The Expendable Gasifier: A Cost Effective Approach to Turbine Power

H.F. Due Jr.*
Teledyne CAE, Toledo, Ohio
and
D.C. Hall†
Air Force Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio

The Air Force Aero Propulsion Laboratory, Aerospace Power and Propulsion Divisions, has an ongoing program to demonstrate a low-cost gasifier (gas generator) for use as the core of a jet fuel starter, turbojet, or turbofan engine. The main emphasis of the program is on very low cost at a preselected performance level, accomplished through such innovative design techniques as 1) a low-speed design which permits the use of aluminum castings for both rotating and stationary components; 2) an expendable design which eliminates overhaul and maintenance; and 3) the use of radial pin construction which eliminates the requirements for precision threaded fittings and multiple pilot diameters. The final result of this type of design approach will be a simple, inexpensive, expendable gasifier for a jet fuel starter (JFS). turbojet engine, or turbofan engine.

Introduction

AIRCRAFT power systems, one of the principal users of small gas turbine engines, have grown dramatically during the past 25 years in terms of complexity, size, power, performance, and cost. The growth has been caused by aircraft users demanding increased performance at reduced weight and volume. This, in turn, has resulted in ever-increasing development, production, and maintenance costs. The increased costs have reached a point where both the suppliers and users of aircraft power systems (APS) need to examine their priorities and place cost on a level at least equal with performance.

One of the highest cost components of a power system in terms of development, production, and maintenance costs is the gas turbine auxiliary power unit (APU). This cost has been rapidly increasing due to the airframe constraints imposed on the power system and, in particular, the APU. The major constraint imposed on the APU is caused by lack of consideration of the power system installation until late in the airframe design process. This causes the power system, and especially the APU with its attendant exhaust and inlet requirements, to be fitted to the "space available" compartment. The configuration is therefore, compromised and oftentimes incurs an unnecessary performance penalty. In addition, the compromised installation is then developed as a system useful on only one aircraft.

The Air Force Aero Propulsion Laboratory has been pursuing development programs to reduce the costs associated with aircraft power systems and in particular the APU. One of the more promising approaches is to use low cost as the design driver, trading off some performance, if necessary. One of the novel techniques used in doing this is to utilize a single unit as the basic building block for several different applications. The low-cost building block, sized as an APU unit, could then be used for many different aircraft power systems. Aircraft designers, aware of the possible uses of this building block, could then design the airframe using the power system as one of the design drivers along with the mission and the propulsion engine(s). This type of design approach could reduce current power system problems and the total power system cost to the aircraft.

This paper will discuss the evolution of the low-cost building-block approach, the low-cost techniques currently being developed and used for gas turbine APU design effort, and possible future applications of low-cost power systems.

Low-Cost Building-Block Approach

In the past 25 years there has been a radical change in military aircraft power requirements. They have gone from totally ground supported, requiring ground support units at all times, toward total self-sufficiency, able to land anywhere and not depend on ground support. Concurrently, the costs of developing, producing, and using military aircraft power systems have grown at a rate faster than the costs of almost any other aircraft system. These costs are now a significant percentage of the total aircraft cost. Control of the rapid cost growth will require a new method of designing aircraft power systems which replaces the previous approach of delaying the system as the last part of the aircraft design process (Fig. 1).

A method which appears to offer a significant system cost reduction is the "common core" method. This design approach will use common generation components, such as an APU, hydraulic pumps, electrical generator, etc., and modify only the integrating and/or distribution components, such as gearboxes, shafting, etc., for many different applications. This design approach can reduce power system development and production and usage costs significantly.

The development costs are reduced by assuring the aircraft designer a reliable and demonstrated APU/power system power production level. In many of the current aircraft, the

Table 1 Performance characteristics—JFS options, typical APU configurations (see Fig. 8)

PARAMETER	STARTER CONFIGURATION: LO-SPEED INTEGRAL EXHAUST	DIRECT DRIVE INTEGRAL	DIRECT DRIVE FRONT POWER OUTPUT
HORSEPOWER	230	240	240
WEIGHT - LBS.	150	132	105
VOLUME - FT^3	2.20	2.00	1.46
POWER/WEIGHT - HP/LB.	1.53	1.82	2.28
POWER/VOLUME - HP/FT^3	104	120	164

(1) EXCLUDES LOCAL PROJECTIONS

Presented as Paper 77-497 at the AIAA Conference on the Future of Aerospace Power Systems, St. Louis, Mo., March 1-3, 1977; submitted March 10, 1977; revision received July 8, 1977.

