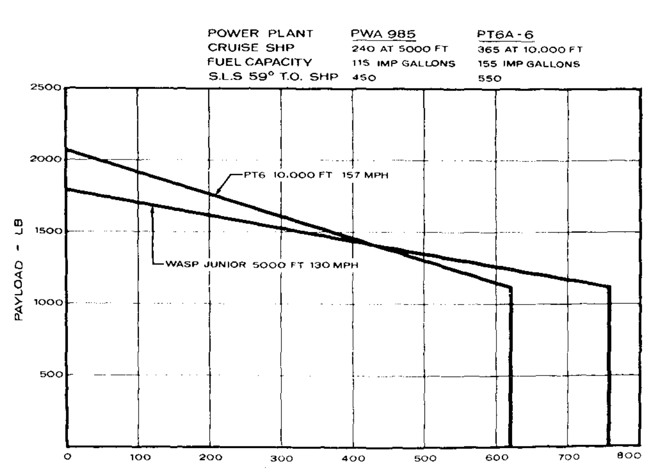

Fig. 6 Comparative payload range for DH Beaver.

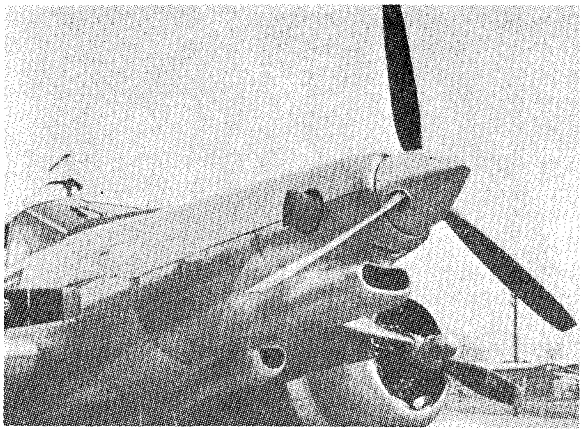

Fig. 7 PT6 installation in Beech 18 flying test bed.

ton engine and now being offered with the PT6A-6 engine. In this case, the fuselage of the aircraft was lengthened to provide accommodation for two additional passengers. Such an aircraft typically operates at low altitude and over short ranges. It will be noted that the PT6 engine provides an attractive increase in payload for ranges up to 400 miles as well as a 20% increase in cruise speed. These combine to substantially increase the earning capability of the aircraft.

Direct Operating Cost (DOC)

Numerous studies have been carried out at United Aircraft of Canada Ltd. (UACL) on the effect of powerplant type on direct operating cost. These can be summarized as follows. Because of the advantageous power to weight ratio of the turbine engine a given mission, i.e., a given payload for a given range, can be carried out with an aircraft of lower gross weight. Airframe costs are consequently reduced, but these are offset by greater initial engine costs. Fuel cost per pound is lower for the turbine engine but sfc's tend to be higher. The general conclusion from our studies was that, for, say, equal utilization in hours per year, at least a 20% increase in cruising speed could be obtained at direct operating costs essentially identical to those of piston engine powered aircraft. On the De Havilland Beaver mentioned previously, where gross weight was maintained constant and where a large speed improvement was not the primary aim, a substantial reduction in DOC was obtained by converting to turbine power along with a 20% increase in cruising speed. DOC based on 800 hr/annum utilization and a 200-mile range show a reduction of 14% in cost per ton mile and 22% in cost per seat mile.

Installation Aspects

The installation of the turbine engine requires consideration of a number of aspects which are not normally of concern with piston engines. For instance the relatively high airflow for a given power level requires more careful consideration of the air intake configuration and the handling of large quantities of hot exhaust gases. The relatively large airflow and forward facing intake employed for maximum ram recovery result in ingestion of foreign objects which can result in serious engine damage. On large jet engines, foreign object damage accounts for 25% of all unscheduled engine removals; for smaller engines operating under poorer field conditions, the percentage would tend to be higher unless adequate protection is provided.

The layout of the PT6 engine has permitted simple solutions to the foregoing installation requirements. The plenum-type intake at the rear of the engine gives low loss and insensitivity to aircraft attitude. Figure 7 illustrates the installation in the UACL Beech 18 flying test bed. The forward location of

