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INSTALLATION OF ELECTRIC GENERATORS ON TURBINE ENGINES

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This discussion of the installation of generators on turbine aircraft is based on studies performed at General Electric, in particular the studies of the samarium-cobalt generator.

Contributing technologies were derived from three contacts: two from the Air Force, and one from the NASA Lewis Research Center. All three programs had two common elements: the samarium-cobalt generator, and variable-speed, constant-frequency (VSCF) solid-state technology. The generator-engine integration study was performed for the Air Force and finished in 1979. The goal was to determine the feasibility of integral generators. A study based on the Energy Efficient Engine (E^3) program was performed for NASA Lewis. It sought to define potential engine improvements that would provide performance increases. The General Electric Aircraft Equipment Division performed a development and hardware study for the Air Force on the 150-kVA permanent-magnet (PM) VSCF starter-generator. The results of this study were applied to the other two programs.

The potential advantages of an electric secondary power system at the engine level are

(1) Improved engine efficiency, by elimination of constant bleed air (electric-driven environmental control system (ECS))

(2) Enhanced reliability because of the solid-rotor PM generator-starter and fewer engine-mounted accessories

(3) Improved maintenance because there is only one type of secondary power

(4) Improved accessibility because the engine periphery is less congested and the line replaceable units (LRU) that remain are more easily replaced.

The secondary power system must be evaluated on the overall aircraft level to determine the net payoff. For example, weight added to the engine could be offset by weight reductions on the aircraft; this is particularly true in the integration of generators with the engine. The applications for the highand low-bypass-ratio engines are quite different. In high-bypass-ratio engines there is much more freedom to locate generators either inside or outside the engine without increasing the engine's frontal area. In low-bypass-ratio engines the location is more difficult because the space in the front end of the engine is smaller and also because we would like to minimize frontal area increase. Existing engines would have to be analyzed for the effect on engine dynamics. Of course, it is much easier to design an engine to incorporate secondary power systems than to incorporate them in an existing engine. A wide spectrum of possible engine configurations would have to be considered. The all-electric secondary power system that has only electric power extraction would have electrically driven accessories. A hybrid power extraction system could still use some mechanical power (e.g., mechanically driven engine accessories).

The parameters for system selection are performance, safety, reliability, maintainability, physical weight, volume, and initial and operational cost. The higher efficiency of electric secondary power systems would reduce the size of heat-exchanging systems, and result in a small improvement in the specific fuel consumption (sfc) of the engine. Permanent-magnet generators require short-circuit protection such as a rotor disconnect. For high-speed applications the generators would also require rotor burst protection. The effect on engine efficiency in terms of specific fuel consumption would not be as important since the secondary power level is relatively small as compared with the engine power, but has to be considered. Permanent-magnet-rotor generators would have to be safe in terms of electric safety, disconnects, or other means and, in high-speed applications, burst protection. Reliability is one of the highest priorities, especially if the generator is to be integrated with the engine. Maintainability for an externally mounted generator would be similar to that for current aircraft. However, the engine would have to be designed for easy access with an integral generator. The engine physical weight might not decrease. The volume available will depend on the type of engine - high or low bypass ratio - and the power required by the aircraft. Initial and operational costs would be major trade-offs.

Two different design concepts will be discussed: the integrated generator and the externally mounted generator. Each concept has advantages and disadvantages.

Figure 1 shows a cross section of the TF-34 high-bypass-ratio engine with a 120-kVA samarium-cobalt permanent-magnet generator integrated into the front end. The generator, which also works as a starter, is placed on an extension of the high-pressure turbine shaft; the stator is mounted into the frame structure. The generator is cooled by 200° F engine oil circulated through and around the stator. To remove the generator, the engine must be removed from the aircraft and split. which is of course a disadvantage. However, because of the large dimensions and conservative design we expect high reliability, and therefore maintenance would not be required frequently. The reliability of this generator could be increased many times with improved technology. It could then be viably integrated, especially in military aircraft. Military aircraft have low-bypass-ratio engines or pure jet engines, where external placement of the generators would increase the frontal area.

To remove and replace this generator would take 4 to 5 hours. It weighs about 100 lb. Sixty kVA would be necessary to start the engine; the startup procedure would take about 23 sec, which is equal to pneumatic starting as was desired.

