# Design and Development of the T64 Turboprop/Turboshaft Engine for Operation in V/STOL Attitude

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**The T64 turboprop/turboshaft engine was designed to afford a wide range of operating attitudes appropriate for use in V/STOL aircraft. The engine can operate from a −45° attitude, useful in helicopter towing applications, to a +100° attitude appropriate to tilt-wing and propeller applications. The primary design consideration for attitude capability is in the lubrication supply, sealing, and scavenging from the engine sumps. Additional considerations of structural design, rotor thrust balance, and aerothermodynamic performance were included in the engine configuration. Proof and qualification tests of the engine's attitude capability included verification of the engine's starting, stopping, stowing, and operational characteristics in its specified range of attitudes and transition modes, and these tests will continue.**

## Introduction

THE T64 engine (Fig. 1) is a high-pressure ratio, free-turbine, turboprop/turboshaft machine in the 2850 hp range.[1] Particular regard was given in the original specification, design, and final development of the engine for use in V/STOL aircraft. The specification attitude capabilities are as follows: 1) Level position with the engine inclined up to 30° either side, 2) 0° to 45° diving angle with up to 10° inclination on either side, 3) 90° diving angle for a period of 10 sec, 4) 0° to 100° climbing angle with up to 10° inclination on either side, 5) Negative *g* inverted flight operation for 20 sec, 6) Zero *g* operation for 20 sec, 7) Starting and stopping from −20° nose-down to 90° nose-up, and 8) Stowage in any attitude. The 45° nose-down attitude is anticipated to be useful in helicopter towing applications. The 100° nose-up attitude is appropriate to tilt-wing and/or tilt-propeller applications. The roll attitudes are appropriate to special installation requirements and to aircraft maneuver requirements.

Selection of the engine to power the Vought-Hiller-Ryan XC-142A Tri-Service, tilt-wing VTOL transport (Fig. 2) was the occasion for an intensive test program to assure the special capabilities that have been designed into the engine for versatile V/STOL operations, and the design considerations and test experience are described. The T64's special attitude capabilities contributed to its being selected to power the Navy's Sikorsky CH-53A heavy helicopter, the Army's de Havilland CV-7A STOL utility transport, and Hughes XV-9A research helicopter.

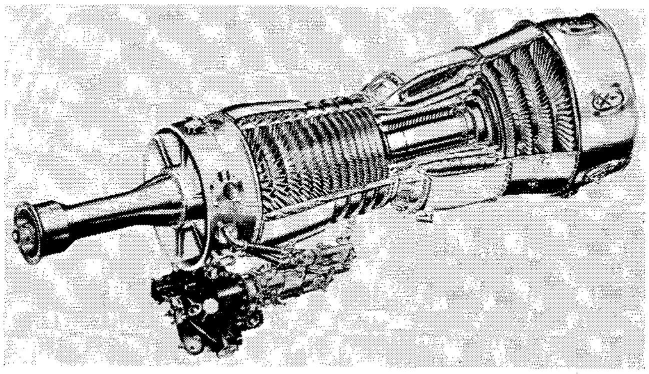

**Fig. 1 The T64 engine.**

## Lubrication System Design

The primary consideration implicit in design for attitude capability is in the lubrication supply, with respect to scavenging from the engine sumps to minimize fluid puddling, dwell time, and flooding and leakage from shaft seals, in all combinations of continuous operation, transient operation, starting, stopping, and stowage. These objectives must be met in a lubrication system that includes services for three gas-generator rotor bearings, four power-turbine bearings (including two intershaft bearings), and a power takeoff/accessory gearbox system (Fig. 3).

The primary design philosophies incorporated in the engine to achieve these objectives are as follows:

1) A multiplicity of scavenge ports are incorporated in the engine sumps, each with its separate scavenge pump element and each capable of handling the entire sump air/oil flow independently. The lube and scavenge pump is a six-element "Gerotor"-type internal gear positive-displacement pump. There is one 6.0 gallons per minute (GPM) pressure element and five 5.0 GPM scavenge elements. All the elements are stacked on a common shaft and are manifolded at the lube and scavenge pump body into a common discharge port, to be returned to the aircraft-furnished oil reservoir via the aircraft-furnished air-oil cooler.

2) The vents in each of the sumps are located at or near the top, at an axial location well away from puddled oil in all engine attitudes.

