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UNDERSTANDING STRUTS

Lockheed

SERVICE NEWS

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Cover:A newC-130H belonging to the Tunisian Air Force taxies out on a training mission.

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Focal Point

TOM DISNEY

Optimization in Action

All landing gear systems are unique to the type of aircraft in which they are installed. This is because these systems must he designed to perform a specific set of functional and structural tasks for a particular airplane. These tasks include furnishing a means of absorbing energy during landing impact, supporting the aircraft during takeoff and all ground operations. and providing for ground steering and braking.

The Hercules aircraft landing gear has proved exceptionally successful in meeting itsdesign requirements. Rugged and straightforward, It performs dependably in an almost unbelievable variety of **operating conditions,** with relatively modest maintenance requirements.

Although the basic gear design and itsoutward appearance have remained fundamentally the same since the aircraft entered production more than thirty years ago, the evolving worldwide mission of the Hercules airlifter haveledtochangeswhich have significantly upgraded the system's overall performance.

Some changes were madetoaccommodateincreasesinthegrossweightcapabilityofthe C-130 series. These include the installation of multipleversussingle-disk brakes, the improved Mark II anti-skid system, and structural strengthening of the landing gear struts.

Particular attention has been paid toenhancingthecapabilityofthe Hercules to operate from semi-prepared runways. This effort has led to a redesign of the shock strut characteristics to provide reduced taxi load responses when the aircraft is operating from rough surfaces.

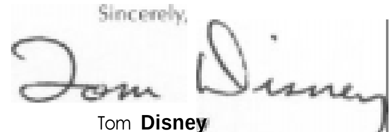
Extensive engineering analysis and development tests were performed to arrive at the com~blnation of strut air volume, inflation pressure, and orifice size that would provide the desired energy absorption characteristics and control of peak shock loads.

This required a careful balancingofthe manyfactors involved. Optimizing the strut load-stroke characteristics only for landing impact could have resulted in undesirable taxi load responses, and vice-versa. Thus a number of tradeoffs had to be considered in the optimizing process.

The feature article in this issue of Service News deals with the results of this effort. It provides an in-depth review of the characteristics and differences between the"hard"and"soft" strut and the reasons why the soft strut was developed.

We of the Lockheed-Georgia Aeromechanics Departmenthopethatthisinformation will provide you with a better understanding of the Hercules aircraft landing gear system and how it has developed. We also hope you will not hesitate to contact us through the Field Service organization if we can answer any questions or assist you in any way.

Sincerely,



Tom **Disney**
Manager
Aeromechanics Department

UNDERSTANDING STRUTS

by W.G. Moses, Aircraft Structures Engineer, Senior

The Hercules aircraft utilizes landing gear shock struts of the oleo-pneumatic type. These struts use both hydraulic fluid and compressed air to produce a controlled resistance to shock loads incurred during takeoff, landing, and ground operation.

Each strut is made up of a telescoping inner piston and a stationary outer cylinder. As shown in Figure 1, the inner piston assembly is the lower part of the strut to which the wheel and brake assembly are attached. The outer cylinder has suitable connections and attaching members to allow correct installation to the airframe.

When the aircraft is being taxied, the shock loads are handled mainly by the compressed air contained in the upper chamber of the strut. The pressurized air in this chamber also serves to extend the strut to its normal operating length in preparation for the next compression load. During landing, the impact of aircraft weight on the landing gear is absorbed by both the compressed air and the controlled movement of hydraulic fluid through the orifice of the orifice plunger assembly.

