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A SERVICE PUBLICATION OF LOCKHEED AERONAUTICAL SYSTEMS COMPANY–GEORGIA

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Photographic Support: John Rossino

Front Cover: The "City of Marietta," a new C-130H belonging to the French Air Force, honors the home city of the Hercules aircraft.

Back Cover: LASC-Georgia General Manager Bard Allison addresses guests and dignitaries during September 14 ceremonies marking the delivery of the 1900th Hercules, an advanced C-130H. The first production Hercules aircraft (left), built in 1955 and still in service, sharesthe spotlight.

Focal Point

H. D. Hall

Bring On the Future!

In slightly over 3700 days we will be in the 2lst century! At Lockheed Aeronautical Systems Company (LASC), we are planning *today* for a bright, productive 21st century for the Hercules aircraft. One of our highest priorities is to apply new technologies to reduce the operational support costs and increase the productivity of the Hercules.

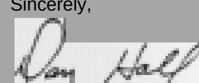
As an integral part of the C-130/L-100 design team, the Supportability Technology Department is investing in the future of the Hercules by accomplishing independent research and development (IR&D) projects that are designed to identify those applications of advanced technologies that will permit the Hercules airlifter to meet its 21st-century operational objectives with minimum expenditures of logistics resources.

Demographic studies of the 21st-century environment indicate that young men and women 18 to 19 years old will be a scarce resource. Therefore, we are concentrating our IR&D work on applying technologies that will reduce manpower-intensive tasks associated with maintaining the Hercules aircraft. We currently have prototype maintenance and diagnostic expert systems, developed usingartificial intelligencetechnologies, runningon portable maintenanceaids that not only provide all technical data requirements, but also emulate the logic process used by the most skilled maintenance technician to diagnose and repair an aircraft malfunction. How would you like to have all the information currently contained in the C-130-2 series and -4 technical orders, and the 20 years of experience of your maintenance chief, immediately at your fingertips in a portable maintenance device weighing less than ten pounds, and no larger than a standard one-inch notebook? Sound exciting? It is, and there is more to come as we move closer to get a clearer view of the 21st century.

Do not be concerned that these "intelligent" maintenance aids will replace you, or make you a non-thinkingentitydoingonlywhat the maintenance aid directs you to do. That would not be very much fun or very fulfilling. On the contrary, you will be the master of the intelligent maintenance aid. The maintenance aid has been designed to complement your training, skills, and basic abilities. Working with the maintenance aid, you will have at your fingertips the collective experience of many skilled maintenance technicians and all the technical information required to accomplish maintenance on the aircraft. You will control the amount and depth of the information presented to you. The intelligent maintenance aid will permit you, whether you are a beginner or highly experienced, to function in a more efficient and cost-effective manner. The bottom line will be a more productive aircraft, requiring less logistics resources.

We'll be looking for you on the Hercules team in the 21st century. Beam me up, Scotty!

Sincerely,



H. D. Hall, Manager
Supportability Technology Department

PRODUCT SUPPORT LOCKHEED AERONAUTICAL SYSTEMS COMPANY-GEORGIA

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Four-Engine Power Fluctuation

by **Larry Arnold,** *Staff Engineer*
C-130/L100 Electrical Design Group

A four-engine power fluctuation or rollback occurs when rpm and torque fluctuate in response to a failure in the aircraft electrical power system or synchrophaser system. Such a power fluctuation is usually a transient phenomenon lasting only a second or two, but the fact that the engines are responding to an uncommanded input can have an unsettling effect on the aircraft crew. In this article we will discuss this type of engine power fluctuation, its causes and influence on the aircraft, and what can be done to reduce its effects or help prevent it from occurring.

Synchrophaser Operation

Since the synchrophasing system is directly or indirectly involved in all cases of four-engine power fluctuation, a brief review of Hercules aircraft synchrophaser system operation will be helpful in understanding the nature of the problem.

In the Hercules aircraft, control of propeller pitch, and consequently engine rpm, is maintained primarily by mechanical governors in the propellers. However, the response of the mechanical system is augmented and made more precise through the stabilizing action of an electronic device known as a synchrophaser.