The possible implications of engine dynamics have been studied, and in this case it was not too great of a disadvantage to have the generator mounted on the high-pressure shaft, although it resulted in a somewhat shorter bearing life. This machine has about a 0.065-in. geometric radial gap. The side forces induced through eccentricity would be small.

Figure 2 is also a cross section of a high-bypass-ratio engine. This is the E^3 engine, the result of the Energy Efficient Engine program General Electric is conducting for NASA. This design shows two generators mounted separately on an external gearbox located in the core area. Because the core area is aft of the fan frame and between the core and the fan bypass flow duct, cowl doors would have to be opened to get to this area. The two generators are rated at 150 kVA each; the use of two generators is the result of a study for the all-electric aircraft where redundancy was required.

The accessory drive system can be made smaller by eliminating the hydraulic pumps. If electric-driven engine accessories are used, the accessory drive system could be reduced even further. Electric-driven engine accessories could be located in strategic areas around the engine for easy access and maintainability. One advantage of this would be, for example, that a fuel pump could be operated to get the flow desired without any bypass flow and with a decrease in fuel temperature.

Figure 3 is a frontal view of the area shown in figure 2, showing the location of the generators mounted side by side. The generator speed is 24 000 rpm and the high-speed fuel pump speed is 27 000 rpm. Each generator weighs about 100 lb and is 10-1/2 in. in diameter and 14 in. long. The cycloconverters are mounted external to the engine and are readily accessible.

When the characteristics of the integrated engine-generator are compared, it is always to a base engine design that uses a conventional secondary power system.

The integrated-engine-generator study was really a matrix of three studies on three existing military engines: a large high-bypass-ratio CF6 engine; a smaller high-bypass-ratio engine, the TF-34 used on the A-10 airplane; and a high-performance, low-bypass-ratio engine, the F-404.

The study was conducted to determine the feasibility of an integrated generator-starter. The ground rules were to use existing engines, a samarium-cobalt generator, and VSCF technology. After the study one engine (the TF-34) was chosen to be studied in greater detail. One requirement was the incorporation of a safety disconnect. Since a permanent-magnet generator cannot be deenergized as long as it is rotating, we had to disconnect it either mechanically or electrically in case of a failure. An electric fuse disconnect was chosen as the best solution at that time, but others working on this problem indicate other possible ways to safeguard against a short in the generator.

The results of this study show that the highest payoff of the integrated generator-starter would be in high-performance aircraft, where it would not induce drag and therefore have a negative effect on aircraft design. The application to high-bypass-ratio engines is not as advantageous because electric power can be extracted through other means without affecting the frontal area of the engine. For example, generators could be located in the core area or in the pylon.

The integrated generator-starter would eliminate the accessory gearbox. There would not be a mechanical drive shaft extending to the outside of the engine. Therefore the engine accessories would have to be driven electrically. An all-electric secondary power system has only one source of power, in contrast to conventional systems, which have multiple sources of power. High reliability results from fewer components and conservative design. Low maintenance results from high reliability and the elimination of subsystems. The interface between the engine and the aircraft would also be simplified since only fuel and electricity are transferred between them.

The disadvantages are obvious: the center of the engine is not readily accessible since the engine has to be split and removed from the aircraft. The redundancy question had not been studied at that time, but it seems that it would be difficult to achieve redundancy in the limited space available. Development risk, as on any new system, would be present.

The objective of the study using the E^3 engines was to define the optimal location of the generator system on commercial aircraft. The selection of a twin-engine aircraft resulted in two generators per engine for redundancy. The study showed that the externally mounted generators had more advantages than integrally mounted generators for this application. The benefits of externally mounted generators are as follows: the generators can be optimized since they are not limited to engine speed, redundancy can be easily achieved by mounting two generators on the accessory gearbox, the generators are easily accessible for repair or replacement, and current-technology generators can be used. The major disadvantage of externally mounted generators is that they require a mechanical drive system and an accessory gearbox.

In summary, the integrated generator is best used in turbojet and low-bypass-ratio engines, where there is no easy way of placing generators externally without influencing frontal areas. This would be the case for high-performance aircraft, especially military, where the adjustment of engine design on existing engines would be feasible.