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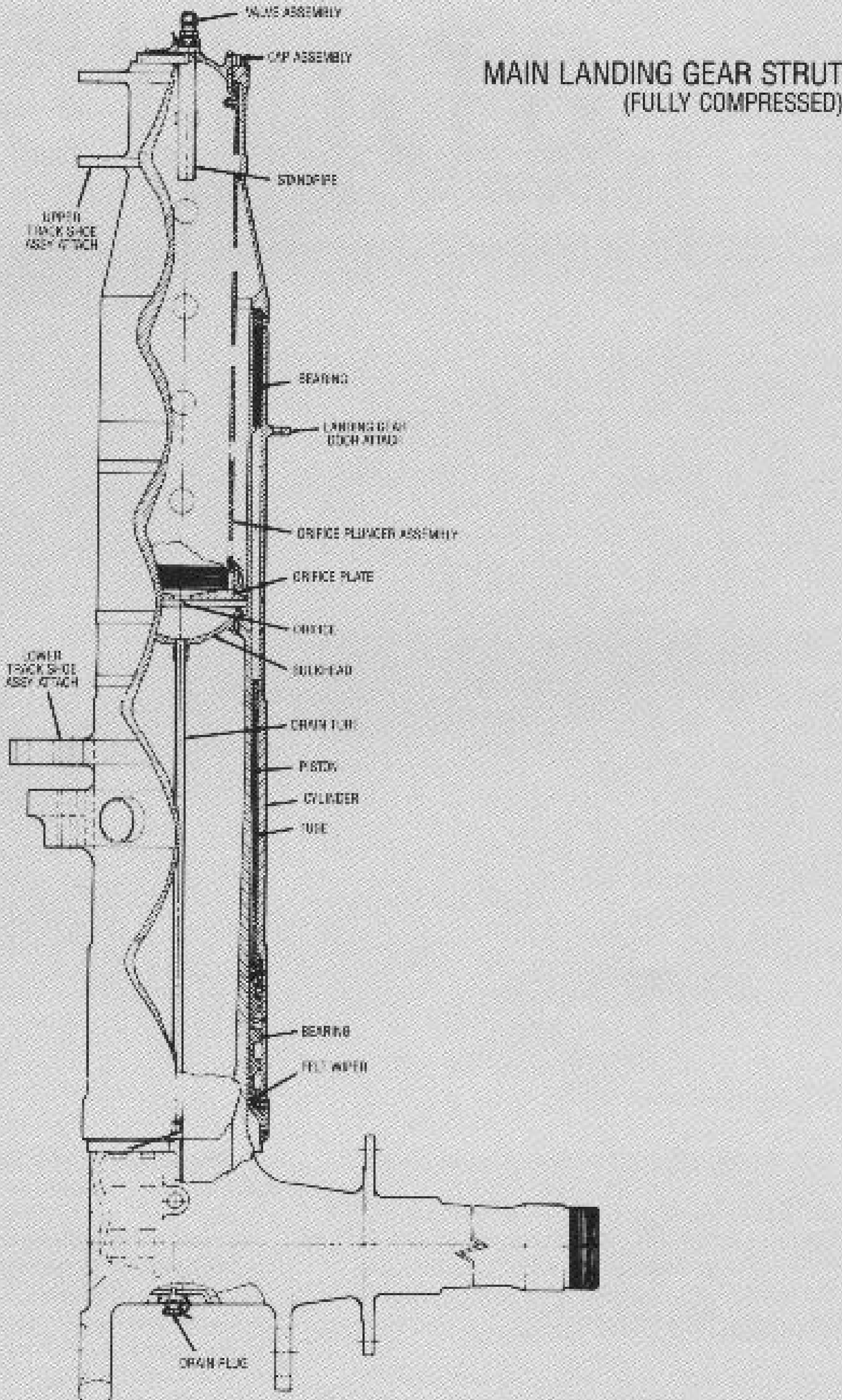
MAIN LANDING GEAR STRUT
(FULLY COMPRESSED)
CAP ASSEMBLY
STANDPIPE
BEARING
ORIFICE PLUNGER ASSEMBLY
ORIFICE PLATE
BULKHEAD
PISTON
CYLINDER
BEARING
DRAIN PLUG

Figure 1.

STRUT TYPES

Hercules aircraft are equipped at the factory with either "hard" or "soft" struts. As we shall see in more detail later, this terminology refers to the strut's performance as **a** shock absorber rather than any specific operating parameter such as inflation pressure.

Although the two types have somewhat different operating characteristics, hard struts are nearly identical in design and appearance to soft struts, and one type may be converted to the other with relatively minor modifications.

Current production Hercules aircraft are normally equipped with soft struts, but hard struts are still being manufactured and are installed in new aircraft at customer direction. The fact that both types continue to be available has resulted in a somewhat mixed picture in the field.

U.S. Air Force C-130 aircraft have usually been delivered with hard struts, or converted to hard struts after delivery. For example, fiscal year 1968 and 1969 USAF C-130s were delivered with soft struts, but later converted to hard struts. The U.S. Air Force and U.S. Coast Guard continue to order most of their new airplanes with hard struts; a recent exception is a new MC-130H aircraft, which will be delivered with soft struts.

On the other hand, the U.S. Navy and many overseas military operators order soft struts on their new airplanes, and have obtained kits to convert the hard struts of aircraft they already possess to soft struts. U.S. Marine Corp KC-130F airplanes have received soft struts as part of their Service Life Extension Program (SLEP). Most L-lOO aircraft also have soft struts.

Identifying Strut Type

If you do not know what kind of struts your Hercules aircraft has, there are several ways to find out. One way is to examine the data plate on the strut to see the part number or servicing pressure. This information can be compared with information in the appropriate illustrated parts breakdown or maintenance manual data to give you an answer.

There is an easier way yet. Look at the cap assembly on top of the strut where the servicing valve is installed. If the boss into which the valve is threaded has two flats machined onto it, it is a hard strut. If the servicing valve boss has four flats, as in Figure 2, it is a soft strut.

Unfortunately, this simple test is not applicable to A-model Hercules aircraft. All A-models are equipped with hard struts, but some of these struts have four flats on the servicing valve boss.

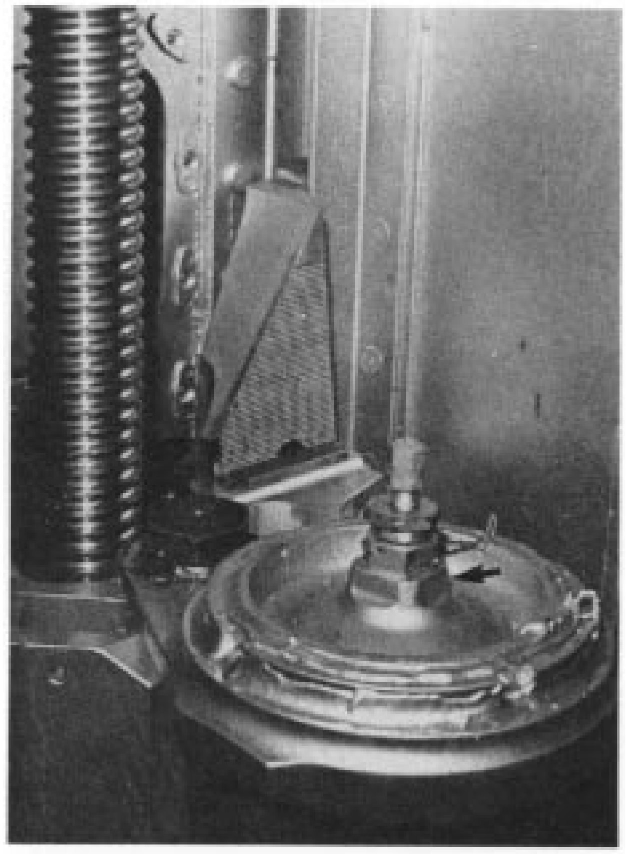

Figure 2. Servicing valve boss with four flats-typical for soft strut.

