

# AH-64D Swashplate Test Stands: Improving Understanding of Component Behavior in Rotorcraft Swashplates through External Sensors

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**Abstract**— This paper discusses the research activities and capabilities at the University of South Carolina going through the theory behind the design of a test stand, laying out the specifications of the two test stands currently in operation, the tail rotor drive train (TRDT) and the main rotor swashplate (MRSP), and then ending with the an example of new sensor development. The Condition-Based Maintenance (CBM) program at the University of South Carolina has investigated many components in the AH-64. Different sensors, including thermal couples and accelerometers are used to gather data from the components being tested.

## I. INTRODUCTION

In every mechanical system with moving parts there will be failures and in aircraft, these failures not only result in downtime and loss of availability, but can also result in loss of aircraft. To address certain types of mechanical failures, the USC is currently focused on the condition based maintenance of the tail rotor drive train (TRDT) and main rotor swashplate (MRSP) of the AH-64. The purpose of Condition Based Maintenance (CBM) research at USC is to predict failures before they happen, extend the amount of time a component can be run and understand when a component becomes unsafe.

Testing conducted on the tail rotor drive train system and main rotor swashplate stand furthers the objectives of CBM. These experiments through their unique design, allow the stands to simulate flight loads experienced by the aircraft. The test stand's goal is to discover new condition indicators (CIs) while validating existing CIs. Current military CIs are calculated using vibration data collected by the Modern Signal Processing Unit (MSPU). Data is gathered by simulating flight loads on components with faults which have naturally occurred in the field or are induced in a laboratory. Testing conducted on these stands has led to modifications in military maintenance procedures, resulting in cost savings for the military, as well as increases in morale and safety. [1-8].

This paper presents the design of each test stand, the sensors used to collect data, and the methods used to interpret the data for the advancement of current CIs through new sensor configurations.

## II. DESIGN

The test stands are designed to investigate the endurance of drive train components, such as gear boxes, bearings, and drive shafts, while simulating flight loading conditions. On the aircraft, both the main rotor and tail rotor swashplates are subjected to various external forces resulting from wind, weight, and blade thrust.

### A. Main Rotor Swashplate

The test stand was designed to emulate the operational kinematics of the swashplate on the aircraft, while being simple in design and operation. In the current configuration, the swashplate rotates about a cantilevered static mast which, like the helicopter, is only supported at the bottom. The test stand also allows swashplates to be changed and aligned, quickly and effectively. The MRSP test stand can be seen in Fig. 1.

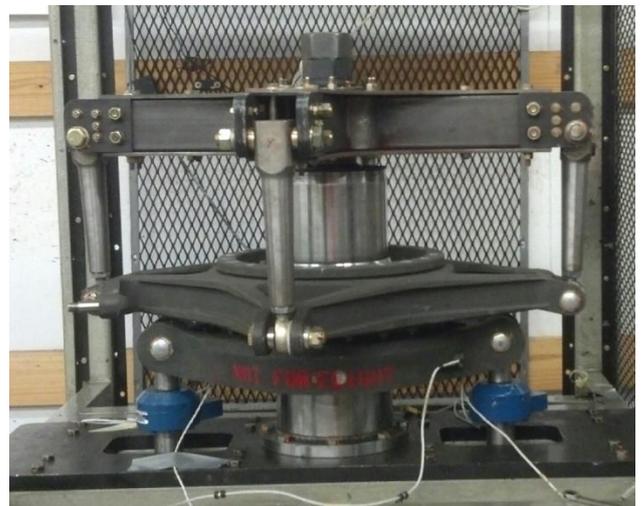


Fig 1. Current MRSP test stand configuration

The stand is actuated by a 50 HP electric motor with a drive shaft and a 90° gearbox. The rotor head is mounted using a taper at the top of a vertical drive shaft extending out of the static mast. Rotation is transmitted to the swashplate through four pitch links, which are connected to the rotor head. On the test stand these pitch links induce loading similar to the aircraft.

The external forces are simplified into two types of loading: static and cyclic, simulating natural forces on the helicopter. The loading conditions are applied by two independently controlled hydraulic actuators mounted underneath the swashplate and measured by load cells. The independent control allows for the application of cyclic loading, with respect to the pitch links, increasing force on one actuator and decreasing the force on the other. The force is applied to the stationary portion of the swashplate, and then travels through

the bearing to the rotating portion and into the rotor head through the pitch links.

The current research uses the MRSP test stand to evaluate failure progression of seeded fault articles, and to develop algorithms to for fault progression using external acoustic sensors.

