SPACE SHUTTLE BODY FLAP ACTUATOR BEARING TESTING FOR NASA RETURN TO FLIGHT

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ABSTRACT

The Space Shuttle body flap is located beneath the main engine nozzles and is required for proper aerodynamic control during orbital descent. Routine inspection of one of four body flap actuators found one of the actuator bearings had degraded and blackened balls. A test program was initiated to demonstrate that it is acceptable to operate bearings which are degraded from operation over several flights. This test exposed the bearing to predicted flight axial loads, speeds and temperatures. Testing at 140 F has been completed, and results indicate the previously flown bearings are acceptable for up to 12 additional missions. Additional testing is underway to determine the lubricant life at various temperatures and stresses and to further understand the mechanism that caused the blacken balls. Initial results of this testing indicates that bearing life is shorten at room temperature possibly due fact that higher temperature (140F) accelerates the flow of grease and oil into the wear surface

INTRODUCTION

The body flap (BF) supports control during critical descent maneuvers of NASA's Space Shuttle orbiter. Four hydraulic actuators on a common shaft control the operation of this body flap. During routine inspection of these actuators, one of the input shaft bearings was discovered to have blackened balls (See Figure 1) the actuator had completed approximately 20 missions and also exhibited minor corrosion and plastic deformation from disassembly. It was deemed unacceptable for service and was replaced and the used grease was discarded. A destructive analysis was performed on this bearing. SEM examination revealed that the balls were worn and pitted and micro-hardness measurements indicated no softening at the surface. Metallographic examination revealed the proper microstructure for this alloy (52100) and heat treatment. It was concluded that mild mechanical wear caused the blackening.

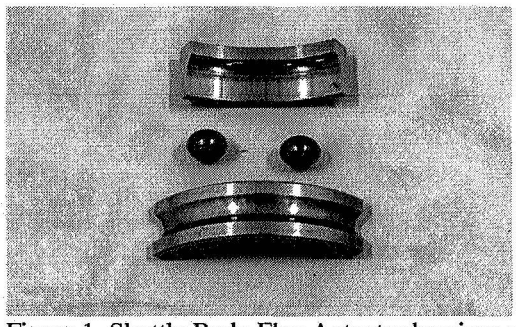

Figure 1. Shuttle Body Flap Actuator bearings with Blacken Balls

Initial visual examinations of similar body flap shaft bearings reveal no blacken balls, so several of these bearings were re-lubricated and put back into service. Subsequent microscopic inspection and metrology of a similar bearing with non-blacken balls revealed significant wear and possible plastic deformation. Six additional shaft bearings were examined and measured.

To determine if bearings with similar damage are acceptable to re-fly, a bearing test program was initiated at the Marshall Space Flight Center. A test program to evaluate the bearing life of re-lubricated, previously flown Body Flap Shaft bearings was started. A bearing test rig was design and built. A series of bearing life tests that simulated the load, speed, temperature and times in Shuttle mission were ran.

Metrology of Flight Bearings

During the refurbishment of body flap actuators, eight shaft bearings were replaced and evaluated both visually and for wear. Wear was measured using a form-talysurf measurement machine. Microscopic examination and wear depth results for these bearings are reported in Table 2. The bearings had mild surface distress but no spalling. The bearings appeared to be highly loaded with ball tracks running near

the raceway shoulder. The balls had discoloration, superficial rust stains, and black complex oxide coatings. Metrology results show that Shuttle flights produced wear depths ranging up to 200 micro inches. The most damaged bearing was S/N V6M002. This bearing had 200 micro inches max wear on the inner race with evidence of plastic deformation in raceways.

Bearing Size	Bearing Serial Number	Number of Flights	Wear Depth Range (micro inch)	Microscopic Observations
106	V6M002	20	200	Mild discoloration
108	V6L009	20	90	Black complex oxide on balls and wear track
108	V89E006	19	90	Light gold color discoloration
108	V6L007	30	80	Superficial rust stains
108	V6L025	32	50	Slightly darken balls
106	V6M014	30	80	Moderate surface distress corrosion
106	V6L013	32	Wear debris build-up	Moderate surface distress, discoloration likely to lubricant degradation
106	V6L001	19	15	Ball banding and mild discoloration and balls and races

Table 1. Metrology of Shuttle Body Flap Actuator Bearings

Bearing Testing

A preexisting test rig (Figure 1) was adapted to conduct life tests on the body flap output shaft bearings (Size 106). The bearing tester supports an angular contact bearing on each end of the drive shaft. Axial load was applied to the bearing pair and shaft by the bearing tester. A drive pulley was attached to the middle of the drive shaft and was driven by a variable speed ac motor. The bearing housing temperature was controlled to 140F by circulating ethylene glycol through coolant passages in the bearing test housings. During testing, the bearing axial load, shaft rotational speed, motor amps, and temperature of bearing outer races were monitored and recorded.

