

# COMPARISON OF ALL-ELECTRIC SECONDARY POWER SYSTEMS FOR CIVIL TRANSPORT

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## Abstract

Three separate studies have shown operational, weight and cost advantages for commercial subsonic transport aircraft using an all-electric secondary power system. The first study in 1982 showed that the all-electric secondary power system produced the second largest benefit compared to four other technology upgrades. The second study in 1985 showed a 10 percent weight and fuel savings using an all-electric high frequency (20 kHz) secondary power system. The last study in 1991 showed a 2 percent weight savings using today's technology (400 Hz) in an all-electric secondary power system.

This paper will compare the 20 kHz and 400 Hz studies, analyze the 2 to 10 percent difference in weight savings and comment on the common benefits of the all-electric secondary power system.

## Introduction

During the last decade, three significant studies have clearly shown operational, weight and cost advantages for commercial subsonic transport aircraft using all-electric/more-electric technologies in the secondary electric power systems. Even though these studies were completed on different aircraft, using different criteria and applying a variety of technologies, all three studies have shown large potential benefits to the aircraft industry and to the nation's competitive position.

The first, by Lockheed for Langley Research Center, in 1982, was a study comparing various technology upgrades to savings in direct operating costs(1). The technologies included in the study were super critical wing, active controls, advanced engines, all-electric secondary power and advanced composites (Fig. 1).

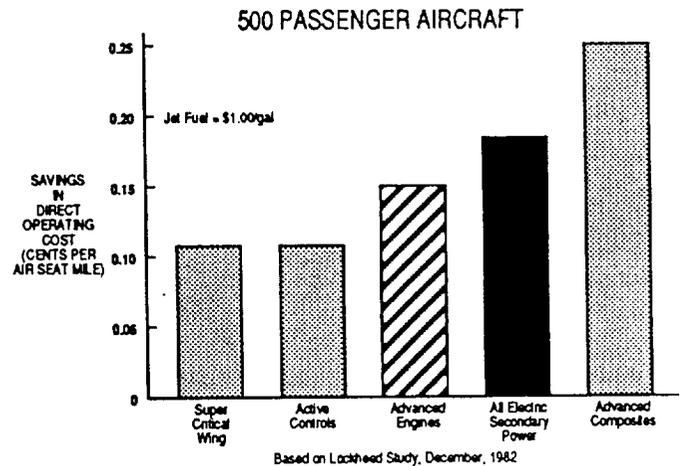


Figure 1 - Technology Upgrades vs. Direct Operating Cost Savings

This study showed that an all-electric secondary power system would provide significant cost benefits to the airline industry. Even though advanced composites showed the greatest cost savings, all-electric secondary power followed closely with advanced engines in third position. It is important to note that the full energy savings of the advanced engines (constant/no bleed) cannot be fully realized unless an all-electric secondary power system is also incorporated. This is because all the functions normally performed by the bleed air will have to be done electrically. Even though they are not completely additive, the combined cost savings of the advanced engines with an all-electric secondary power system should exceed the cost savings of the advanced composites.

In 1985 Lewis Research Center completed an in-house study to determine the benefits of using a 20 kHz all-electric secondary power system(2). The

Lewis study used a Boeing 767 as the baseline airplane. The hydraulic and pneumatic systems were replaced with a 20 kHz secondary power system employing advanced zero or fixed bleed engines. The study incorporated an integral starter/generator and eliminated the Auxiliary Power Unit (APU). The results after resizing the airplane showed a 10 percent weight and fuel savings.

In 1991, McDonnell Douglas completed a study for Lewis Research Center to determine the cost benefits of a conventional (400 Hz) all-electric secondary power system based upon today's available technology(3). This study used a 300 passenger tri-engine airplane with an integral starter/generator, electrical actuators and electrically driven environmental control units. The APU was retained for this study. The study results showed a 2 percent weight savings with a resized airplane. The significant impact of the Douglas study resides in its value as a baseline to calibrate the benefits of new technology to commercial subsonic aircraft. Using the conservative trade based upon accurate design, cost and operational models provides an essential reference for future technology trades.

This paper will compare the 20 kHz and 400 Hz studies, analyze the 2 to 10 percent difference and comment on the benefits of an all-electric secondary power system (Fig. 2).