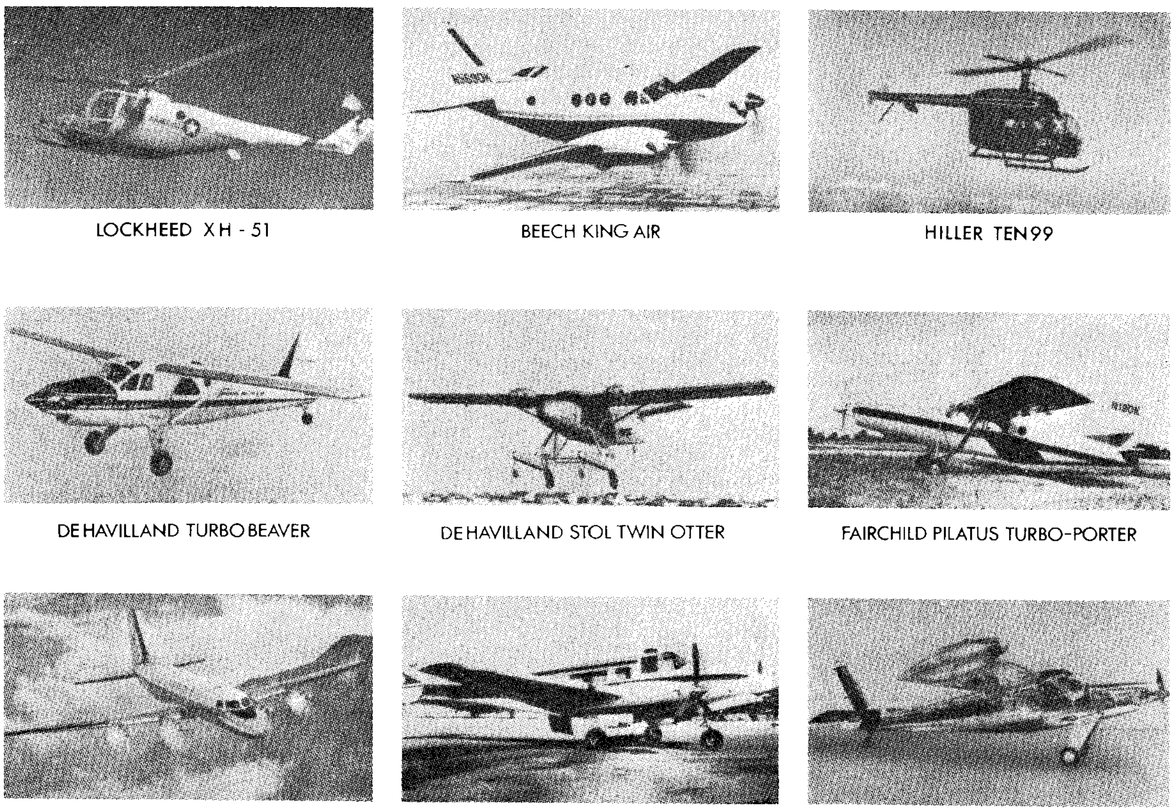

Fig 8 PT6 engine installations.

the two exhaust ports results in an insignificant length of hot ducting within the engine cowlings with attendant simplification. This has proved to be particularly useful in applications where piston engines have been replaced by the PT6 since no significant alterations of the basic structure aft of the engine were required to accommodate the exhaust pipe of more stereotyped turbine engine layouts. Figure 8 shows a number of installations of the engine.

Several attempts have been made over the years to protect turbine engines from foreign object damage through the use of inlet screens. Generally the velocity through the screen was so high that significant power loss resulted, particularly if anti-icing provisions were inadequate. Provision of a screen of large area and hence low loss is extremely difficult in a straight through engine. On the reverse flow PT6 configuration, large area can be provided, and the fact that the screen is parallel to the direction of flight results in effective inertial separation of foreign objects. Such a screen can be effectively anti-iced using alcohol spray; this system has been certified.

When considering a turboprop propulsion system the engine is only one of the two main elements. The development of a compatible and economical propeller is essential. On the free turbine engine this is relatively straightforward since the propeller and propeller governor are essentially independent of the gas generator portion. A conventional piston engine propeller that maintains a particular selected speed by alteration in blade pitch for varying power levels and flight conditions can be employed. Speed variations are sensed by a conventional hydraulic governor that regulates oil flow to or from the propeller as required, and no complex control interconnects are required. On the PT6 the only problem encountered in adapting such a propeller to a free turbine engine resulted from the substantially lower engine vibration level. Satisfactory synchronization on twin-engined installations was obtained by introduction of antifriction bearings in the place of plain bearings on the blade shanks which reduced propeller hysteresis substantially.

In order to increase their general usefulness, the general aviation category aircraft are being called upon to operate from smaller fields and on icy runways. The provision of propeller reversing will, as a consequence, become more general. Considerable interest in reversing capability has been shown by current and potential PT6 users, and a development program which has led to a successful system was undertaken early in 1963. The first production engines so equipped were shipped in March, 1964. The system varies propeller blade angle with reverse power providing smooth variation in thrust from full forward through zero to full reverse. Apart from the use of reverse to reduce the landing run, such a fully modulated system is particularly useful for maneuvering float equipped aircraft on the water.

Future Prospects and Conclusion

The introduction of turbine engines into aircraft in the general aviation category is rapidly gaining momentum. The installation of these engines requires consideration of several factors associated with the relatively high airflow of this type of engine and the engine configuration has a considerable influence on the ease with which a satisfactory installation can be realized. The operational features, high power to weight ratio and competitive operating cost, which have been achieved on engines such as the Pratt and Whitney Aircraft PT6 make this type of powerplant extremely attractive. The nature of the turbine engine is such that substantial performance improvements are possible within the same over-all envelope and with relatively small increases in weight. Continued development effort and increasing awareness of the advantages of the turbine engine will accelerate their adoption in the general aviation field.

References

[1] Vrana, J. C., "Aerodynamics of the gas path in the PT6 engine," IAS Paper 60-96 (October 1960).

[2] Smith, E. L., "Development of the T-74 (PT6) turboprop/turboshaft engine," Society of Automotive Engineers Paper 624B (January 1963).

[3] Wilkinson, P., *Aircraft Engines of the World—1962/63*, (P. H. Wilkinson, Washington, D. C., 1962).