### B. Tail Rotor Swashplate

The TRDT allows multiple components from the AH-64 to be evaluated simultaneously. Articles on the stand are the forward hanger bearing, aft hanger bearing, intermediate gearbox, tail rotor gearbox, and tail rotor swashplate. These components are driven by a computer controlled 800 HP motor. Torque is generated by a similar motor that is connected to the output shaft and able to place a load of 1200 ft-lbs on the system while also generating up to 70% of the energy to be put back into the original motor. Normal operating speed of the test stand is 4863 rpm with the tail rotor output being 1417 rpm. The test stand is shown in Fig 2.



Fig 2. A view of the entire TRDT test stand

Recently the tail rotor swashplate (TRSP) has been added to the TRDT test stand with the hopes of furthering testing capabilities with an additional component. To implement these changes new components including the TRSP, spherical bearing, and hydraulic cylinders were added to the stand to allow for swashplate testing. An additional benefit is that more sensors can be tested. For example, adding strain gauges to the pitch links creates the opportunity to verify the pitch link loads, and to also quantify the load experienced during regular aircraft operation.

TRSP loading operates under the same principle as the MRSP; using two hydraulic cylinders, one for cyclic loading, one for static loading. The static actuator is attached to a bell crank at the base of the swashplate which transmits the static load to each of the pitch links equally. The cyclic load is created by a customized clevis that houses a wheel on the end of a hydraulic actuator. To create a cyclic load, the wheel presses into a plate connected to a spherical bearing and

transfers the negative load to the pitch link 180° away from the wheel.

On the TRDT stand, research is being conducted into the failure progression of seeded fault articles, and new sensing methods such as strain gaged pitch links for monitoring Tail Rotor load.

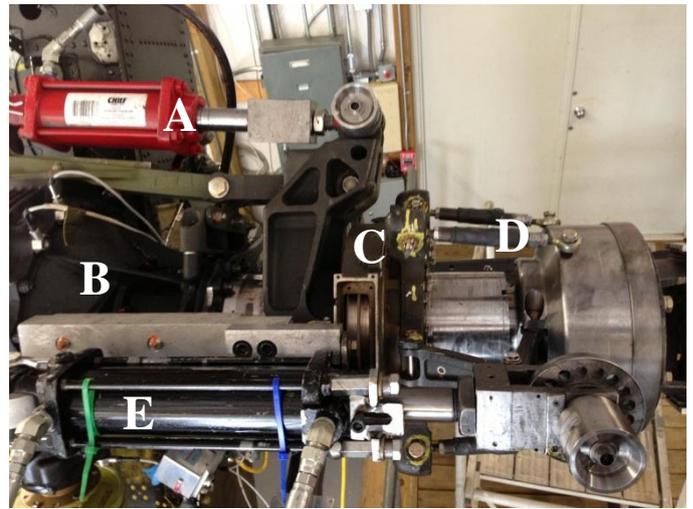


Fig 3. Overhead view of the current configuration of the test stand with the addition of the TRSP

The components are labeled in Fig 3. as follows: A is the static hydraulic cylinder, B is the tail rotor gearbox, C is the TRSP, D is a pitch link, and E is the cyclic hydraulic cylinder.

## III. SENSORS

### A. MSPU Accelerometers

A condition indicator is a scalar value derived from different types of data. The vibration data is collected and saved in the time domain. For frequency monitoring purposes and subsequent analysis, the fast-Fourier Transform is performed converting this data into the frequency domain. These scalar values are often represented with colors such as green, yellow, and red, or keywords such as Normal, Caution, and Exceeded [10].

Condition Indicator values are based on the magnitude of vibration recorded by accelerometers attached to the MSPU. The two modes of data acquisition built into the MSPU are called Survey and Monitor. Surveys are the primary source of information, when trying to determine a component's health. Surveys are regularly scheduled at the FPG 101 loading profile, creating a standard load against which the measurements can be compared. Fig. 3 shows the survey CIs for the life of a MRPS test article while it was on the test stand. High CIs, such as these, are expected for an article with this type of seeded fault, a bearing that has been packed with a mixture of coarse sand and grease. It can be gathered from this data that the fault is very severe, based on the high CI values, and that the fault is progressively getting worse based on the upward trend. It is also possible to gather that the remaining useful life is predictable based on the linear trend.

Monitor CI data is taken at regular time intervals by the MSPU. A monitor CI is uses the same type of data collected for the survey CI, except the data is collected during cyclic loading instead of FPG101 loading.