Index categories: Powerplant Design; Airbreathing Propulsion; Support Systems.

*Program Manager.

†Air Force Project Engineer.

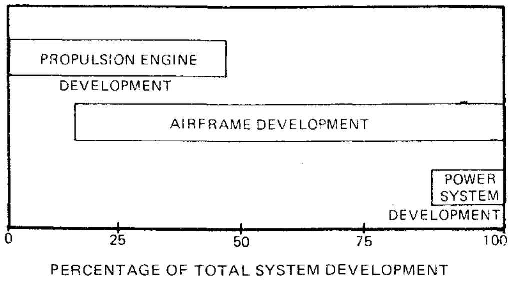

Fig. 1 Total aircraft development process.

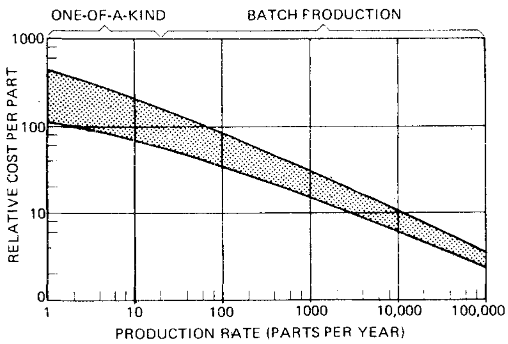

Fig. 2 Cost sensitivity with production rate.[1]

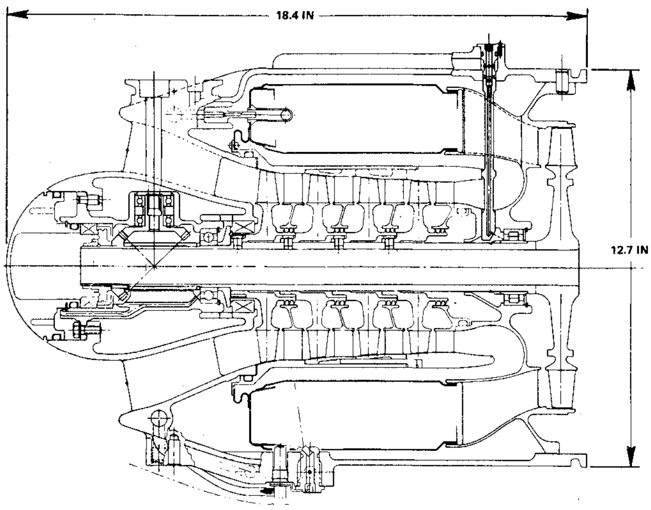

Fig. 3 Model 506 expendable gasifier.

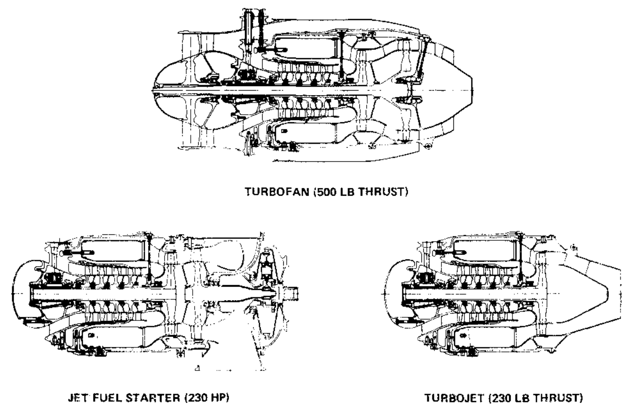

Fig. 4 Expendable gasifier applications.

APU has failed to produce the power required to operate all aircraft systems and has required an expensive redevelopment effort or an aircraft structural change to accommodate a larger one. This effort can be avoided if the designer knows that he can rely on an existing "off the shelf" APU to provide the necessary power with only minor modifications (Table 1).