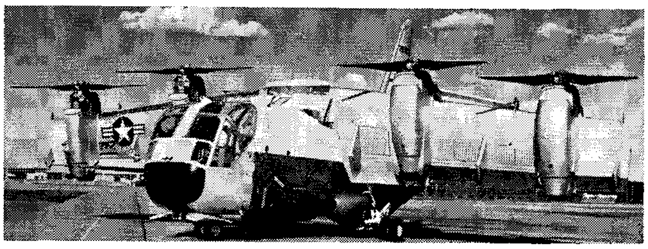

**Fig. 2 The XC-142A tilt-wing VTOL transport.**

Presented as Preprint 64-174 at the AIAA General Aviation Aircraft Design and Operations Meeting, Wichita, Kansas, May 25–27, 1964; revision received August 13, 1964. The basic engine described here was designed and developed by General Electric Company for the Bureau of Naval Weapons with additional development supported by the U. S. Air Force.

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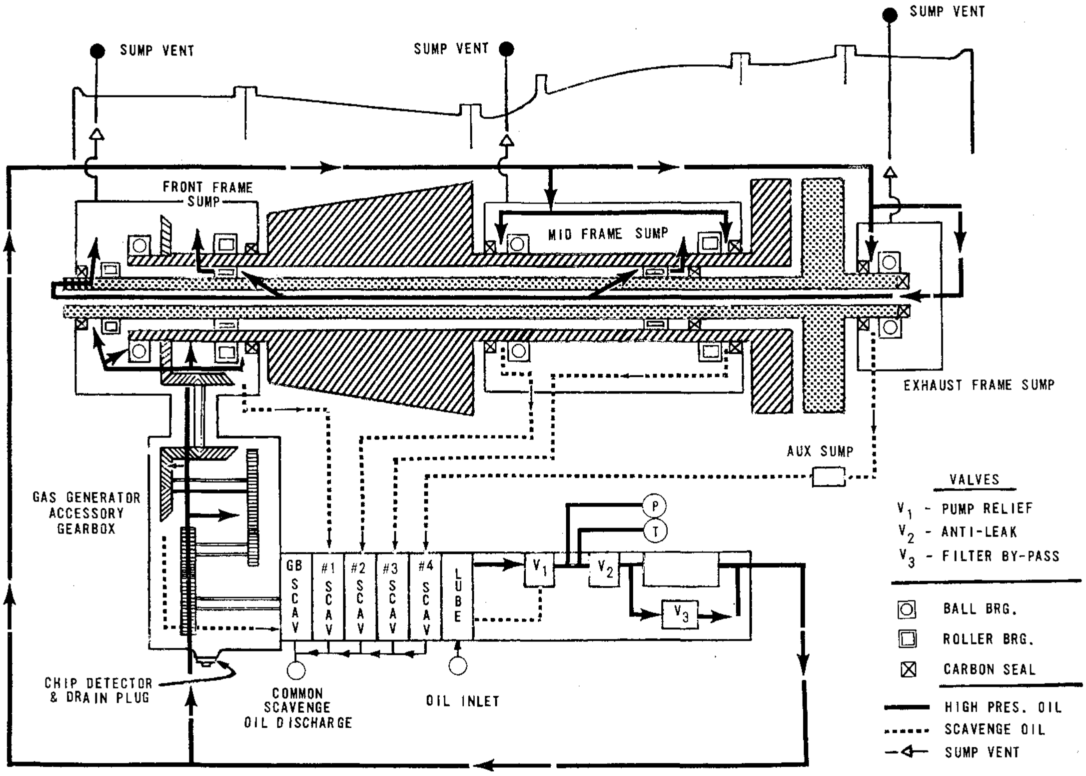


**Fig. 3 The T64 lubrication system.**

3) All shaft seals are circumferential, shaft rubbing, externally pressurized carbon seals. The differential seal, between the two concentric shafts, also includes an elastic organic element for sealing at low relative shaft speeds. Depressed areas are provided around seals, as appropriate, to assure that the level of accumulated oil is below the seal level.