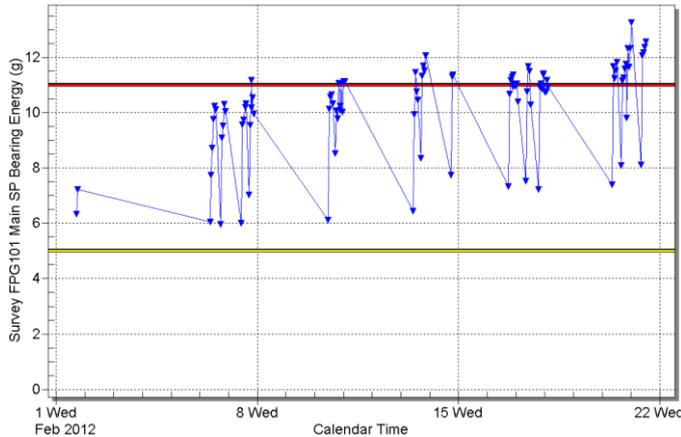


Fig 3. Survey CIs for the life of an article on the test stand

1) Temperature

Temperature is recorded on both test stands by thermocouples that are placed on the outside of each of bearing casing. They are used in conjunction with the information provided by the accelerometers to determine the condition of the article being evaluated. Bearing temperature monitoring is of limited value in case of a physical damage, since a noticeable temperature rise does not occur until there is significant damage. However, there are situations in which the damaged part does not vibrate enough to trigger a warning, but temperature rise will. These situations include improper installation or overload. [9]. The data from the thermocouples are collected in real time, enabling the operators to monitor temperature during the test run. A safety loop was created using this information. The stand is programed to alert the operator if the temperature passes a certain value, or increases at a higher than normal rate.

2) Force

Strain gauges were installed on the pitch links in order to measure the loads on the TRSP. Generating know loads by an 810 Material Tester System, the readings from the strain gauges were matched to a voltage value. Using this relationship, voltage values recorded during a test run could be translated and compared to expected load values. Respective equations on how these voltages are converted to strain are seen in Table 1.

Table 1 Table 9: Calibration Factor for Each Pitchlink

	Pitchlink 1	Pitchlink 2	Pitchlink 3	Pitchlink 4
Calibration Factor	-9.3577x	9.6459x	9.1859x	10.396x

In order to obtain readings from the strain gauges, which are attached to a rotating component, a wireless transmitter

was installed. The device transmits a signal to a receiver located in the control room so that the data can be seen in real time.

3) Testing

Most of the articles tested on the main rotor swashplate test stand are seeded fault articles while the remaining tested articles are field faulted. Table 1 shows different types of fault and the number of articles of each fault type tested. There are a few differences between the articles tested on the MRSP stand and the TRSP stand, as seen in the tables

TABLE II. Summary of the types of articles tested on the MRSP stand

Fault Type	No. of Articles
Natural Fault	1
Saltwater Injection	1
Acid Etching	1
Heat-Quenching	1
Loss of Grease	4
Coarse Sand Contaminant	2
Broken Cage	1
Baseline	2
Low Grease	1

TABLE III. Summary of the types of articles to be tested on the TRSP stand

Fault Type	No. of Articles
Saltwater Injection	1
Acid Etching	1
Loss of Grease	4
Baseline	2
Low Grease	1

IV. RESULTS

The objective is to simulate the TRDT in the field as accurately as possible, including the external pressure applied through and on the TRSP. In order to create this external load, both the phase and magnitude need to be representative of the actual helicopter. The orientation of the pitch links around the swashplate can be seen in Figure 6. The magnitude of strain on a pitch link as it cycles around the swashplate is expected to be related to the phase separation between the pitch links, e.g. the two pitch links 180° apart should have the same magnitude but opposite sign.

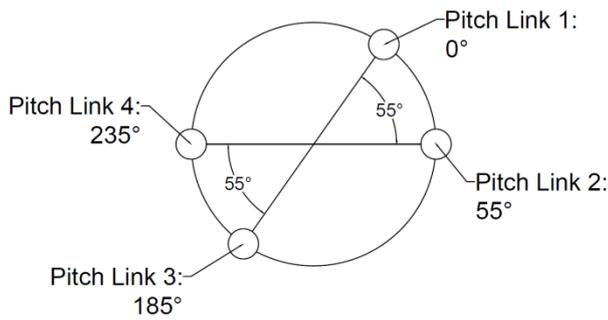


Fig 6. A drawing of the pitch link assembly as oriented on the TRSP

Figure 7 shows that the pitch links are in phase with one another, but do not meet the secondary requirement that they are the same magnitude, a graph depicting this is shown in Figure 8.