Applying the "common core" approach can significantly reduce the production costs of the power system by allowing a higher component (APU, hydraulic pump, etc.,) production rate (Fig. 2). In the past, this has been almost impossible for military aircraft since all power systems components were designed to fit a particular aircraft and could not be used on other aircraft (particularly true of the APU).

The user costs associated with the power system are reduced in two ways. First, by using common parts for many different aircraft, the number of different types of spare parts that must be bought, stored, shipped, and accounted for are drastically reduced. Also by using common parts, training time for flight-line technicians and depot technicians can be reduced. Therefore, the total using costs associated with the aircraft are reduced. Second, a common power system can take advantage of all possible advances in technology to reduce maintenance and/or overhaul costs. This is particularly true of the APU. The next section will discuss the techniques used in an Air Force/Teledyne CAE program to reduce APU costs. Specific details on the program are given in Ref. 2.

Expendable Gasifier Power Unit

The Expendable Gasifier (EG) design, (Fig. 3) was configured to interface with turboshaft, turbofan, and turbojet applications (Fig. 4). The EG was sized to meet a turboshaft power requirement of 170 kW (230 shp) at 288 K (59° F), sea level static conditions. Additional power requirements imposed on the EG were, 1) 2.2 kW (3 hp) for accessories and, 2) 5 kW (7 hp) to account for variations between engines during production.

The term "expendable" means the gasifier will be discarded rather than overhauled after its useful life is expended. It is not used to mean the gasifier is to be used only once. The gasifier is designed to have multimission life capability.

The term "gasifier" is used to mean the portion of a gas turbine engine which produces hot gas, e.g., the compressor, combustor, compressor drive turbine, and housings. The U.S. Air Force unit sponsoring this project develops both airbreathing and nonairbreathing machinery, and the term gasifier is used to differentiate between a nonairbreathing gas generator and an airbreathing core engine.

During the preliminary design, mechanical, aerothermo, structural, materials, and manufacturing engineering were integrated witl flowpath engineering, construction, and assembly techniques to meet mission requirements. A few of the low-cost design features of the expendable gasifier evolving from these efforts were:

1) extensive use of aluminum castings;

2) identical rotor castings for all four compressor stages with the tip diameters machined to form the individual rotors;

3) pot-lube front bearing and fuel lubricated rear bearing;

4) main frame casting containing fuel passages for primer fuel, main fuel, and rear bearing lube (no external tubing required);

5) radial pin construction to reduce piloting requirements;

6) relaxed requirements on surface finish, flow surface tolerances, and airfoil thickness to ease casting difficulties;

7) perforated sheet metal combustor liners;

8) turbine rotor cast to net shape and EB welded to the shaft;

9) a low rotor speed, allowing the use of investment cast aluminum for the compressor rotors.

However, in order to make the throwaway concept pay off, particular attention was given to the many factors which influence acquisition cost. Smith[3] describes the initial conceptual studies which address designing a JFS for low cost from the beginning. During the preliminary cycle analysis, low cost is considered by: 1) choosing adequate performance

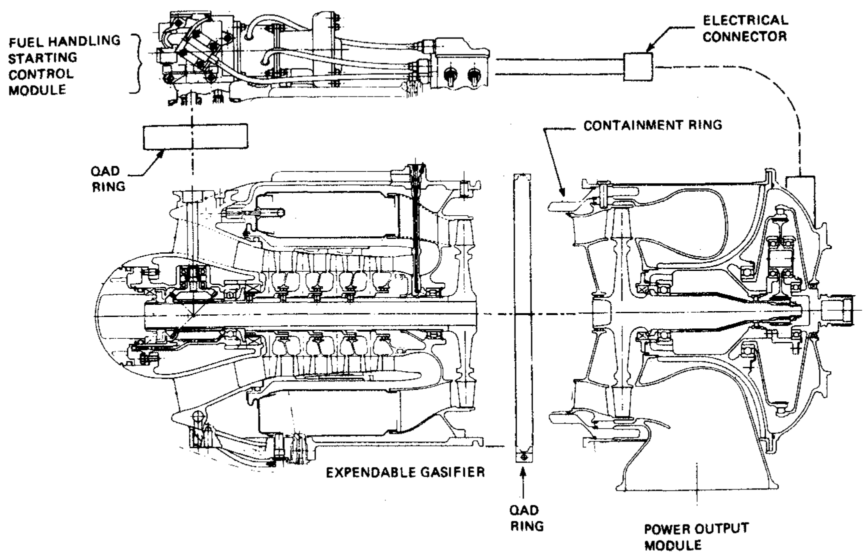

Fig. 5 Jet fuel starter modular construction.