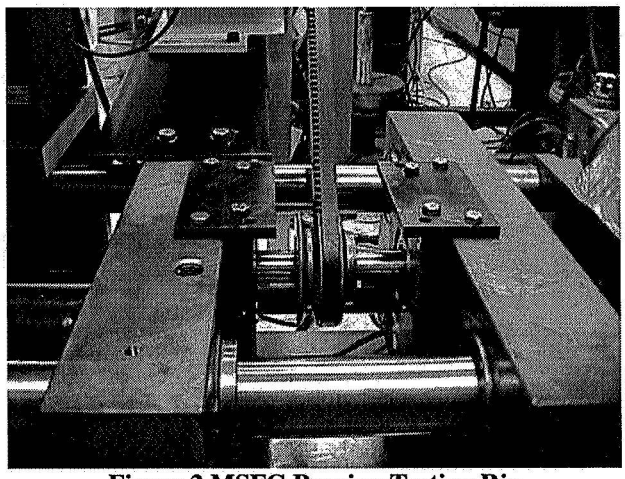

Figure 2 MSFC Bearing Testing Rig

The life test conditions for a single mission were derived from the flight load spectrum for the body flap actuator. The body flap qualification test load spectrum was made worst case to establish the single mission life test load profile for the body flap input shaft bearings shown in Table 1.

Cycle	Axial load (lbs)	Speed (rpm)	Time (minutes)	Temperature (F)
1	3500	80	27	140

2	4100	70	1.5	140
3	4400	60	1.0	140
4	5000	50	0.5	140

Table 2. Single Mission Load Profile

Test Results at 140 F

With a limited supply of post-flight bearings available, similar commercial bearings were procured with identical dimensions. Balls and cages were removed from the commercial bearings and 18 matched balls were added to make a full complement test bearings i.e. no ball separator. Because flight bearing S/N V6M002 had a maximum wear of 200 micro inches (Table 1), a commercial bearing was loaded to 6000 Pounds and operated for 10 minutes at 72 rpm to produce a "wear" scar similar to this worst case flight bearing. After this testing, the maximum "wear" scar on a test bearing (BF-003.Table 2) was 175 micro inches; almost 200 micro inches.

These damaged bearings ran a 48 mission life test. The bearings successfully completed this testing. During testing no evidence of degradation of bearing performance was observed. Post test inspection and metrology of the bearings showed moderate additional wear and damage to the bearing as shown in Table 3.

Test Serial Number	Max. Wear Depth during Flight Simulation (micro inch)	MSFC Life Test Number	Max. Wear after 48 mission life test
BF-001	25	LT002	100
BF-003	175	LT002	225

Table 3. Wear for 48 Missions of Life testing on commercial bearings

Two additional 48 mission life tests were performed on previous flown actual flight bearings. The results of this testing are shown in Table 4. Both tests were successfully completed. During the life testing, all bearings performed without anomalies and no evidence of torque increase was observed with increasing test time. In addition, no rise in bearing operating temperature was observed which also indicated no gross degradation in bearing performance.

Test Serial Number	Max wear 48 mission life test (micro inch)	MSFC Life Test Number
V6M014	80	LT003
V6L013	20	LT004
V6L001	Wear debris build up	LT004

Table 4. Flight Bearing Wear after a 48 Mission Life Testing

Post test inspection of these bearings showed additional wear, but evidence of fatigue spalls was not observed. One bearing showed plastic deformation similar to that observed in V6M002. The bearing balls showed significant banding indicating localized surface heating due to possible lubricant depletion. The races also showed evidence of discoloration (blue color) and deposits of a degraded lubrication film.

Conclusions

1. Three post-flight body flap output shaft bearings successfully completed the 48 mission life testing with no degradation in bearing performance, and with no significant increase in drive torque, and with moderate additional wear.
2. Two purposely damaged size 106 commercial output shaft bearings completed the 48 mission life testing successfully with no degradation in bearing performance, no increase in drive torque, and minimal wear increase.
3. Successful 48 mission life test of three post flight input shaft bearings and of two intentionally damaged commercial bearings indicate that previously flown Shuttle Body Flap bearings should operate successfully for at least 12 more Shuttle missions.

Test Results at 75 F

Addition testing is underway at 75 F. The initial results are shown of the testing is shown in Table 5.

Brg Number	Thrust Load (lbs)	Temperature (F)	Time to Failure (Hrs)	Failure Mode	Lube
BF015	**3500**	**140**	**65**	**Severe wear due lube failure plus fatigue spall**	**100 %**
BF011	**3500**	**75**	**11.3**	**Severe wear due lube failure**	**100 %**
BF012	**3500**	**75**	**19**	**Severe wear due lube failure**	**100 %**
BF013	**3500**	**75**	**26.3**	**Severe wear due lube failure**	**100 %**
BF009	**4500**	**75**	**16.9**	**Severe wear due lube failure**	**100 %**
BF010	**4500**	**75**	**16.9**	**Severe wear due lube failure**	**100 %**
BF008	**5000**	**75**	**12.8**	**Severe wear due lube failure**	**25 %**

Table 5. Bearing test results at 75 F