By the way, do not use the data plate color as a designation for hard or soft struts. All struts manufactured in the last decade or so, hard and soft, have data plates that are red in color.

HARD STRUTS AND SOFT STRUTS

Figure 1 shows typical components common to both strut types. There are two basic internal differences between hard struts and soft struts: (1) orifice diameter and (2) standpipe length. Kits are available for converting hard struts to soft and vice versa. The kits consist of the following interchangeable parts: a cap assembly, and an orifice plate.

Cap Assembly

In the hard strut, the cap assembly includes a shorter standpipe, but the same piston diameter and stroke as the soft strut. The hard strut consequently has less air volume than the soft strut. Differences in the cap assemblies give the differences between the hard and soft struts shown in Figure 3.

Differences Between Hard and Soft Struts

	Hard	Soft
Air Volume		
Fully extended (cubic inches)	318.7	355.5
Fully compressed (cubic inches)	21.6	58.4
Fluid **capacity (quarts)**	**8.59**	**8.10**

Figure 3.

Orifice Plunger Assembly

The hard strut orifice has a diameter of 0.500 inch; the soft strut orifice has a diameter of 0.555 inch. The orifice plunger in the soft strut has a larger hole, which works in combination with the strut's higher pressure air charge to provide improved control of peak shock strut compression loads.

Different Data Plate

The data plate indicates the strut part number and specifies inflation pressure. The recommended hard strut inflation pressure with strut fully extended is 215 psi(g) for normal operations.

The early-model soft strut (prior to Lockheed serial number LAC 4430) was originally serviced to 515 psi, but all maintenance manuals have since been revised to specify 450 psi inflation pressure for all soft struts. As can be seen from these figures, the terms "hard" and "soft" do not refer to operating pressures of the struts, but rather to their operating characteristics.

DEVELOPMENT OF SOFT STRUTS

Prior to 1968, all Hercules aircraft were equipped with hard struts. The soft struts were primarily developed to reduce the stresses applied to the airframe when the aircraft is operating from semiprepared airstrips. More specifically, the objectives of the soft strut configuration versus the hard strut were to accomplish the following:

1. Reduce the incremental strut loads during taxi and landing roll on rough surfaces.

2. Give equal or better energy absorption and equal or lower peak vertical loads during landings.

3. Eliminate the requirement of changing strut inflation pressures to accommodate high gross weight and rough airfield surfaces.

The high degree of success achieved by the soft struts in meeting these objectives has led to the incorporation of soft struts as part of the standardequipment installed in new baseline Hercules aircraft.

OPERATIONAL CHARACTERISTICS

Operators often ask why the strut with the higher pressure is called a "soft" strut while the strut with the lower pressure is called the "hard" strut. To explain this, it is best to use an example. Refer to Figure 4, and assume that a strut of each type is loaded to 31,000 pounds. This corresponds to aircraft gross weight of 130,000 pounds (with 6,000 pounds being carried by the nose gear).

If each strut is then compressed an additional one inch, such as might happen when the aircraft rolls over a bump, it can be seen by tracing the curves plotted in Figure 4 that the resultant force transmitted by the soft strut to the airframe is significantly less than that transmitted by the hard strut. The soft strut has a higher initial air pressure and volume, and it requires less compression to support a given load.

Main Strut Static Load Versus Compression

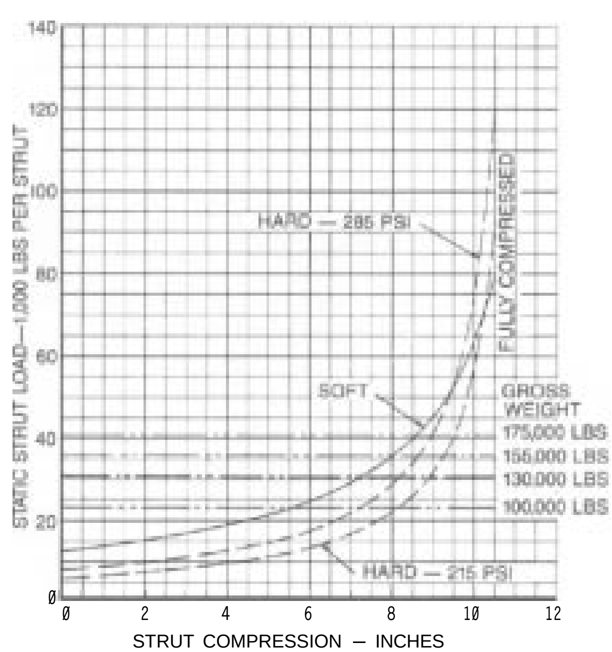

Figure 4.

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Another way of looking at this is to compare peak strut load during landing as determined by the drop test results for the two strut configurations. Drop test data is acquired through the use of a special piece of test equipment which simulates the conditions that will be experienced during landings at various weights, sink rates, and attitudes.