The synchrophaser system acts through the propeller flyweight governors to provide automatic control of the propeller rpm and “phase,” the rotational position relationship among the blades of the four propellers. When the

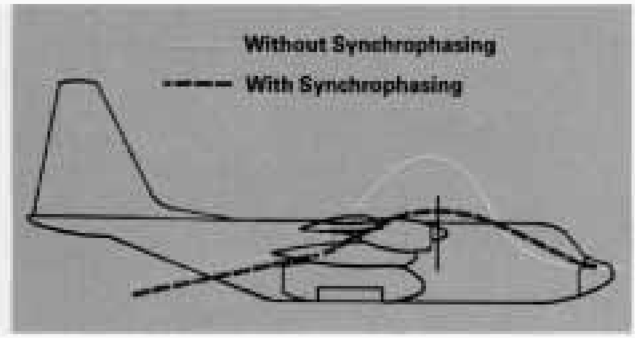


Figure 1. **Synchrophasing significantly reduces propeller noise and vibration levels.**

flight crew selects a "master" engine (No. 2 or No. 3), the synchrophaser senses the position of the master engine's propeller blades and adjusts the relative positions of the three "slave" engine propellers in such a way as to achieve the optimum phase relationship for all four.

Maintaining the same rpm and an optimized phase relationship within close limits reduces propeller noise and vibration within the aircraft, and decreases stress on the airframe. The synchrophaser also anticipates changes in propeller speed due to throttle changes and the effects of external forces, and furnishes signals to the propeller to help suppress any tendency of the mechanical governor to overshoot or undershoot the proper governing speed.

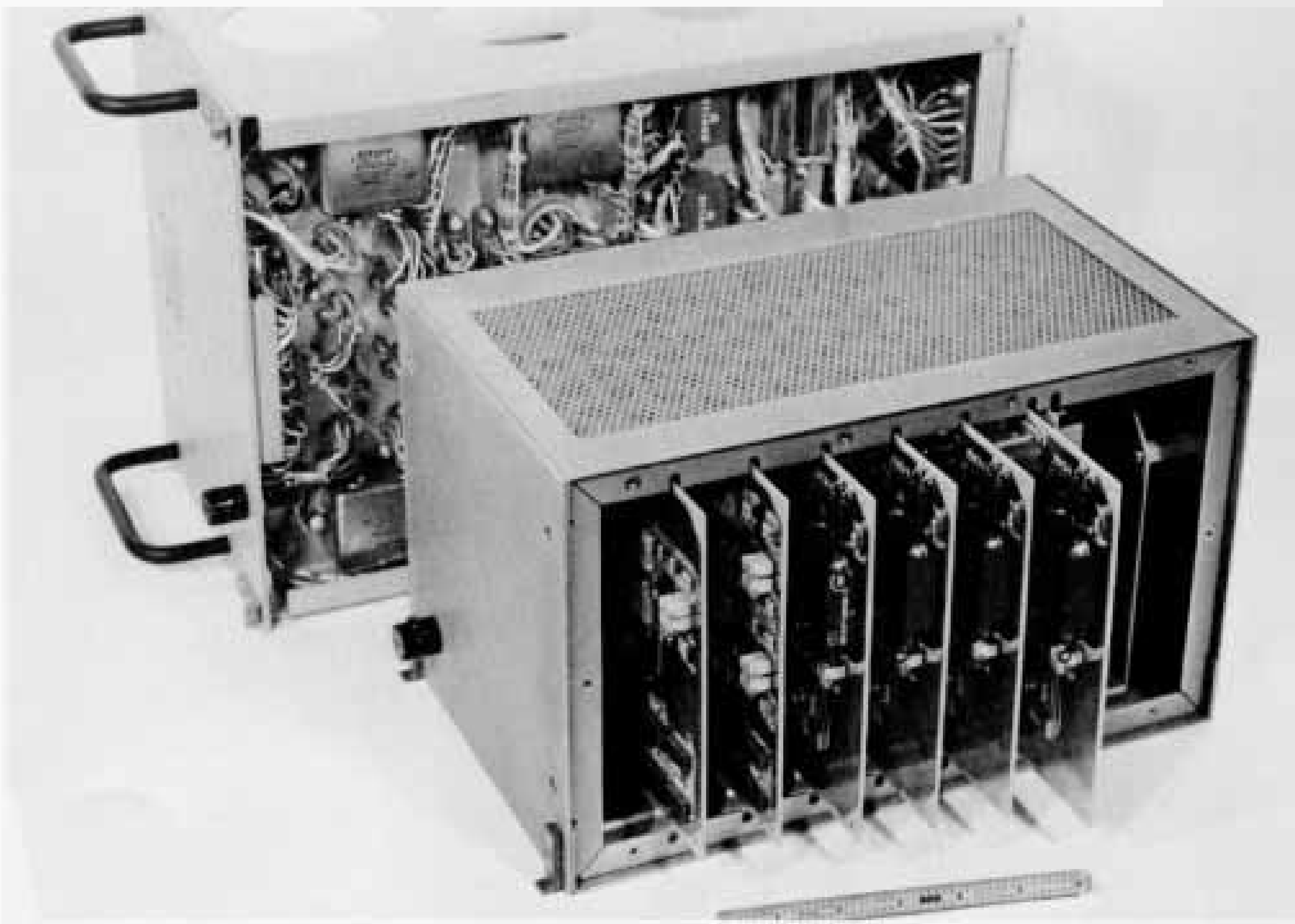
Older Hercules are equipped with the PN 588584 synchrophasing unit, which uses vacuum tubes in its circuitry. Most newer Hercules aircraft, Lockheed serial number LAC 4772 and up, are equipped with the solid-state synchrophaser; PN 774800-l for U.S. military aircraft, and PN 766840-l or 766840-2 for other operators. The new unit offers improved accuracy, stability, and ruggedness. While there are some differences in the details of their operation, the solid-state synchrophaser is functionally and physically (with an adapter rack) interchangeable with the tube-type unit.