The front frame sump contains the power turbine shaft forward carbon seal and roller bearing (no. 0 bearing), and the compressor forward roller bearing (no. 1 bearing) and carbon seal. Between these two bearing and seal areas is the power takeoff assembly used to drive the accessory gearbox assembly by a drive shaft in the six o'clock strut. The carbon seals are tandem split-ring circumferential designs pressurized by compressor discharge leakage air. In the case of 45° nose-down continuous operation, the front frame sump is primarily drained by gravity through the six o'clock strut and the oil returned to the tank through the accessory gearbox scavenge port (Fig. 4a). Early in the design of the engine, an additional scavenge element had been incorporated forward of the no. 0 bearing, but it was verified that simple gravity porting was sufficient to drain this forward area, and the special scavenging provision was eliminated. Total oil flow of slightly more than 1 GPM to the front frame and accessory gearbox is more than adequately handled by the 5 GPM accessory gearbox scavenge element. In the 90°–100° nose-up attitude, the scavenge port in the no. 1 bearing sump area is below the face of the no. 1 carbon seal to prevent flooding and oil loss (Fig. 4b). The accessory gearbox scavenge port in the bottom rear surface of the gearbox continues its function of scavenging the gearbox area.

The midframe sump contains the engine thrust (no. 2) bearing in the forward section and the gas-generator turbine roller (no. 3) bearing in the aft section. Each end of the sump is sealed with a pressurized shaft rubbing circumferential carbon seal (Fig. 3). The geometry of the seal housings and scavenge ports was designed to satisfy the functional scavenge attitude requirements of the particular bearing areas, that is, to minimize puddled oil and prevent carbon seal flooding and leakage.

In the 45° nose-down attitude, the total oil supplied to the midframe sump is gravity drained to the no. 2 bearing area for pickup (Fig. 5a). All the oil is gravity drained to the no. 3 bearing area for pickup during 90°–100° nose-up attitude (Fig. 5b). Each of the 5 GPM elements associated with each of the scavenging systems at either end of the sump has ample capacity to handle the total flow of approximately 2 GPM into the midframe sump.

The exhaust frame sump contains the power-turbine thrust bearing (no. 4). The sump cover contains an axial-face-type carbon seal for transfer of oil to the rotating oil tube mounted concentrically on the centerline of the bore of the power-turbine output shaft. Since there is a shaft seal at only one end of this sump, only a single scavenging system is provided. But to minimize the residual oil, the system has two ports, one on either side of the bearing. To assure priming of the double-ported system in all attitudes, an angled bend is included in the scavenge line (Figs. 6a and 6b).

The aft differential bearing area on the power-turbine shaft is sealed by a single pressurized split-ring carbon seal assembly (Fig. 7). Scavenging is accomplished in all attitudes by centrifugal force alone. Scavenged oil is returned to the midframe sump through drainage slots and holes in the tienut and turbine shaft assemblies.

The forward differential bearing lubrication oil is also scavenged in all attitudes by the centrifugal action of radial porting in the gas generator shaft (Fig. 8). The oil is fed into the front frame sump and is scavenged by that system, as has been previously described.

## Additional Design Considerations

In a structural sense, design for attitude operation must include consideration of the variation in the 1 $g$ vector relative to the engine and the angular velocities associated with rapid engine tilt in aircraft transition modes. In actuality, the T64 engine was designed for more strenuous maneuvers, such as catapult launch, arrested landing, and rapid turn and climb maneuvers (Table 1), so that the special requirements of VTOL operation lie well within its total capability. Thrust on the engine rotors, as felt by the engine thrust bearings, was designed to act in the aft direction to minimize rotor shifting in the transition from horizontal to vertical attitude.