Figure 5 shows the results of drop tests designed to simulate a typical set of landing conditions. These tests clearly show the lower peak vertical loads for the soft strut, lower loads which translate into less stress applied to the airframe.

Peak Strut Load for Landing

DATA BASE: DROP TEST GROSS WEIGHT 130,000 POUNDS RATE OF SINK: 9 FEET PER SECOND		
	STRUT PEAK VERTICAL LOAD	
Strut	**Hard**	**Soft**
Strut Pressure	215 psi	515osi
Level Attitude	54,000 lbs	52,600 lbs
10 Degree Tail Down	70,000 lbs	69.500 lbs

Figure 5.

NOTE: STRUT PRESSURE SUBSEQUENTLY REDUCED TO 450 PSIG FOR OPERATIONS

It is worth noting that the drop tests for the soft strut shown in Figure 4 were conducted using the original strut inflation pressure of 515 psi. Even lower loads would result using the current operational pressure of 45Opsi. Note also that the peakvertical loads transmitted by the hard strut at 285 psi inflation pressure are higher than those shown in Figure 5 for 215 psi pressure.

OTHER IMPROVEMENTS

When the soft strut was first being manufactured, the strut bearings were changed to a Teflon-impregnated nylon material to reduce strut binding or "striction."Field tests revealed that the new bearings did not improve the strut action as much as hoped. The smaller bumps continued to be absorbed more by tire compression than strut compression.

About 1979, however, a new Teflon-impregnated cotton material was developed for strut bearings and successfully tested on fighter aircraft. Strut bearings made of this new material were subsequently installed on a commercial Hercules aircraft for testing. The tests indicated that the new material was a great improvement, and it is now used for all new struts, whether hard or soft, and also for the preferred spares. A great advantage of the new bearing material is that it allows the soft strut to meet its design objectives more fully.

ADVANTAGES OF THE SOFT STRUT

Equipping a Hercules aircraft with soft struts provides several operational and maintenance advantages when compared with aircraft equipped with hard struts.

1. Universal Inflation Pressure

The soft strut uses the same inflation pressure for all gross weights and airfield surface conditions. For military aircraft, this eliminates the reservicing of the struts before and after operations into substandard airfields or at gross weights above 155,000 pounds, which is required for hard struts. The inflation requirements are summarized in Figure 6.

Main Strut Inflation Pressures

Operation	**Strut Pressure**	
	Hard	**Soft**
Normal	**215** psi	450 psi
Substandard Airfield	285 psi	450 psi
Gross Weight Above 155,000 lbs	285 psi	450 psi

Figure 6.

2. **Additional Ground Clearance**

As shown by Figure 4, the soft strut requires less compression to support the static strut load. This difference in strut compression translates into more ground clearance. Figure 7 shows the additional ground clearance to be expected on aircraft equipped with soft struts compared to aircraft equipped with hard struts. It should be noted that these differences occur at the main gear and that there is no change in ground clearance at the nose gear.

3. Longer Service Life

The soft strut absorbs a given bump with less additional strut load than does the hard strut. This in turn provides a longer service life for affected airframe components, including the wing upper surfaces.

4. Increased Fuel Weight Limit for Taxi

The softer ride which is provided by the soft strut allows a higher fuel weight for taxi, as shown by Figure 8.

5. Increased Fuel Weight Limit for Landing

The hard and soft struts impose the same fuel weight landing limits for normal operation. However, as shown in Figure 8, aircraft equipped with hard struts have more limited landing fuel weights for substandard airfields or after takeoff at gross weights above 155,000 pounds. This is because hard struts must be inflated to 285 psi for operation under these conditions.

6. Higher Limit Gross Weight for Jacking

As limited by the strength of the removable jacking and towing fitting, the maximum weight for jacking a single strut is shown by Figure 9 to be 175,000 pounds for aircraft with soft struts, versus 155,000 pounds for aircraft with hard struts inflated to the normal pressure of 215 psi.

Additional **Ground Clearance with Soft Struts**

Gross Weight	**Soft** Strut at 450 psi versus Hard at 215 psi	Soft Strut at 450 psi versus **Hard** at 285 psi
100,000 lbs	2.6 ins	1.6 ins
130,000 lbs	1.7 ins	1.0 in
155,000 lbs	1.2 ins	0.7 in
175,000 lbs	0.9 in	0.4 in

Figure 7.

Fuel Limits for Hard and Soft Struts

Strut Configuration	**Hard**	**Hard**	**Soft**
Strut Pressure-psi	215	285	45(
Maximum Taxi Fuel-lbs'	62,920	62,920	65,742
Maximum Landing Fuel"'			
Tanks 1 & 2-lbs per side	6,600	5,420	6,601
Total All Main Tanks-lbs	25,000	20,250	25,000

*Maximum taxi fuel is:
Hard struts-9,680 gals of JP-4 at 6.5 lbs per gal
Soft struts-9,680 gals of JP-5 at 6.8 lbs per gal

**540 fpm rate of sink

Figure 8.