Note that whichever unit is installed, the synchrophasing of the propellers remains a secondary function, and the system's influence on rpm control is limited. The primary hydromechanical governing system will always function in the event of an electrical malfunction and ensure safe operation of the aircraft.

"Manually" Induced Engine Power Fluctuations

In analyzing engine power fluctuation problems, it should be recalled that there are occasions when engine rpm and torque will fluctuate even though no failure has

Figure 2. Comparison **between the tube-type synchrophaser (background) and solid-state version shows the newer unit's space-saving modular design.**



occurred and the synchrophasing system is operating normally. The fluctuations in these cases will typically be less than +/-2 percent rpm and less than 1000 inch-pounds of torque. Some of the conditions that can induce such normal fluctuations are listed below:

(1) Selecting normal governing will sometimes cause a propeller to change rpm, particularly if a master engine has been selected previously.

(2) Selecting a master engine will also affect all engines, but the changes will usually be gradual and would be expected to show up only in the form of an audible change in the propellers.

(3) Pulling the circuit breaker to the synchrophaser and then re-engaging it with the propellers in normal governing and the master engine selected in the case of the solid-state unit.

Each of the above situations can cause more noticeable fluctuations if the speed bias motor in the propeller is not set to the middle of its range of travel. The potentiometer is centered during propeller reindexing. In the case of the tube-type synchrophaser, periodic resynchrophasing of the system may be necessary to cancel any synchrophaser circuit offsets that accumulate during operation.

The solid-state synchrophaser uses semiconductor devices which do not exhibit any circuit offsets during operation. Thus, no resynchrophasing or reindexing is required and none should be attempted following the initial reindexing, except in the course of approved maintenance procedures on the ground.

Note that if the resynchrophase switch on a solid-state unit is actuated when reindexing is not in progress, the speed bias motor feedback potentiometer could be driven off center. The synchrophaser would then not have its full range of adjustment for controlling the propeller. This could cause the engine to operate at a different speed in normal governing than in mechanical governing, and would be noticeable as a 0.3 percent or more rpm change when switching from mechanical to normal governing and vice versa.

Electrically Induced Engine **Power Fluctuations**

To be effective, the synchrophaser must be able to make adjustments to all propellers simultaneously, and all will therefore respond similarly to any inputs to the synchrophasing system. This characteristic means that the implementation of the synchrophaser system in the Hercules aircraft makes it possible for a single failure to affect the operation of all four engines.

It is instructive to look at some specific examples of the kinds of failures that have been involved in engine power fluctuation. From September 1986 through June 1989, the U.S. Air Force documented a total of 52 power rollback incidents. Thirty-seven of these events happened when the aircraft experienced an interruption in essential AC bus power. Twelve of the remaining incidents were caused by failure of tube-type synchrophasers, one by a solid-state synchrophaser failure, one was traced to a wiring problem, and one was the result of a No. 2 engine gearbox failure.

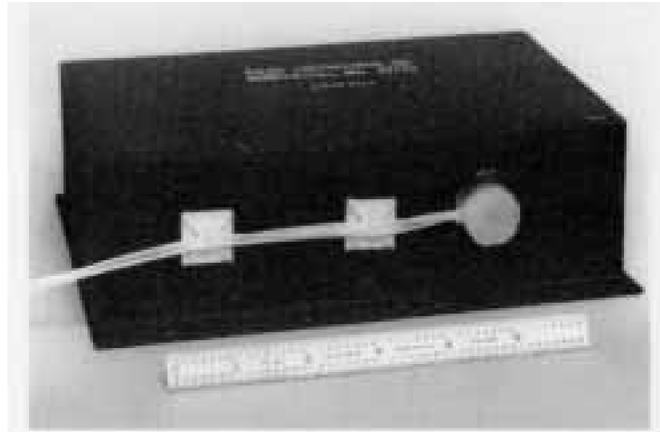


Figure 3. A constant-voltage transformer (CVT) can be used to stabilize synchrophaser input voltage (page 7).