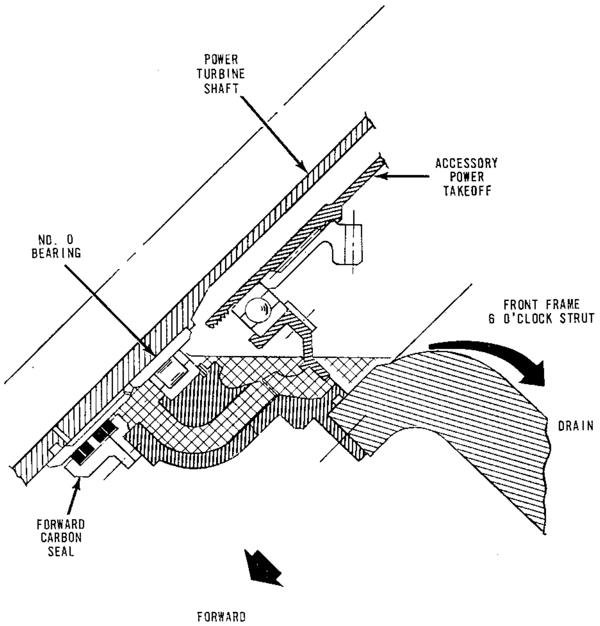


Fig. 4a **Front-frame sump, 45° nose-down.**

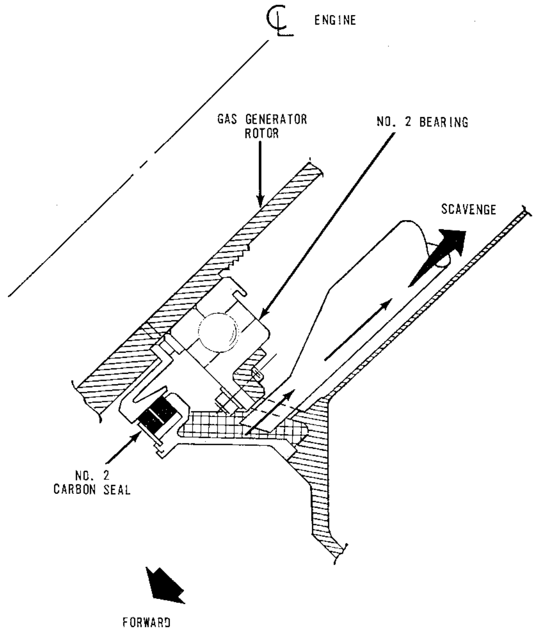


**Fig. 5a Mid-frame sump, 45° nose-down.**

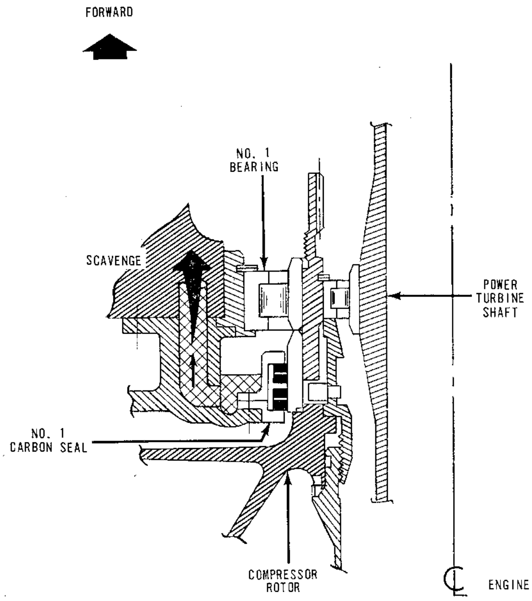


**Fig. 4b Front-frame sump, 90°–100° nose-up.**

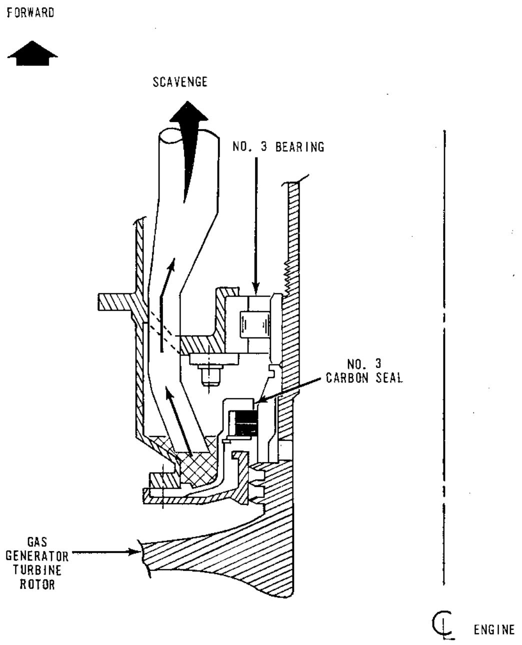


**Fig. 5b Mid-frame sump, 90°–100° nose-up.**

Although all generalities of superior engine performance, such as high performance, low weight, high reliability, etc. are as important or more so in the VTOL aircraft as compared with conventionl aircraft, some have particular special relevance:

1) Large air-bleed capacity for use in stabilizing reaction jets on VTOL aircraft. The T64 is qualified for bleed of up to 6% of total engine airflow.