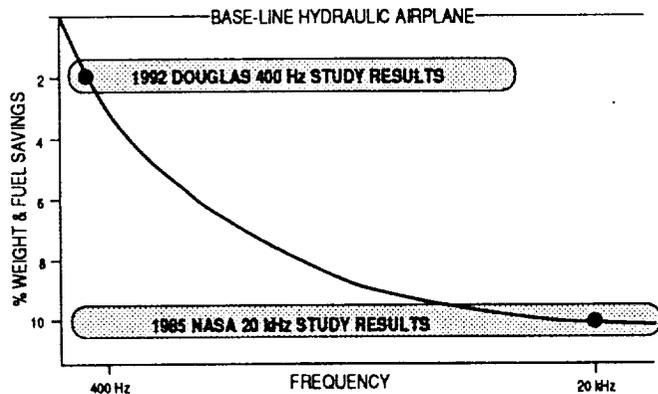


Figure 2 - All-Electric Airplane Study Summary

### All-Electric Secondary Power System

The all-electric secondary power system described in these studies consisted of an integral starter/generator, a power management and distribution system and electrical loads. Both studies used a distributed power system. The Lewis study used a fully distributed dual bus power system (Fig. 3) and the Douglas study used a tri-bus power system (Fig. 4).

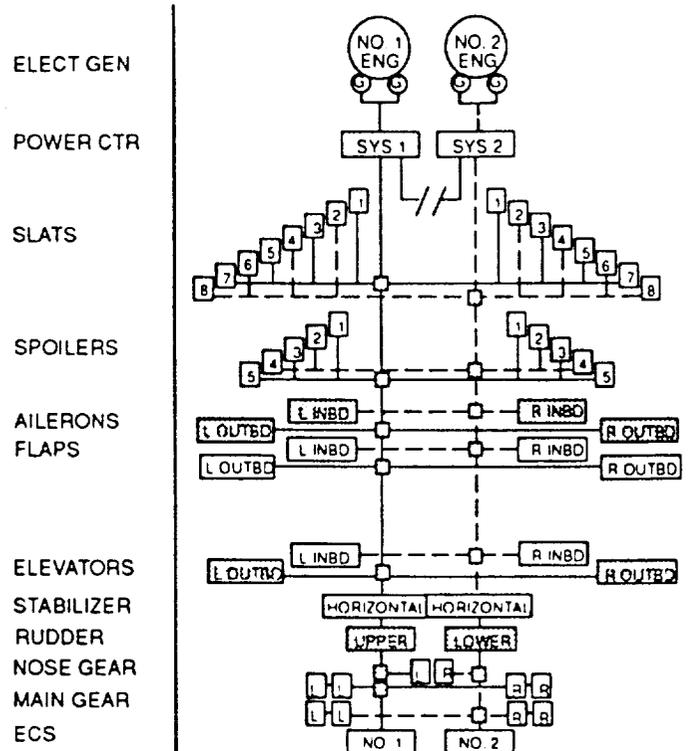


Figure 3 - Dual Bus Architecture

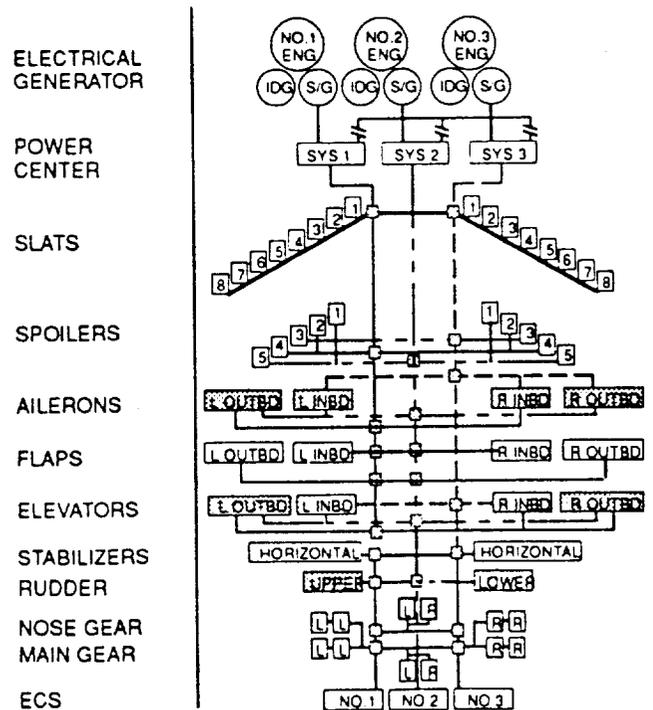


Figure 4 - Tri-Bus Architecture

The selection of the tri-bus power system in the Douglas study was not driven by reliability concerns but was due to the fact that their study used a tri-engine airplane. Therefore, it made sense to add another bus to service a rear power distribu-

tion center. Since the power bus is a very reliable part of the system, the addition of another bus does not substantially increase the system reliability. What makes the secondary power system reliable, however, is the fact that any of the power sources can be connected to any of the loads via bus switching units. For example, if a generator fails, then all critical loads on that bus would be switched to an active bus or an active source could be switched to the inactive bus with all non critical loads of both buses being switched off. Both secondary power systems were considered to be fault tolerant. Through bus switches, any bus segment could be switched out and the loads on that segment would be switched to an active bus.

### Power Sources

Today's aircraft use three separate sources of power: hydraulic, pneumatic and electric. There are two problems with this arrangement. The first is that each power source must be over sized to meet the system reliability requirements, which results in a heavier power system. The second is that power cannot be shared between the systems. For example, if the hydraulic power source fails, the hydraulic loads cannot be powered by the pneumatic or electric power sources.