Further analysis of these statistics shows that over 70 percent of the reported engine power fluctuation incidents occurred as a direct result of electrical system failures in flight. Since the essential AC bus power input is common to all four syncrophaser channels, an essential AC bus power interruption can readily affect the operation of all four engines simultaneously. The exact amplitude of the power change that will be experienced is not entirely predictable since it depends not only upon such factors as the specific failure mode, but also the type of synchrophaser involved.

Tests and Results

Some of the factors involved in engine power fluctuation induced by electrical system failures were well understood, but further research was required to pinpoint the specific causes and effects closely enough to permit practical countermeasures to be developed. However, because the problem is typically transitory in nature, and because of the obvious difficulties of conducting appropriate troubleshooting activities in an operating aircraft, it was necessary to design a series of ground tests to determine just which of the engine controls were being affected during the electric power failures.

The most important of these tests were conducted on a specially instrumented engine and test stand at the Allison Gas Turbine Division of General Motors. The tests were set up so that the voltage could be varied individually to the synchrophaser, the temperature datum (TD) amplifier, and the engine instruments. Critical responses of the engine were also monitored. These included torque, rpm, fuel flow, TIT, and propeller blade angle.

The test results obtained at Allison clearly demonstrated the following points:

(1) The synchrophaser is sensitive to voltage variations and can command propeller pitch changes during an electric power system malfunction.

(2) The torquemeters are also sensitive to voltage variations, and are therefore unreliable indicators of actual torque during an electrical power interruption.

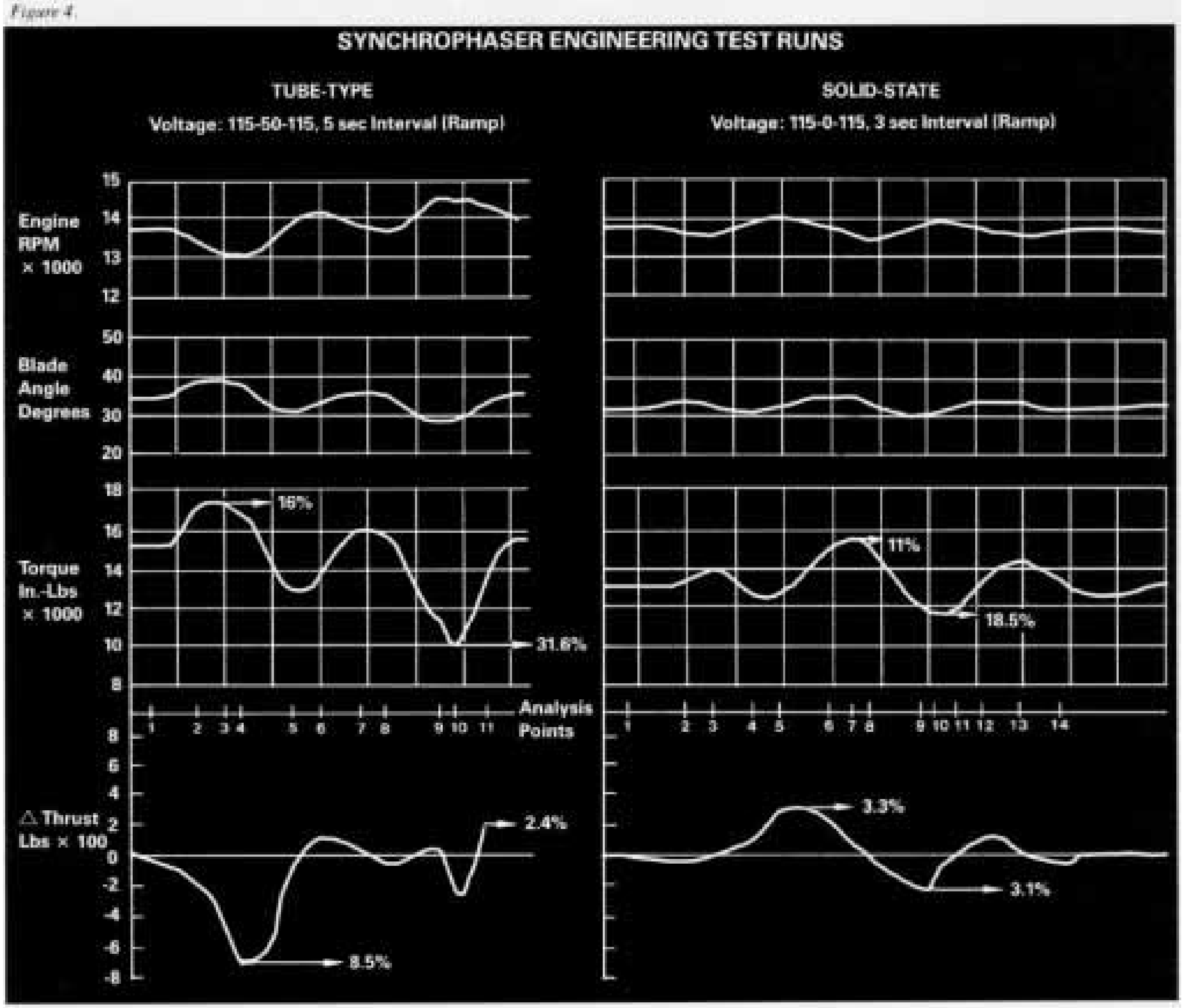
(3) The TD amplifier system does not contribute to four-engine power fluctuations.