2) Fast power response for applications where engine power manipulation is part of the aircraft stabilization mode in vertical operation. The T64 is specified for a maximum of 5 sec from flight idle to military power and consistently betters this requirement by 1–2 sec.

3) Low power-to-weight ratio for economy in the critical VTOL mode. The T64 power producer has a power-to-weight ratio of 4 shp/lb.

4) Good fuel economy for efficient sustained hover. The T64 has a fuel consumption of 0.5 lb/hp/hr.

## Engine Test and Development

In addition to the extensive component, factory, altitude, and flight testing of the T64 engine, two separate T64 engine tests were conducted at the General Electric Company facility in Peebles, Ohio (Fig. 9) to evaluate the attitude capabilities of the T64 engine. A proof test was conducted from October 1962 to April 1963, and the second test, an Official Attitude Qualification test, was conducted during July 1963 to September 1963. The configuration of the second engine was identical in all essential respects to that of the production T64 engines shipped for use in the XC-142A aircraft test program.

Both tests evaluated the engine-starting, steady-state, acceleration, stopping, and stowage capabilities at various stationary and transitional attitudes from 45° nose-down to 100° nose-up (Figs. 10a and 10b). In Table 2 a description is given of the endurance-evaluation test cycle developed by the

General Electric Company, the Bureau of Naval Weapons, and the Air Force Aeronautical Systems Division to simulate the anticipated attitude operation on the XC-142A aircraft.

The Official Attitude Qualification test included 75 of these 24-min cycles for a total time of 30 hr. The test, therefore, included 300 attitude changes, of which 75 were conducted at maximum power and 75 were conducted during power transients. All attitude changes were conducted at a rate of 10°/sec. Eighty percent of the endurance operation was in a vertical attitude. Seventy-five percent of the endurance operation was at normal rated power or above. The test included 25 vertical starts and 20 horizontal starts. Prior to and following the endurance test conducted in Ohio, the engines were calibrated at the Lynn, Mass. factory facility in which an electric dynamometer was used to absorb power. The endurance test was conducted using a Hamilton Standard 23F60 fixed-pitch propeller. The propeller pitch was adjusted during the endurance test to provide high torque during the first half of the test and to provide high speed during the