The all-electric secondary power system may incorporate an integral starter/generator as the main power source. This would allow the use of a fixed/no bleed engine and would eliminate the hydraulic and pneumatic systems, and the gear box. In addition, the integral/generator would benefit the new high by-pass ratio engines under development.

One concern is that the starting requirements for the new large transport engines may cause the integral starter/generator to be oversized. Since there is only one power system, the generators will become much larger because they now have to supply power to an increased number of loads. The Douglas study, however, showed that the generator may be sized within the engine core with sufficient power to start the engine.

### Loads

Both studies eliminated all hydraulic and pneumatic loads and provided the required functions electrically. What the studies showed was that the Environmental Control System (ECS) is by far the largest connected load (Fig. 5) and would drive the size of the power system. It also showed that ECS should be studied to determine methods for reducing it's size and utilization profile, since

improvements in this system will have the largest impact on the entire power system.

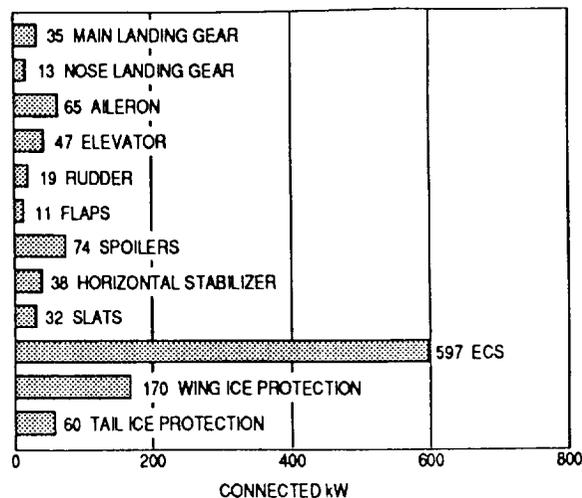


Figure 5 - All-Electric Load Comparison

### Weight Analysis

The Lewis study (20 kHz distribution, twin engine, 200 passenger), showed a 10 percent weight savings for a resized airplane and the Douglas study (400 Hz distribution, tri-engine, 300 passenger) showed a 2 percent weight saving for a resized airplane. Even though different airplanes were used for the studies, the large difference between the two studies can be explained by a cursory analysis.

If an APU was added to the Lewis study (APU included in the Douglas study), the Lewis weight savings would be reduced by 2 to 3 percent. Also, the Douglas study used 110 volts as the distribution voltage where the Lewis study used 440 volts. A 440 volt distribution voltage would improve the Douglas weight savings by 1 percent.