The tests further showed that the synchrophaser type had an important impact on the amplitude of engine power fluctuations. The engine experienced the most pronounced fluctuations using the tube-type synchrophaser, with rpm changes of up to 6 percent, and torque variations as high as 4500 inch-pounds.

With the solid-state synchrophaser installed, the engine fluctuations were much less significant. In this case, the rpm changes in the test engine were less than 2 percent, and torque variations less than 1500 inch-pounds. These differences can be attributed to the improved power supply regulation in the solid-state unit, plus the incorporation of an internal speed reset circuit that inhibits any speed or throttle derivative (anticipation) correction for 1.9 seconds upon restoration of electrical power.

The sensitivity that the torquemeters showed to voltage variations on the essential AC bus during the tests was of particular interest. When the voltage was varied only to the torquemeters, they would indicate torque fluctuations of +/-5000 inch-pounds. even though the engine torque actually

Figure 4



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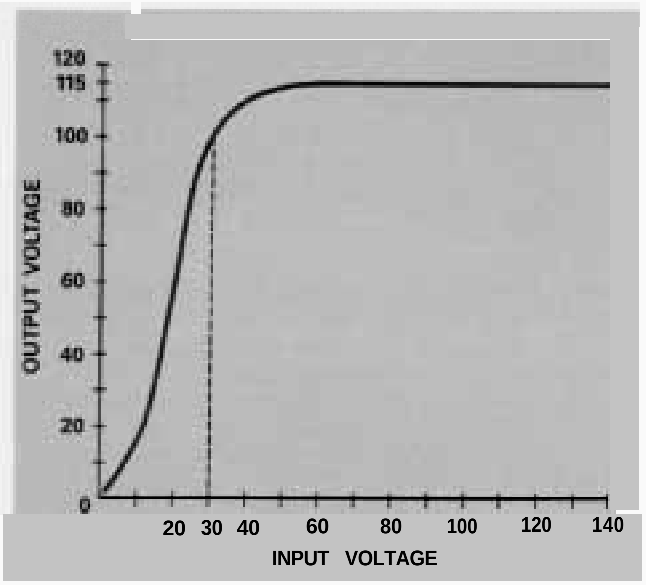

Figure 5. Typical CVT input/output curve with l00-watt load.

remained constant. This led to the conclusion that when a four-engine power fluctuation occurs as a result of an electrical malfunction affecting the essential AC bus, the torque readings are an unreliable source of data to determine the magnitude of the true torque fluctuation. It would be entirely possible in some circumstances to get torquemeter readings indicating a power fluctuation when none had actually occurred.

Thrust Effects

During the few-second transient that can result from an electrical system interruption, calculations based on actual tests showed that thrust losses with the tube-type synchrophaser were nominally only 9 percent when the torque loss was 27 percent. The apparent disparity between these values arises from the fact that although torque decreases as the propeller blade angle is decreased, rpm increases at the same time. The resulting change in thrust and effect on the airplane flight parameters are therefore minimized. The charts in Fig. 4 show the results of some additional test runs which illustrate the relatively small magnitude of thrust losses experienced during voltage fluctuations.

The effect on a 120,000-pound aircraft during takeoff would be only a 0.04G decrease in the rate of acceleration, with airspeed continuing to increase and negligible effect on altitude. The effect on a higher gross-weight aircraft is even less, with only a 0.03G decrease in acceleration for aircraft weights up to 175,000 pounds.

A careful review of the test data was also performed in order to calculate the effects on total engine thrust when a failure in the synchrophaser system itself, rather than in the aircraft electrical system, results in an engine power fluctuation. It was determined that in the worst-case failure modes that apply to the synchrophasers, the thrust could theoretically be reduced by up to 27 percent, which is roughly equivalent to losing one engine. There are no failures of this severity on record, but even in such an extreme case the condition would be corrected immediately upon selection of mechanical governing.