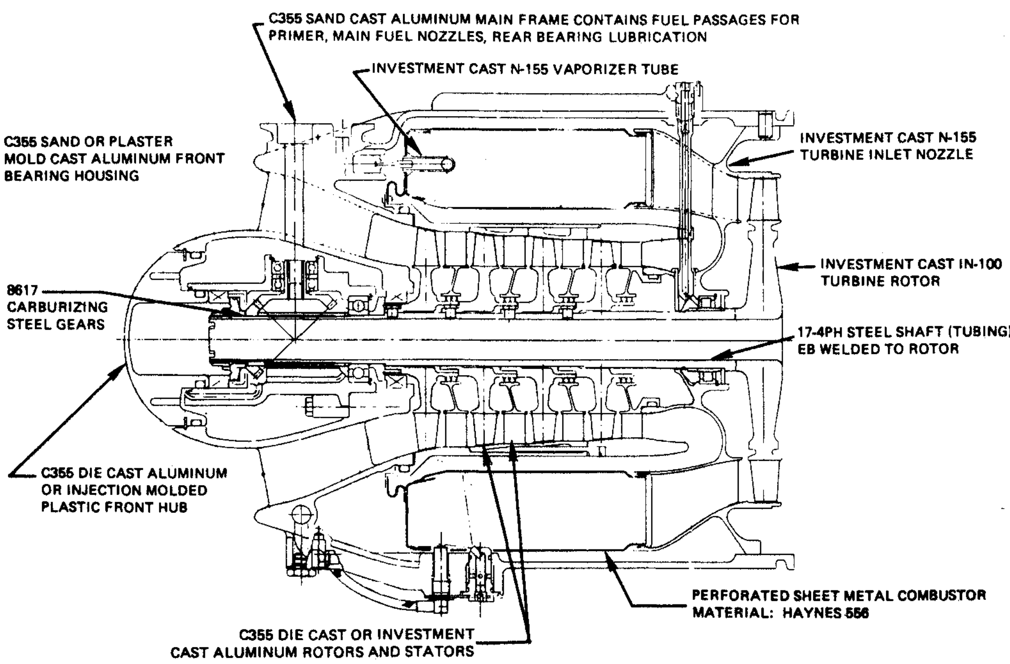

Fig. 6 EG material summary.

objectives to meet mission requirements; 2) selecting conservative estimates of component efficiencies to permit manufacturing tradeoffs and minimize development cost; and 3) selecting a relatively low pressure ratio/low turbine inlet temperature design for minimal use of costly materials.

The factors which enter into the total cost of a gas turbine engine can be divided into two categories: acquisition cost and life-cycle cost. Acquisition costs are affected by the design of the unit and the production rate over a finite production time frame. Life-cycle costs are affected by maintenance, parts replacement, overhaul, and accountability paperwork in addition to acquisition cost.

To achieve low cost for the expendable gasifier core engine, all of the aforementioned items are considered. The concept of an expendable, "throwaway" core engine has been the original intent of the program. Life-cycle costs are considerably reduced when this concept is applied. The sum of maintenance and overhaul costs of existing JFS systems are nearly equal to the acquisition cost, and in many cases those costs are exceeded before the expected time between overhaul (TBO) has been reached. The expendable gasifier core, which is easily replaceable, would be removed after 2000 main engine starts by removing two quick-assembly-disconnect

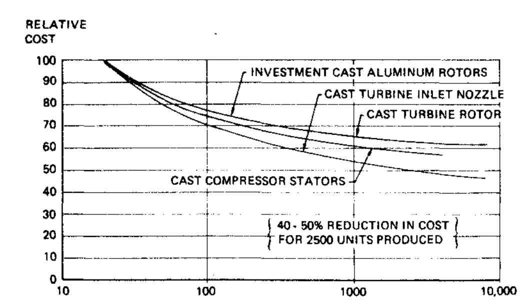

Fig. 7 Low cost by high production rate.