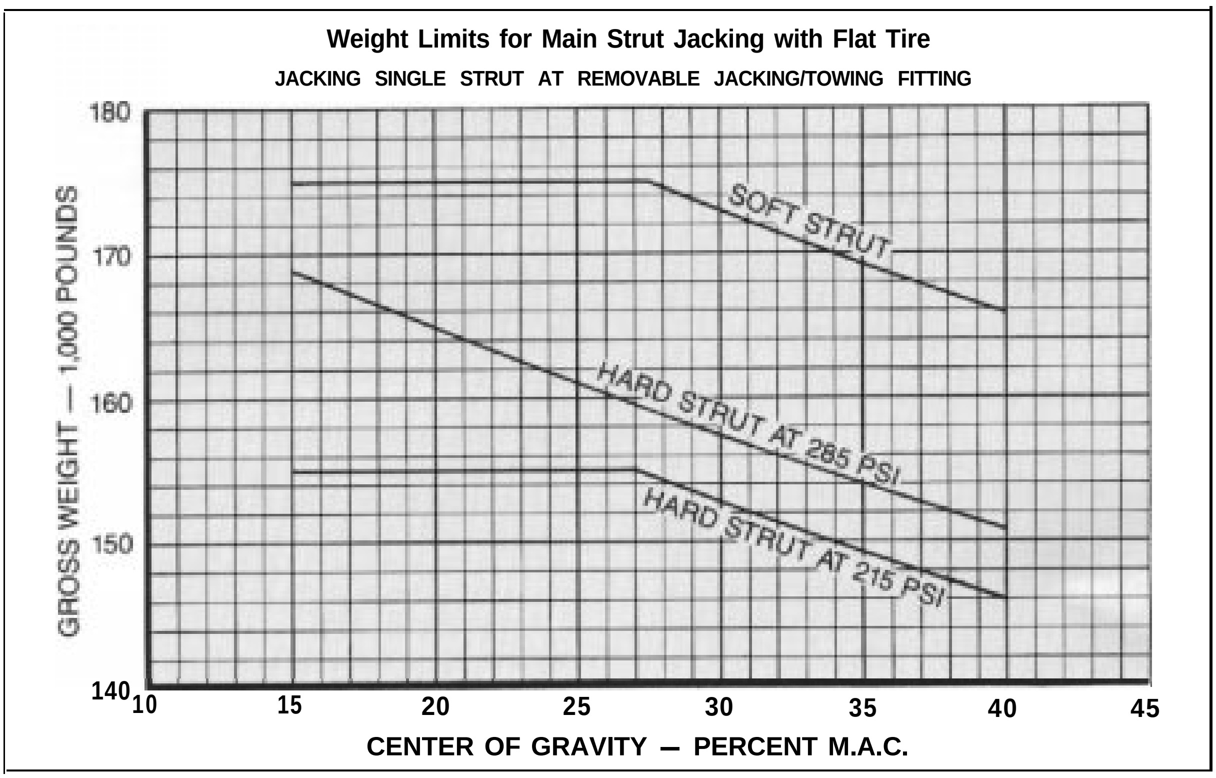

Figure 9.

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MAKING A CHOICE

The soft strut was developed as an improvement over the hard strut, and for most applications it is. It can be seen from the foregoing discussion that the soft strut offers many operational advantages over the older type, the most significant being that the soft strut applies less stress to the airframe and thereby extends service life and reduces maintenance costs.

In the past, a number of the operators who have specified the hard strut for their aircraft have done so mainly for the purpose of maintaining spares compatibility within their fleets. This practice may to some extent have been based on inadequate information, however. As we have seen, the mechanical differences between the hard strut and the soft strut are quite small, and one type may be readily converted to the other.

But the hard strut has two characteristics which some operators may feel offer certain operational advantages.

One is that the hard strut is effectively a stiffer spring than the soft strut. Therefore, aircraft with hard struts will tilt less while making taxi turns and rock less while rolling along uneven runways or taxiways. Actually, tilt angle is quite small in either case.

Another is that the vertical force required to bottom the hard strut is much higher than for the soft strut. For the hard strut, a force of 95,700 pounds per strut is required at 215 psi pressure or 125,000 pounds at 285 psi pressure. For the soft strut, the force required is 79,700 pounds per strut.

It should be noted, however, that this is less of an advantage in favor of the hard strut here than meets the eye. Even with this lower force required for full compression, the soft strut should not bottom out if properly serviced and the flight manual operational limitations are observed.

service news

OIL FUMES
IN THE All? CONDITIONING SYSTEM

by Darel Traylor
Service Analyst

Operators of Hercules aircraft have occasionally noticed the odor, and sometimes the eye and nose irritation, associated with engine oil fumes being introduced into the air conditioning system.

Experienced Hercules aircraft crews are aware that the 501/T56 engine can under some conditions develop nuisance-type static oil leaks caused by seepage through the power section filter check valve, filter bypass valve, or pressure regulating valve. This leakage may result in the sumps overflowing and flooding the compressor section with engine oil. When the engine is started, the oil is forced into the bleed air system and finds its way into the air conditioning system.

It is possible to minimize the undesirable effects of this contamination problem by making minor changes in the engine start and run-up sequence.

Normally, the crew should be aware of the existence of oil in the compressor section prior to engine start because of telltale oil on the bottom of the nacelle or the drain mast. When the source of the oil is determined to be caused by leakage at one or more of the locations previously mentioned, the engine should first be motored, and then started and run up to scavenge the oil in the sumps back to the tank. The engine start should be accomplished normally except for the following.