Stabilizing Input Voltage

A constant voltage transformer (CVT) was inserted in the power line to the synchrophaser during the engine tests to see if it would provide stable electrical power during transient voltage changes and thereby stabilize engine performance. The CVT employed was designed to provide a constant output voltage with input voltage that varied between 40 and 140 VAC.

In these tests, the CVT effectively prevented the synchrophaser from initiating uncommanded rpm and torque fluctuations when the AC voltage was varied between 115 and 30 VAC. If the voltage was varied all the way down to 0 VAC, the fluctuations were less than 2 percent rpm and 1000 inch-pounds of torque with the tube-type syncrophaser, and negligible with the solid-state synchrophaser. The results showed conclusively that an appropriate CVT will prevent four-engine power fluctuations during virtually all AC power interruptions.

Conclusions and Recommendations

A thorough review of the test results and the data from aircraft four-engine power fluctuation and rollback incidents shows that there are several failure modes that can cause the engine power to fluctuate. They all affect the synchrophaser system, which in turn causes the changes in the engine rpm.

New production Hercules aircraft built in recent years have included the solid-state synchrophaser as standard equipment. The effects of electrical power system interruptions on this unit are transitory and of small amplitude, with engine rpm changes typically ±1/2 percent. These result in negligible thrust losses and only minor audible changes. Such effects are much too small to be hazardous to the aircraft or a source of concern for the crew.

The overall effect on the aircraft when a tube-type synchrophaser is involved can be more significant in terms of thrust loss and changes in engine sound and vibration levels, but are still too small to pose a safety of flight problem. The current recommended flight and maintenance procedures are considered adequate to keep the incidence of inflight electrical system power interruptions to a very low level.

The U.S. Air Force has elected to reduce the exposure of its C-130s equipped with tube-type synchrophasers to the effects of electrical power interruptions by implementing the following steps:

(1) Efforts to improve maintenance procedures for the electric power generating and distribution system and

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thereby reduce electrical system failures are being continued.

(2) The solid-state synchrophaser is being incorporated into all C-130 aircraft on an expedited basis.

(3) A constant voltage transformer is being installed in the AC power line of the synchrophaser in all U.S. Air Force C-130s through TCTO action. With the CVT installed, brief interruptions in the flow of AC power will not be able to induce significant engine power fluctuations. Complete instructions for installation of the CVT are contained in TCTO IC-130-1309.

The same measures could also be applied by other operators of Hercules aircraft equipped with tube-type synchrophasers who are concerned about engine power fluctuations. For further information, please contact: Supply Sales and Contracts, Dept. 65-11, Zone 0577, LASC-Georgia, Marietta, GA 30063. Telephone: 404-494-4214, FAX: 404-494-7657, Telex: 804263 (LOC CUST SUPPLY).

Propeller Retaining Nut Torque Values

by W. H. Mitchell, *Specialist Engineer*
Propulsion and Equipment Design Group

An extensive study by Allison and Lockheed Aeronautical Systems Company-Georgia has determined the minimum allowable torque value for 501/T56 engine propeller retaining nuts used on the C-130 aircraft. The study has revealed that torque is more critical than was previously believed.

Unfortunately, the applicable maintenance manuals do not yet reflect the findings of this study, and reports from the field indicate that the new information on the subject has not been adequately disseminated.

Background

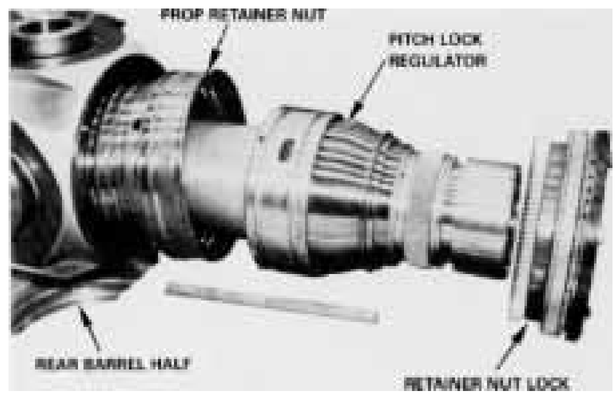
The engines of a number of Hercules aircraft were checked for proper propeller nut torque during inspections over a period of fourteen months. Several were found to be below the installation torque values, and Allison subsequently embarked on an engineering program to establish the allowable minimums.

Recommendations

Engineering personnel from Allison and Lockheed Engineering have made a number of recommendations, based on the results of Allison's program.