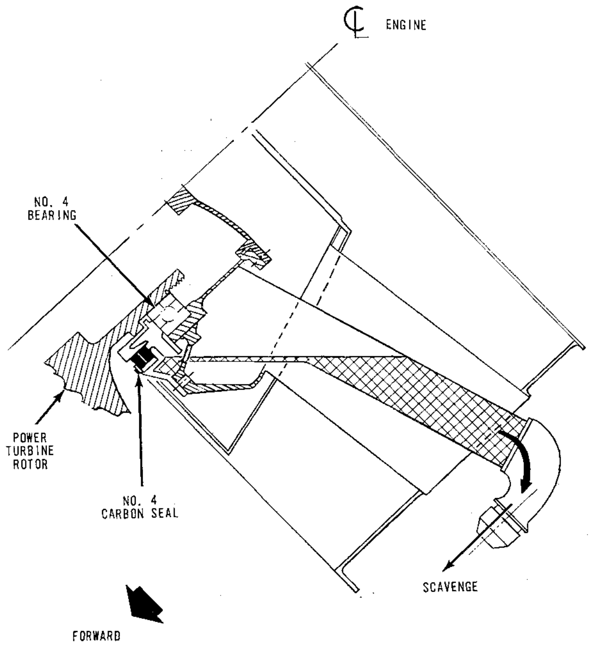


**Fig. 6a Exhaust-frame sump, 45° nose-down.**

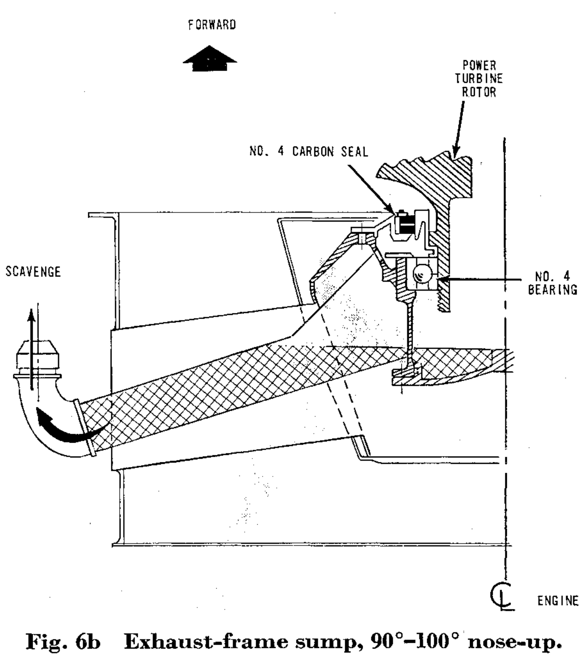


**Fig. 6b Exhaust-frame sump, 90°–100° nose-up.**

**Table 1 Specification maneuver load capabilities of the T64 engine[a]**

| | |
|---|---|
| Vertical acceleration | +6/-10 $g$ |
| Side acceleration | ±4.0 $g$ |
| Fore/aft acceleration | +7/-6 $g$ |
| Yaw rate | ±2.5 rad/sec |
| Pitch rate | ±2.0 rad/sec |
| Yaw acceleration | ±6.0 rad/sec$^2$ |
| Pitch acceleration | ±12.0 rad/sec$^2$ |

[a] All axes referred to engine in horizontal position. Combination load are as specified in MIL-E-8593.