The hybrid system, which would use generators and mechanically driven engine accessory systems, has advantages for high-bypass-ratio engines. The highest payoff would be on the overall aircraft level, where maximum power can be extracted and used on the aircraft, for example, for all-electric environmental control systems. The primary advantage of using samarium-cobalt generators, either integrated or external, would be their higher reliability as compared with conventional wound-rotor generators. They also require less maintenance and have lower life-cycle costs. The technology of samarium-cobalt generator starters is available now and could be incorporated into any existing engine.

In conclusion, a comprehensive study would be required to show the advantages and disadvantages of all-electric secondary power on the overall system level. This multidimensional matrix would have to include military as well as commercial aircraft. The electric power requirements for engine-out and peak-power conditions would have to be established and matched to the redundancy required. The electric system question of ac versus dc or the hybrid system would have to be addressed, and the development of end-user equipment would have to proceed. Studies at the engine level would include the evaluation of the location and design of secondary power systems, comparing integrated and externally mounted generators. Systems have never been compared on an equal basis: they have been compared with the baseline only, but not against each other with the same ground rules. Advanced engine accessory development would have to continue, since fuel and lubrication pumps are components that actually size the accessory gearbox because of their frontal area and mounting requirements. The use of electric power on the engine level would have to be investigated, including systems for thrust reversal and geometric actuation as well as new methods of electrically anti-icing engine nacelles. New technologies must be pursu[illegible] provide protection against stator shorts in permanent-magnet generators. [illegible]hine construction would allow redundant integral generators to be [illegible]

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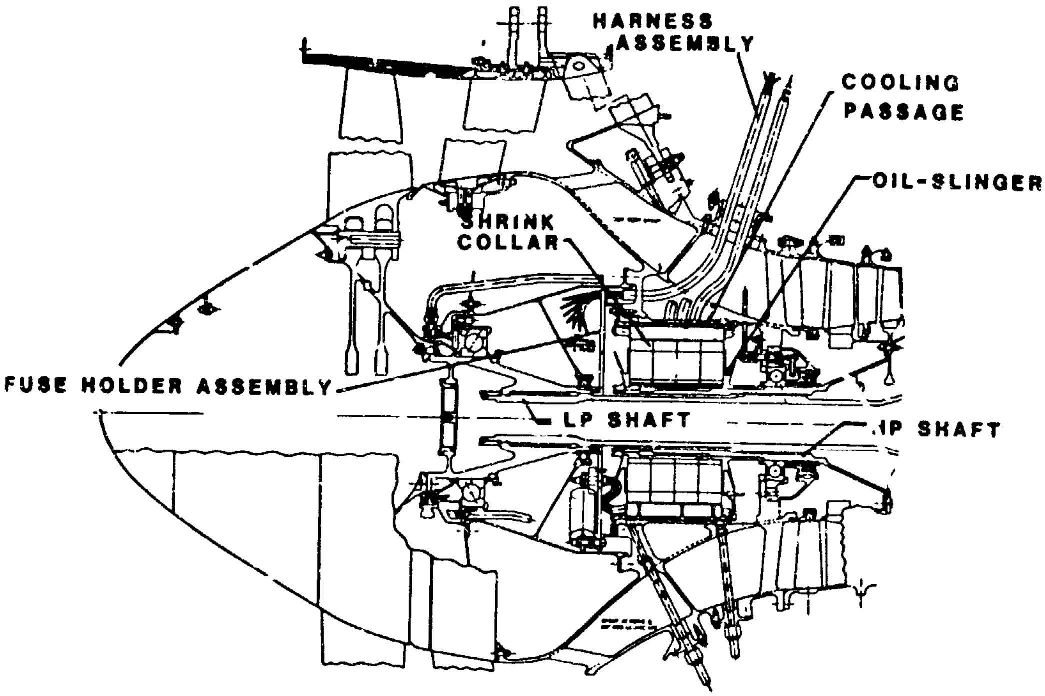

Figure 1. - 120-kVA, permanent-magnet integrated engine starter-generator.