1. Allow the engine to stabilize in low speed ground idle and immediately close the respective engine bleed air valve. In low speed ground idle, the 5th and 10th stage bleed valves are open, allowing most of the oil to escape from the compressor through the acceleration bleed manifold.
2. Now shift to high speed idle as desired, but keep the engine bleed air valve closed as long as possible (a minimum of several minutes) to allow the oil residue to dissipate through the engine.
3. Opening the bleed air valve at this time should not introduce any oil into the bleed air manifold and there should not, therefore, be any fumes in the air conditioning system.

Bleed air system contamination by engine oil could occur at any time as a result of an internal oil leak; however, this will usually be accompanied by high oil consumption and the constant presence of malodorous fumes in the air conditioning system. Note how this differs from static oil leakage, which will normally cause fumes immediately after engine start that gradually diminish as the oil vaporizes and dissipates through the system.

The next time your preflight reveals that an engine has leaked some oil into its compressor section, give this procedure a try. We believe you will find it to be an effective way of keeping unpleasant and irritating oil fumes out of the air conditioning system-and the interior of your aircraft.

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INSTALLING THE IMPROVED AC BUS POWER-OFF INDICATOR RELAY

An improved, solid-state bus power-off relay (PN 3317781-l) has been incorporated on production C-130 aircraft Lockheed serial number LAC 4871 and subsequent, in place of the Hartman PN AVR-834B (Lockheed PN 695835-l) relay used on earlier aircraft. There are four of these relays on the aircraft, one for each of the three-phase AC buses: essential, main, right-hand, and left-hand.

This new solid-state relay offers the advantage of more positive and reliable "bus-off" indication if one of the three phases drops off the line for some reason. The earlier relays did not always recognize the absence of one of the three phases because of their location in the circuit and their method of operation.

The Hartman relay was designed to turn on the bus-off light for its respective bus when the voltage to the relay armature dropped below a designated level (around 90 VAC), causing the relay to de-energize. The theory was that if one of the phases should drop to zero volts, the average voltage among the three phases would be less than that required to keep the relay energized. The relay would then de-energize and complete the circuit to the bus-off warning light of its respective bus.

This is in fact how the relay works under most conditions. However, there are certain situations in which a current limiter for one of the phases can open its circuit to the bus without causing the bus power-off warning light to illuminate.

The reason for this peculiarity is that three-phase motors, such as the ones that drive fuel boost pumps, hydraulic suction boost pumps, and the auxiliary hydraulic pump, allow voltage to be fed back through the motor windings to the failed phase. This may prevent the average voltage to the bus power-off relay armature

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from falling below the nominal voltage required to keep the relay energized.

The solid-state sensing circuit in the PN 3317781-1 relay (Figure 2) is designed not to be fooled by such a feedback condition. It will provide a positive bus-off indication each and every time one of the phases is lost.

However, although the PN AVR-834B relay and the new PN 3317781-1 relays are physically interchangeable, there are some things that the technician should be aware of to avoid difficulties when replacing the earlier relay with the solid-state version.

The Hartman AVR-834B relay may be found with the power lead (wire W304( )22) connected to either terminal A2 or A3 of the relay. The Hartman relay will work wired up either way. But **watch nut!** When installing the PN 3317781-1 solid state relay, the power lead **must** be connected to the A3 terminal of the relay.

There are four of these relays per aircraft, and the wiring for most of the earlier-style relays is compatible with the wiring for the new relays. The exception is to be found in the right-hand distribution panel (see Figure 1). At this location on aircraft prior to LAC 4871, the main AC bus-off indicator relay was wired so that the power lead (W304D22) would beconnected to the **A2** terminal of the relay (see Figure 3). Note that on military airplanes modified in compliance with TCTO lC-130-1130, the main **AC** bus-off indicator relay is wired the same as the other three relays.

To avoid difficulty when installing the new solid-state relays, always doublecheck for proper wiring before applying power to the circuit. If the power lead is not connected to the A3 terminal, at best the relay will not operate properly. A more likely result is that it will be severely damaged and unable to perform the important function for which it was intended.