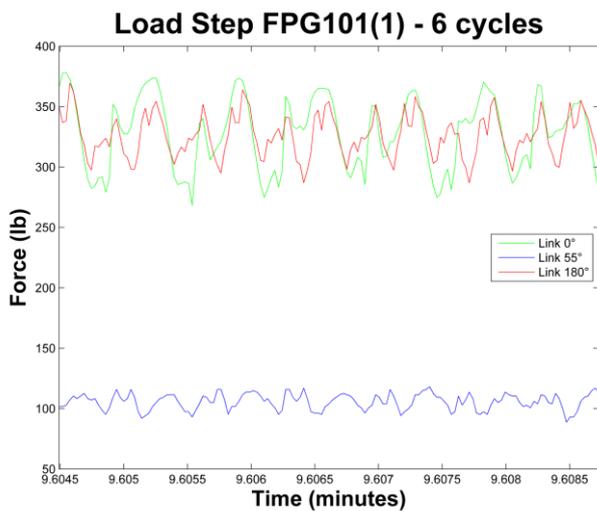


Fig 7. A graph of a load step showing phasing of the pitch links

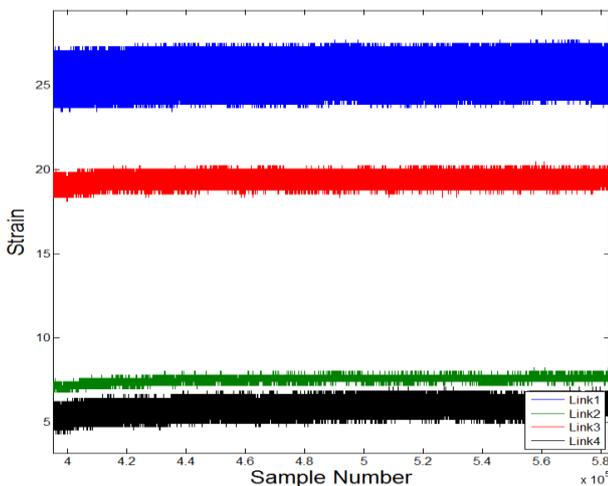


Fig 8. An example of four pitch link values during a run

Since there is a difference in the strain reading, it is likely that this swashplate is faulted. Current tests on another tail rotor swashplate will compare results from both faulted and non-faulted articles. If the difference in expected and experimental strain persists there are two possibilities: either there is an outside factor on the test stand causing this variation in load or this variation is a result of swashplate construction.

#### IV. CONCLUSION

The creation of both tail rotor and main rotor swashplates has allowed USC to investigate possible field failures and explore new approaches to identifying condition indicators. Information obtained from the test stands promises to yield benefits during use in the field. These outcomes will be achieved by continuing to gather and analyzing data from multiple sensor types including accelerometers, thermocouples, and strain gauges. The test stands will also be used to develop future monitoring systems that do not diagnose a particular fault, but rather notify the maintainers whenever the condition is changing or abnormal [11]. Introducing new sensor such as strain gauges into the system not only allows verification that the load being experienced by the test stand swashplate is similar to the actual aircraft but may also prove to be an effective condition indicator (CI), allowing maintainers and engineers to rely on more than just accelerometers for condition-based maintenance data.

The University of South Carolina is a pioneer in rotorcraft testing because of the ability to adapt to different aircraft and sensor configurations. The unique design of the TRDT stand and MRSP allows components from a range of rotorcraft, small to very large, to be tested with only minor modifications to the test stands. In addition to testing different types of articles, an over speed condition can be applied on the main rotor stand and an over torque condition on the tail rotor stand to simulate extreme conditions the air craft may undergo during flight. Examples of new sensor technology are wireless strain gauges on the TRSP stand and sound recordings of the MRSP stand. By using advanced data collection methods signals from the stand's sensors can be combined to get the most efficiency out of the information possible, eliminating any surplus data. As a result of testing and data analysis, the goal is to reduce maintenance costs by eliminating unwarranted component change outs, and increase the readiness the fleet by reducing the amount time spent on unnecessary aircraft maintenance. These new additions to the stand will provide beneficial data that can be used for refinement of condition indicators for the furthering of condition-based maintenance goals.

#### V. ACKNOWLEDGMENTS

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