1. The minimum allowable propeller nut torque on T-561501 engine for the Hercules aircraft is 1500 foot-pounds.

2. Lockheed maintenance manuals will be amended to describe the following propeller nut check procedure to be carried out any time a propeller is to be removed.



Correct propeller retaining nut torque is essential to prevent component damage.

Propeller Retaining Nut Torque Check

- Place the torque wrench on the propeller retaining nut. Apply the wrench in the tightening direction to ascertain nut pretorque. Note the pretorque value and refer to the information below for appropriate maintenance action.

- If the pretorque is 1500 foot-pounds or more, the shaft is serviceable. Retorque the propeller retaining nut to 1900-2200 foot-pounds and return the aircraft to service.

- If the pretorque is less than 1500 foot-pounds, the metal structure of the propeller shaft may have been excessively fatigued. The affected shaft must be removed from service immediately and condemned. Be sure that all condemned propeller shafts are mutilated with a hack saw or similar tool to preclude further use.

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Hydraulic Housekeeping

by **Len Galati,** *Service Analyst*
C-130/Hercules Service Department

The maintenance manuals typically call for capping the affected lines when a hydraulic component must be removed for replacement or repair. This is good advice in many situations, but there can be a problem when a component is located below the fluid level of the reservoir, and in a line connected directly to it.

The result may then be something of a mess. It is nearly impossible to disconnect hydraulic lines filled with fluid under gravity pressure without spilling some of it. In locations where a catch container cannot be used, this means that hydraulic fluid ends up on the floor, the insulation batting, or whatever else happens to be within range.

A better technique in such cases, in view of the unbending and uncooperative laws of gravity and fluid dynamics, is to drain the associated reservoir before spillage can occur.

There are three hydraulic system reservoirs: utility, booster, and auxiliary. These systems have different functions, and this is reflected in differences in system design. One consequence is that the removal of a component may require that the reservoir be drained in the one system, but not in another.

Affected Components

In **all systems,** the associated reservoir should be drained when removing and replacing the following components:

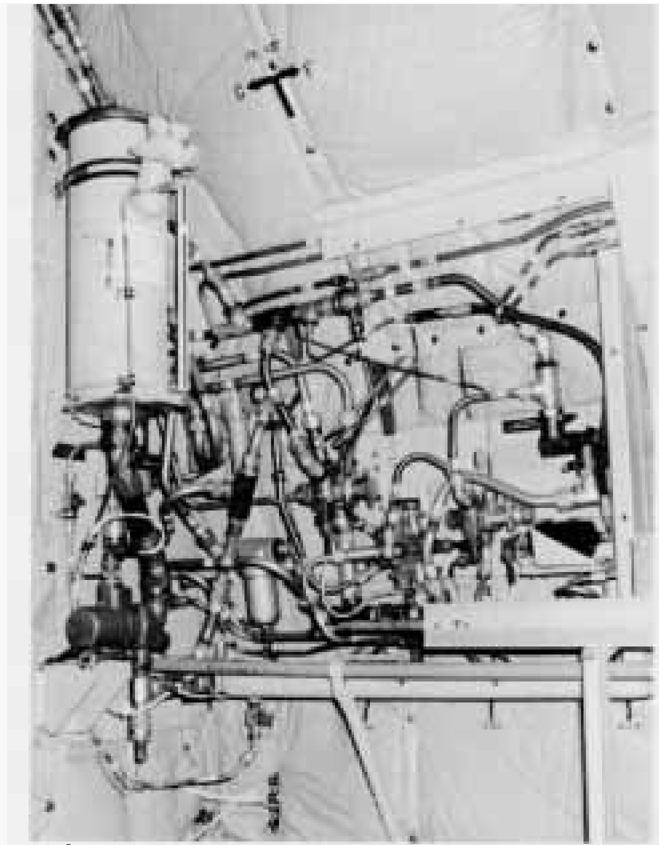
- Reservoir
- Suction boost pump
- Hose (from reservoir to suction boost pump)
- System return filter elements

The **utility system** reservoir should be drained when removing these components:

- Suction boost low pressure switch
- System relief valve
- System return filter elements

The **booster system** reservoir should be drained before the following component is removed:

- Suction boost low pressure switch



Utility hydraulic system reservoir and associated components (typical).

Strictly speaking, the reservior will not have to be drained in this case if a properly fitting cap is available. There is, however, great potential for a large loss of fluid since the contents of the reservoir can drain through the switch fitting if it is not adequately capped.

The **auxiliary system** reservoir should be drained when removing these components:

- Auxiliary system pump
- Ramp and door manifold
- Hand pump

Draining Hydraulic Reservoirs

Draining a hydraulic system reservoir need not be a difficult or especially messy task. The following suggestions should help get the job done easily and quickly.