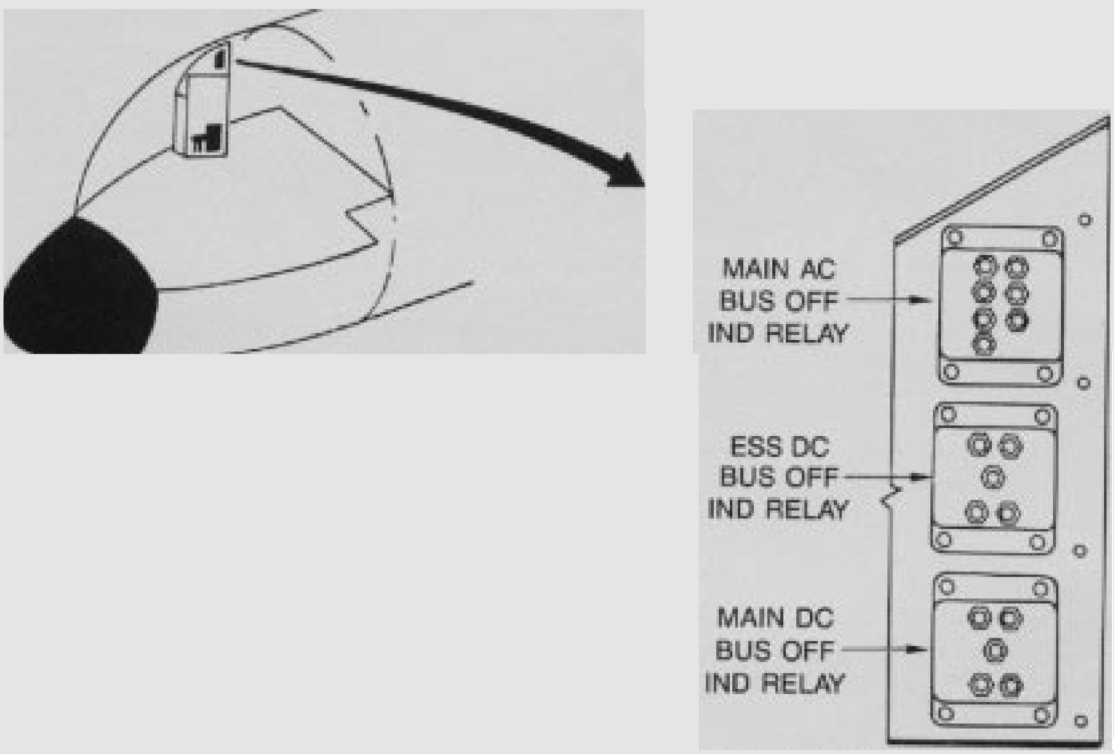

Figure I. **RH distribution panel bus-off relay locations.**

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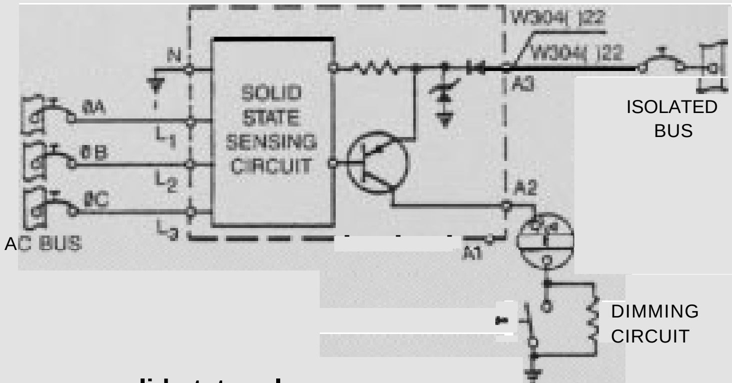

Figure 2. Wiring diagram – solid-state relay.