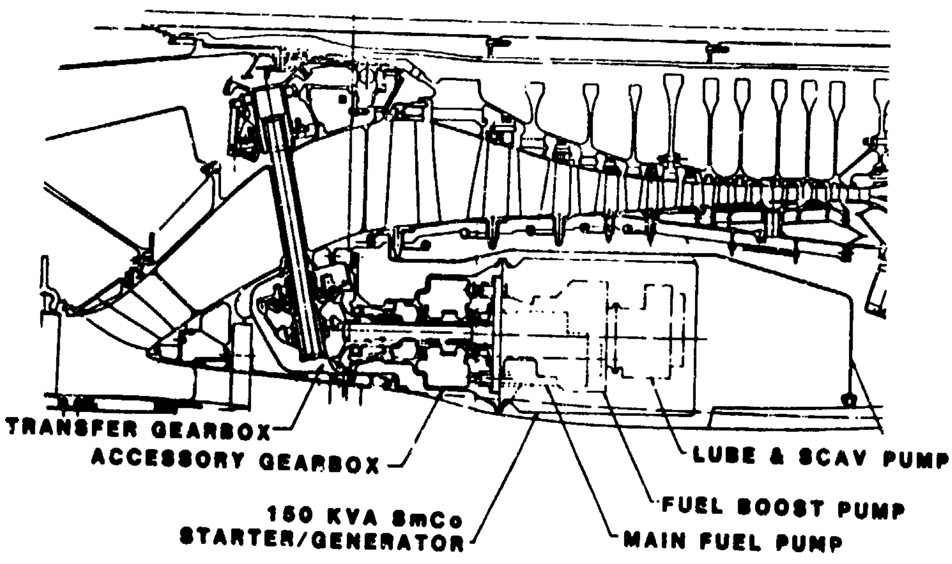

Figure 2. - Gearbox-driven starter-generator.

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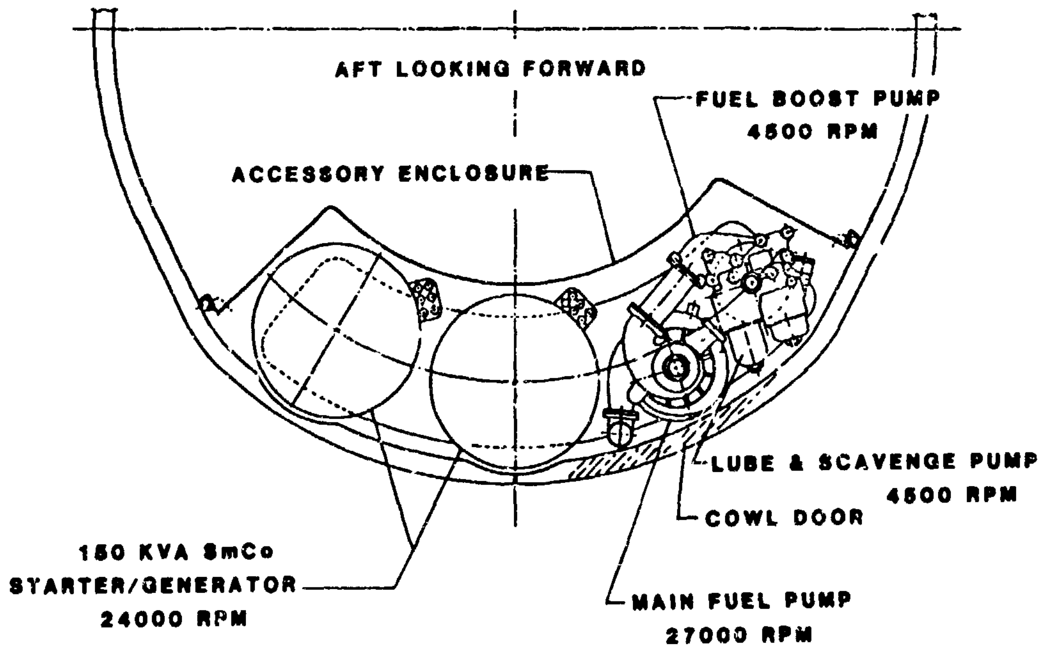

Figure 3. - Starter-generators and engine accessories.