1. For the booster and utility system, place a large container under the aircraft inboard and forward of the tire in line with the hydraulic drain tube on the appropriate side of the aircraft.

   For the auxiliary system, place a large container under the left side of the airplane approximately even with the cargo door to ramp junction. Screw an elbow fitting into the threaded overboard drain boss located on the side of the fuselage near FS 788. Then attach a hose long enough to reach the container and proceed to the next step.

2. Open the reservoir drain valve.

3. Monitor the container fluid level to prevent overfilling; empty the used fluid into an approved container for disposal.

4. Open the drip pan drain valve.

5. Remove and replace the affected component according to the maintenance manual.

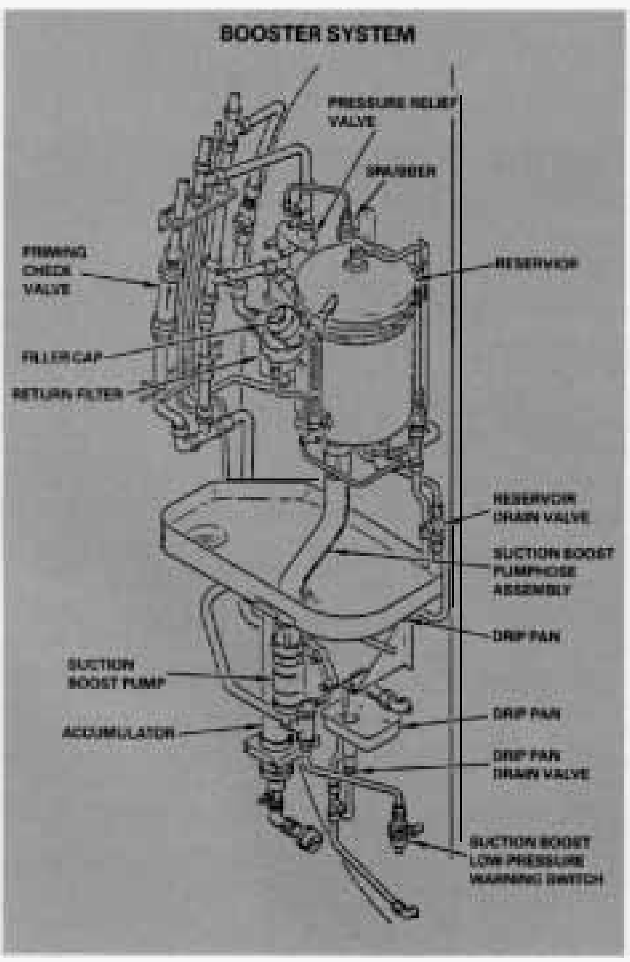
6. Restore the system to normal by closing the drain valves and refilling the reservoir. Always use new fluid to refill the system; the used fluid contains contaminants and must not be returned to service.

7. Perform system bleeding procedures in accordance with the maintenance manual.

Hydraulic Hints

Keep in mind that the removal of some components allows the fluid above it to siphon off or flow down by gravitational force. This can result in a significant fluid loss even though the reservoir is not directly involved.

One such component is the priming check valve in the booster system. In this case, draining the reservoir would have no effect on the amount of fluid lost.




Drain the auxiliary system reservoir when removing system pump. ramp and door manifold, or hand pump.

When you are getting ready to remove a component that has a considerable length of hydraulic tubing above it, prepare the area, and yourself, first.

Ensure that the insulation blankets are protected from splatter-a plastic sheet is useful for this-and that a container of ample size is in place to keep the floor clean. Have rags handy to wipe up. Make sure that you have the right quantity and sizes of caps and plugs readily available for use on the lines to the affected component.

When a component that has rigid tubing entering from opposite sides must be removed, it is generally advisable to disconnect the remote ends of the tubing and any supporting clamps before loosening the ends that enter the component itself.

This is because the ends of rigid tubing that enter a component’s fittings may protrude far enough inside to “lock” the component in its mounted position. This can happen even though the mounting bolts have been removed and the B-nuts on both sides have been thoroughly loosened; loosened enough, in fact, to allow fluid to escape at a disconcerting rate.

Disconnecting the remote ends of the tubing first will ensure that the component end of the tubing will be easy to extract once the B-nuts have been loosened, and that all potential sources of fluid spillage can be quickly plugged or capped.

Take a moment before you remove a component to analyze the potential for fluid loss. Prepare your work area for possible spills, and follow all the instructions in the maintenance manuals. Planning component replacement with an eye toward hydraulic housekeeping can transform what could be very messy job into a routine repair.

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1900 . . . and Counting!