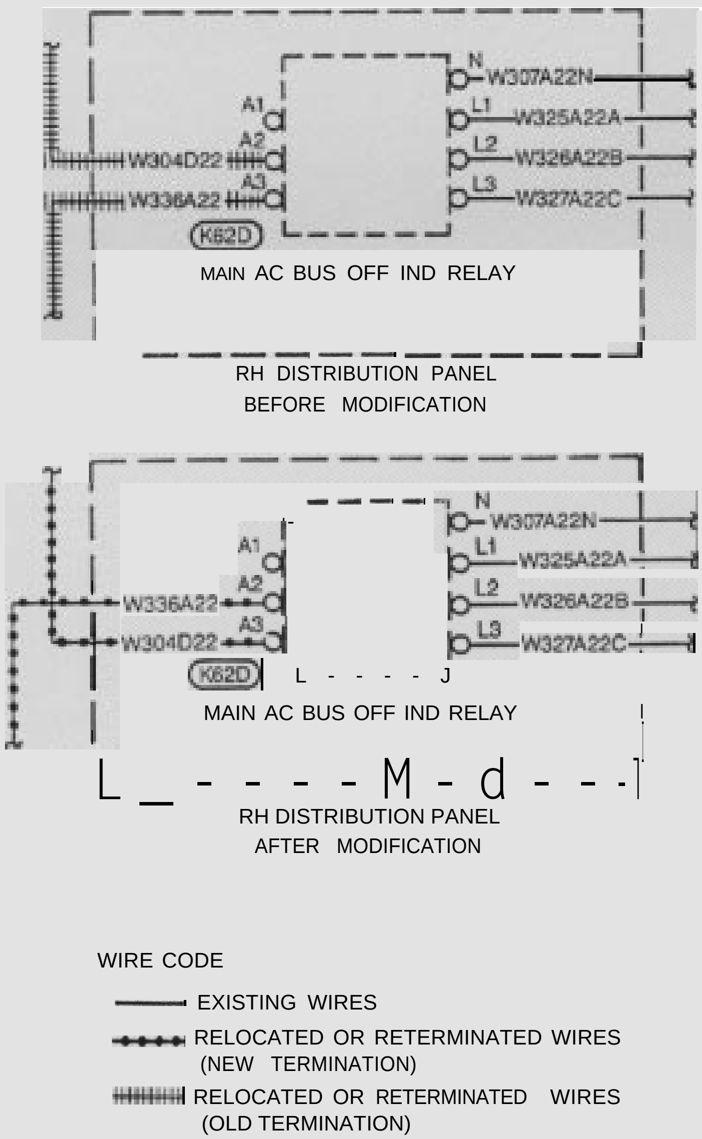

Figure 3. **Wiring diagram – main AC bus-off indicator**

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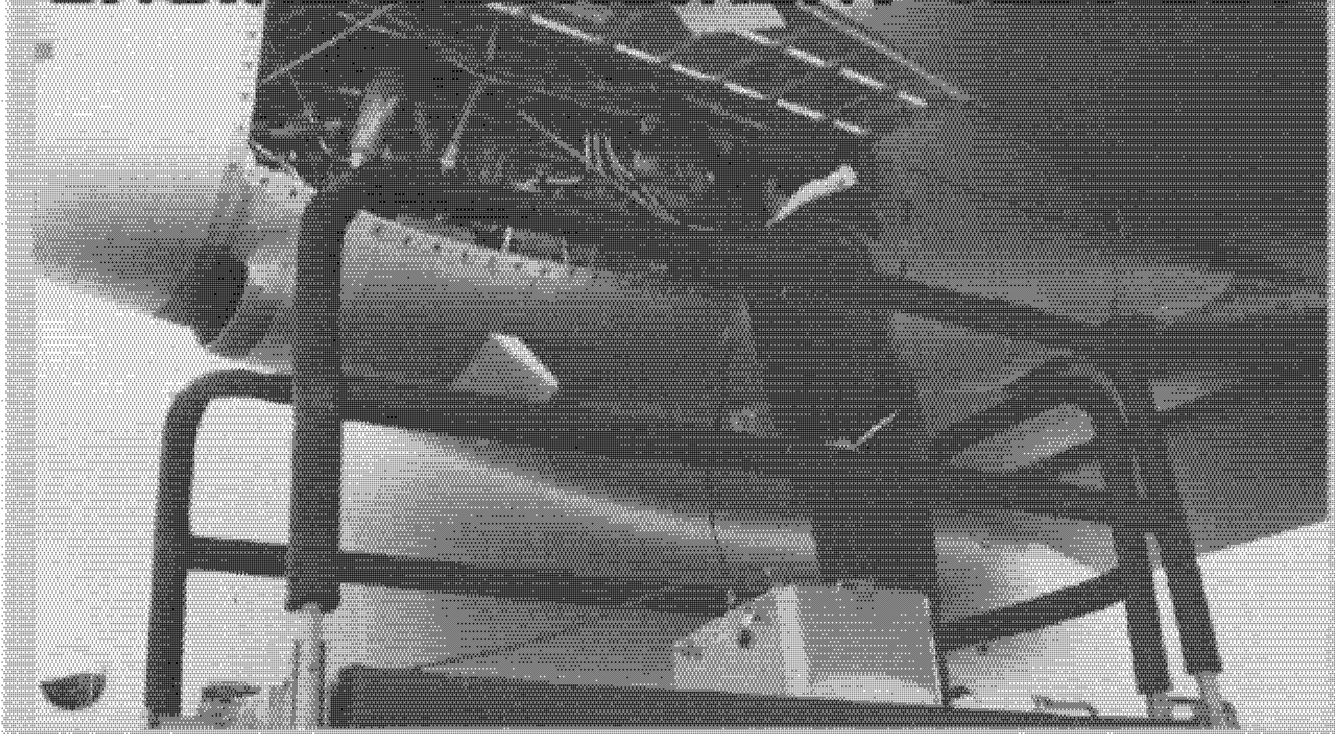
ENGINE INSTRUMENT TEST SET



by **Bill Turbyfield**, *Electronics Engineer and*
Raymond Yearty, *Senior Supply Planner*

Testing and troubleshooting aircraft engine instruments is an important, but sometimes difficult maintenance task. In addition, running aircraft engines to test a possibly faulty indicator—only perhaps to find that a broken wire connection is the problem—is an expensive and time-consuming process.

Modern, state-of-the-art electronics have led to a more efficient and effective way of testing these instruments: the Lockheed-manufactured Hercules Engine Instrument Test Set, PN 3403172-1.

This newly developed test set allows functional testing of the Hercules aircraft engine instruments with minimal (if any) run time on the engines. This test set can be used either on the flight line or in the shop to test the following indicating systems:

* Fuel flow
* Fuel pressure
* Hydraulic pressure
* Oil pressure
* Oil quantity
* Tachometer
* Torquemeter
* Turbine inlet temperature

Fast and precise testing of these systems with the new unit is accomplished by the use of highly accurate analog and digital circuitry. Aircraft signals to each of the indicators are simulated by the test set for static testing, and precision measurement devices are used for testing aircraft sensors under dynamic conditions. A1so built into the test set is a digital multimeter for resistance and voltage measurements.

Flight Line Maintenance

The Hercules Engine Instrument Test Set is designed to be used as a portable, flight-line tcstcr, with all of the equipment needed for functional testing of the engine instruments contained in one enclosure. Cables are provided to allow connection to each of the systems at the flight station, or at the aircraft engines for use in troubleshooting intermittent wiring problems. Test points are also provided on the test set to allow resistance and voltage measurements to be taken for each system.

Operation of the test set is simple. The technician evaluates the performance of an aircraft indicator by connecting the cables, adjusting a control on the test set to a specified value, and observing the indicator for proper readings. Aircraft sensors are tested in the static mode by resistance readings, and in the dynamic mode by observing test set monitor displays.

Shop Maintenance

Functional testing of each of the indicators may also be performed in the shop with this test set. As an added feature, the unit can be used together with a dead-weight tester for checking pressure transmitters. The technician is thus able to functionally test new indicators or pressure transtnitters prior to installation on the aircraft.

The Hercules Engine Instrument Test Set is designed to make testing and repair of the Hercules aircraft engine instruments less time-consuming. The resultant cost savings, the high accuracy of the unit, and its ease of operation make this test set a valuable aid to the Hercules aircraft operator. It is worth noting that with the appropriate accessory cables, the test set may also be used to check similar instrumentation on other aircraft.

If you would like additional technical or procurement information about the PN 3403172-l Hercules Engine Instrument Test Set, please direct your inquiries to the Manager, Supply Sales and Contracts Department, at the following address.

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