(QAD) vee-band clamps as shown in Fig. 5. A new unit would be installed quickly. The power turbine module and the control and accessories have proven to have considerably longer life than the gasifier and are not expendable.

Production rate has the greatest influence on unit cost of any product. Typically, automotive-type production rates achieve the lowest possible costs. Part of the expendable gasifier intent is to achieve the highest possible production

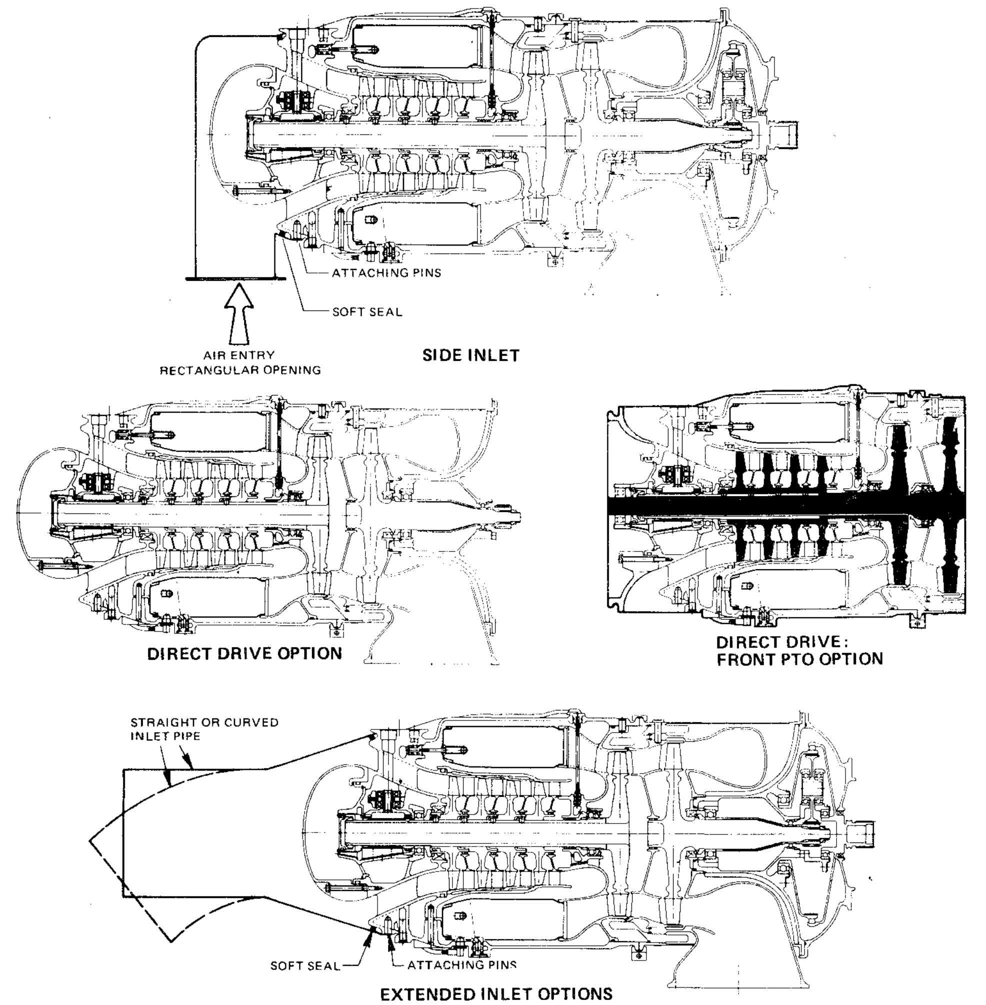

Fig. 8 Typical APU configurations.

rate by having a common core for jet fuel starters, turbofans, and turbojets. Even with those applications, the total estimated production quantity (500/yr) does not approach automotive production levels. The relatively low level of production rate experienced by the gas turbine manufacturer restricts the dollar investment in automation and tooling which contribute to lower unit cost. Figure 2 shows that the cost reduction with increasing production rates can be as much as 10 to 1 for a rate of 2500 parts per year. However, for 500 parts per year, the cost reduction is only one-half.