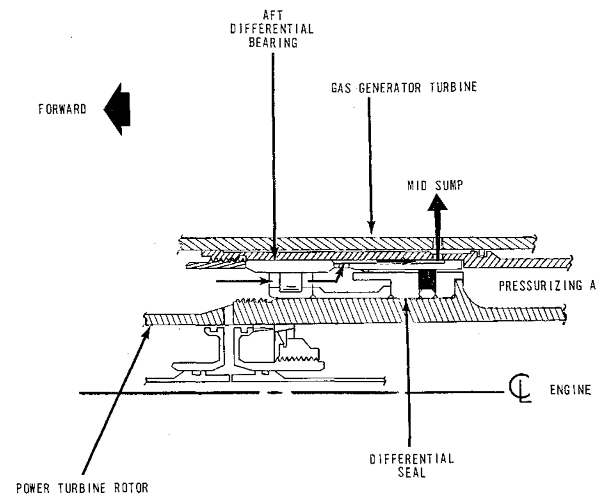


**Fig. 7 Aft differential bearing sump area.**

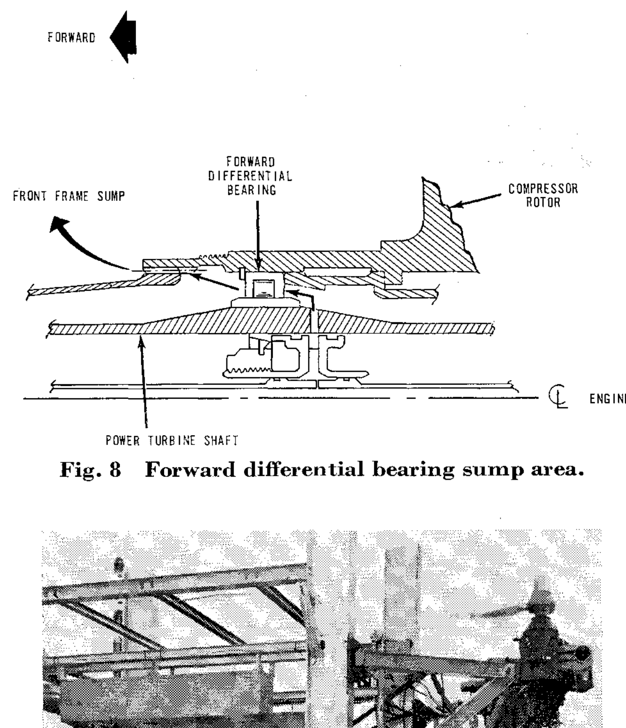


**Fig. 8 Forward differential bearing sump area.**

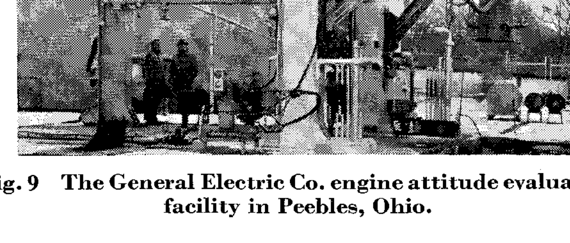

**Fig. 9 The General Electric Co. engine attitude evaluation facility in Peebles, Ohio.**

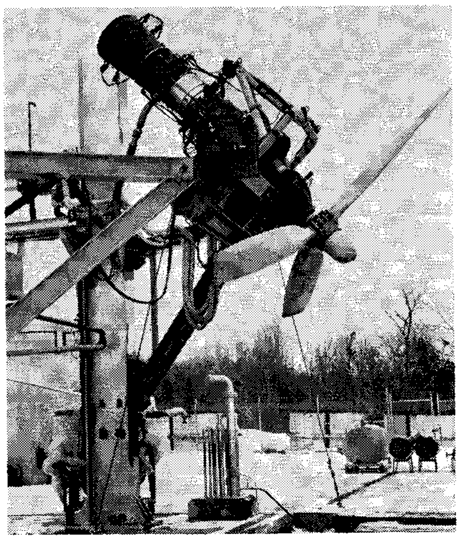

**Fig. 10a The T64 in 45° nose-down attitude.**

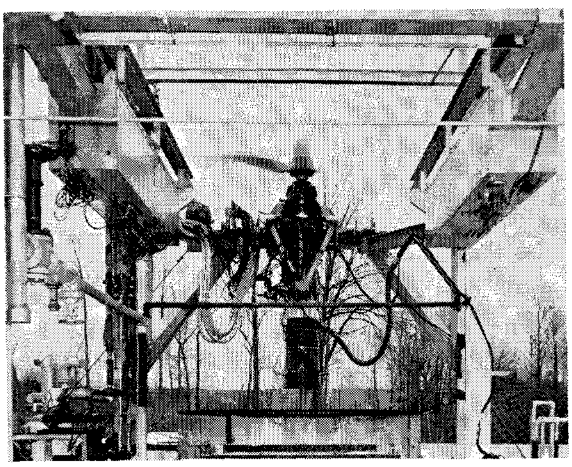

**Fig. 10b The T64 in 90° nose-up attitude.**

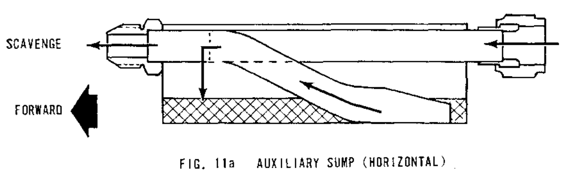


**Fig. 11a The auxiliary sump, horizontal.**

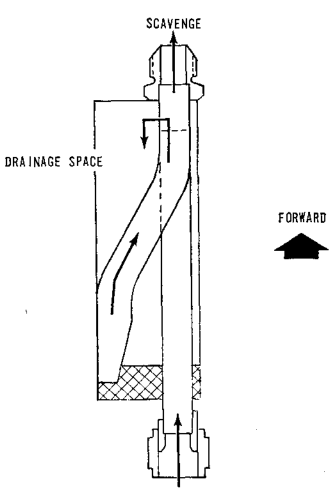


**Fig. 11b Auxiliary sump, vertical.**

**Table 2 T64 engine attitude endurance cycle**

| Power, setting | Engine attitude, deg | Time, min |
|---|---|---|
| Maximum | 90, vertical | 2 |
| Maximum | 90 to 100 to 0 | 1 |
| 50% normal rated to military | 0 to −45 to 100 to 90 | 1 |
| Military | 90 | 5 |
| Normal rated | 90 | 5 |
| Transients from maximum to idle to maximum | 90 | 3 |
| Normal rated | 90 | 1 |
| Ground idle | 90 | 2 |
| Normal rated | 90 to 0 | 1 |
| Flight idle to 90% normal rated | 0 to −45 to 100 to 90 | 1 |
| 90% normal rated | 90 | 2 |
| Total cycle time | | 24 min |

remaining test portion. Although the actual aircraft nacelle was not used, all available aircraft equipment (such as the exhaust system) was included in the test setup.

Two engine sensitivities to attitude were disclosed during the proof test. The fuel control flyweight governor force proved to be somewhat sensitive to engine attitude, and a decrease in gas generator speed of $\frac{1}{4}\%$ was noted in transition from horizontal to vertical operation. The effect of the resultant 50 hp change was minimized by adjusting the engine topping in the vertical mode where power requirements are more critical.