The Douglas study did not change any of the existing electrical systems. It only added what was needed to replace the eliminated hydraulic and pneumatic systems. The Lewis study on the other hand distributed 440 volts to all loads and not to just the eliminated hydraulic and pneumatic loads. If Douglas had done this, it would have added about 0.5 percent to their weight savings.

Finally, the Lewis study incorporated the weight advantage of a new engine design, whereas the Douglas study only took into account the fuel savings which are the result of the elimination of the bleed air. The Douglas study could improve the projected weight savings by 2 percent with resized engines.

## Results

The Lewis study now shows a new projected weight savings of 7.5 percent and the Douglas (400 Hz) study projected weight savings of 5.5 percent. The Douglas study used a very conservative approach. Therefore, the actual percent weight savings for an all-electric civil transport using near term technology is probably in the 6 to 6.5 percent range (Fig. 6). The 1 to 2 percent weight difference that still exists between the two studies after factoring in the study differences is due to the weight benefits of the high frequency distribution system. The weight and size of all the magnetics (inductors, capacitors, transformers) will be significantly smaller in the high frequency system. The use of high frequency and zero crossing switching techniques will greatly reduce the weight and size of the large motor controllers and starter/generator electronics.

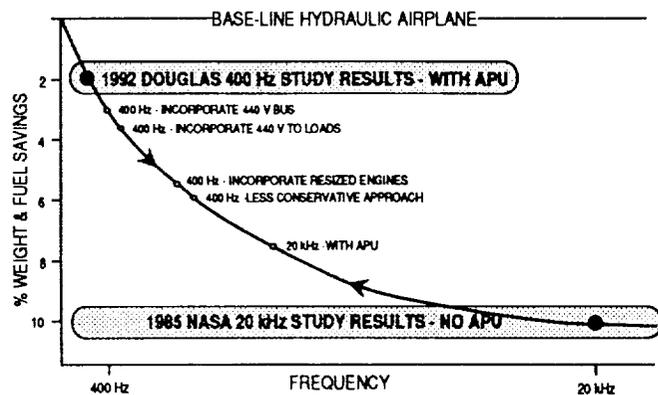


Figure 6 - Comparison of the All-Electric Airplane Studies

## Comments

From the analysis of the Lewis and Douglas studies, it is apparent that a 6 percent weight savings for the subsonic civil transport using an all-electric secondary power system is attainable with today's technology. This benefit can only be achieved if the entire airplane is designed to be all-electric. The weight benefit could be raised to 8.5 percent if the airlines were to determine that they did not need the APU. Airplanes have been certified without the APU but to date the airlines prefer having them available on board. Presently, there are large focused efforts in battery technology both for aircraft and for electric vehicles. Substantial improvements in maintenance free batteries could significantly reduce the 2.5 percent APU weight penalty.

With the entire secondary power system all-electric, the airlines will only have to train technicians in one discipline instead of three and will only have to stock one type of spare parts. The

elimination of the hydraulic system will reduce the toxic waste handling and removal procedures for the airlines and/or their maintenance contractors. Most of the electrical components are Line Replaceable Units (LRU) which will reduce substantially the maintenance manhours and the down time of the airplane. Ground support equipment will be simpler because only one type of power has to be supplied to the airplane instead of three.

Based on the Douglas study, a 16 percent increase in reliability for the airplane is achieved due to the elimination of two of the three existing power systems. These items will reduce the operating costs of the airplane and will achieve long term cost benefits. The Douglas study has demonstrated both a develop cost savings and a reduced direct operating cost for the all-electric approach.

NASA is currently doing significant research in the area of vehicle health management, which is directly applicable to the all-electric airplane. It will allow preflight system checkout of the entire power system and continuous diagnostic checks during flight. The need for scheduled maintenance could be reduced because electric components with degraded performance will be detected before failure. Components would be replaced when they begin to show degraded performance and not at regular intervals. An example of this would be sensing that an actuator was drawing more current than normal but was still meeting the operational requirements. This actuator LRU could be replaced before failure.

## Concluding Remarks

If the all-electric technology is integrated into the nation's civil transport fleet, America's airline industry would have a product that is more efficient, more reliable and less expensive to operate. This technology would give our airline industry a competitive edge which would enhance their position in the world market.

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