Some of the expendable gasifier features mentioned earlier are shown in Fig. 6. Detailed cost estimate drawings of the individual gasifier parts were prepared and distributed to vendors. Several quotes were obtained on each part. The quotes were based on production quantities of 500 units per year for 5 years for a total of 2500 units. Cost data received from vendors on the expendable gasifier parts (Fig. 7) have indicated a 50% reduction which is in fair agreement with Ref. 1. However, if all 2500 engines were produced in one year, the cost could be expected to be reduced substantially.

The manufacturing cost analysis performed on the EG included the cost increments of manufacturing operations (machining time, setup, tool support, inspection, scrap and rework, wash and degrease, manufacturing efficiency, nonrecurring tooling), assembly, test, test rework, and shipping. The variation of manufacturing hours required per engine over a production run of 2500 engines was determined by applying an 80% improvement curve to all engines before the 400th engine and a 95% learning curve for all engines after the 400th. Based on that analysis, it was estimated that all manufacturing, raw material, and labor costs will result in total gasifier cost of less than $10,000.

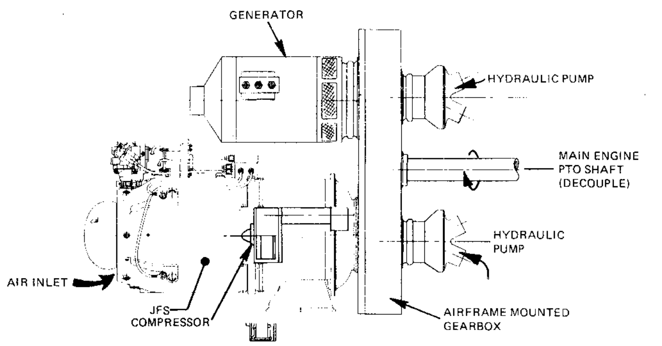

Fig. 9 JFS—representative ground checkout system.

The expendable gasifier concept, when evaluated on the life-cycle cost basis, is expected to show a considerable savings in the JFS application. On a preliminary basis, the JFS is projected to cost less than $20,000 including the power turbine, reduction gearbox, controls, and accessories. It is estimated that the JFS will require three expendable gasifiers over the JFS life, extending the number of main engine starts from 2000 to 6000. Using these estimates, it is projected that the life-cycle cost will be about one-half to one-fourth the life-cycle cost of existing operational jet fuel starters in the same power class as the expendable gasifier JFS.

Future Applications

Future military aircraft, in order to meet the self-sufficient mission requirements, will need a high-performance power system. With budget restraints, this power system will also have to be low in cost. In order to reconcile these two requirements, it will be necessary to apply the common unit approach previously described. A promising "building block" that could be employed is the low-cost gas turbine designed to be used for either shaft power or propulsion applications. The shaft power unit can be configured in several different ways (Fig. 8). It has the inherent versatility necessary to enable an aircraft designer to use it on any type of aircraft without loss of commonality. As an example, the low-cost APU version can be used as shown in Fig. 9 to establish a fighter/trainer aircraft power system. Two or more of these systems could be used as a bomber/cargo/tanker aircraft power system. Doing this would establish: 1) maximum commonality among many aircraft, thereby increasing the production rate of the components, 2) only one system for maintenance technician training, 3) maximum commonality among spare parts/reserve parts, 4) drastically reduced overhaul/repair costs due to the expendable concept, and 5) drastically reduced power system development costs.

References

[1]Cook, M.H., "Computer Managed Parts for Manufacturing," *Scientific American*, Feb. 1975.

[2]Hall, D. and Due, H.F. "The Expendable Gasifier Program," *1976 JANNAF Conference*, Chemical Propulsion Information Agency, Publication No. 280, Vol. 1, Nov. 1976, p. 369.

[3]Smith, R., "Low Cost Jet Fuel Starter," SAE Paper 751117, Nov. 1975.