The proof test also revealed an oil scavenging discrepancy in the power turbine sump. After engine shutdown in the vertical attitude and subsequent stowage in the horizontal attitude, 4–8 oz of oil leaked from the rear side of the aft turbine disk, indicative of leakage from the carbon seal at the no. 4 bearing. Analysis and component tests indicated that the power-turbine sump system was left with an excessive amount of oil on shutdown in the vertical attitude from the incompletely evacuated scavenge lines. The problem was effectively solved by addition of an external auxiliary sump (Fig. 11) in the scavenge line to trap this volume of oil before it reached the power turbine sump. All other engine parameters and engine functional characteristics remained insensitive to engine testing in the various attitudes.

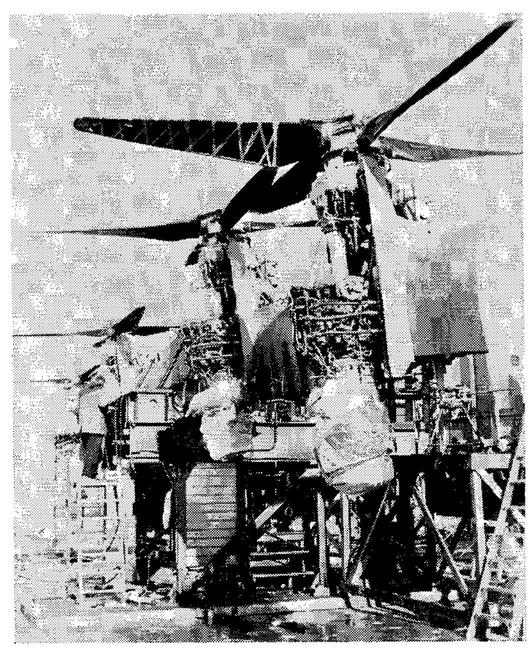

**Fig. 12 Hiller tilt-wing test stand.**

**Table 3 Hamilton standard gearbox endurance test cycle, proposed**

| Power setting | Engine attitude, deg | Time, min |
|---|---|---|
| Grounde idle | 0 | 5 |
| Ground idle | 90 | 5 |
| Maximum | 90 | 5 |
| Military-normal rated | 90 | 5 |
| Normal rated | 0 | 10 |
| 90% normal rated | 0 | 10 |
| 75% normal rated | 0 | 10 |
| Transients-flight idle to maximum | 0–100 | 5 |
| Maximum | 100 | 5 |
| Total cycle time | | 60 min |

The proof test was followed by the Official Attitude test. The basic engine parameters of performance, oil consumption, engine oil heat rejection, oil sump pressures, oil sump scavenge temperatures, vibration, and torque system accuracy were monitored and found to be well within specification limits and insensitive to attitude testing. The Official Engine verified the satisfactory engine characteristics experienced during the proof test.

Further engine attitude testing will be conducted in conjunction with the XC-142A aircraft development program. Testing at Hamilton Standard (per the proposed schedule of Table 3) will include a 50 hr integral-propeller-gearbox endurance test at various engine powers and attitudes. Hiller Aircraft Corporation is developing the complete power transmission system and is conducting various system tests at a variety of power and attitude conditions (Fig. 12). Chance Vought will conduct various engine nacelle development tests, which will include several power conditions at different attitudes. These tests will assure complete engine and propulsion system attitude capability prior to aircraft flight.

## Conclusion

The T64 turboshaft/turboprop engine was designed with special capabilities for attitude operation from −45° nose-down to 100° nose-up in anticipation of its application to V/STOL aircraft. These features were evaluated, developed, and qualified in the course of an extensive test program. These special attitude capabilities were contributory to the engine's having been selected to power the Tri-Service Vought-Hiller-Ryan XC-142A tilt-wing VTOL transport, as well as the Navy's Sikorsky CH-53A heavy helicopter, the Army's deHavilland CV-7A STOL utility transport, and the Army's Hughes XV-9A hot-cycle research helicopter.

## Reference

[1] Ehrich, F. F., "Design and development of the T64 turboprop/turboshaft engine," Am. Soc. Mech. Engrs. Paper 61-GTP-7 (January 12, 1961).