

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



CEN23LA232

POWERPLANTS

Group Chair's Factual Report - Attachment #3

Woodward Inc's Final Reports

January 8, 2024

CUSTOMER HONEYWELL ENGINES & SYSTEMS		INVESTIGATION NO 1193788	
CUSTOMER ORDER Crash Investigation	WOODWARD SALES ORDER 3907448	WOODWARD WORK ORDER C872180	
CUSTOMER REJECTION DOCUMENT (CAR, QN, RFA, DMR, ETC.) N/A	WARRANTY DISPOSITION N/A	PRODUCT STATUS N/A	
PROGRAM/ENGINE TYPE GARRETT		ITEM RECEIVED 8070-186	ENGINE MFR MODEL RECEIVED N/A
PROGRAM CODE 82228	SERIAL NUMBER 923051	ITEM SHIPPED 8070-186	ENGINE MFR MODEL SHIPPED 869199-25
PARENT ITEM NUMBER 8070-186	PARENT ITEM SERIAL NUMBER 923051	FIRST SHIPPED 20-DEC-1989	LAST SHIPPED 20-DEC-1989
CUSTOMER SERIAL NUMBER N/A	APPLICATION N/A	VESSEL TYPE & VESSEL NUMBER Grumman G-164B, N48485	SITE & LOCATION GRID ID N/A
TIME/CYCLES SINCE NEW, OVERHAUL, OR REPAIR N/A			
DATE REPORT OPENED 08-DEC-2023		DATE PART REMOVED N/A	DATE RECEIVED 05-DEC-2023

TEAM MEMBERS (D1)

Product Engineer: [REDACTED]
 Customer QA Engineer: [REDACTED]
 Tech Advisor/Reviewer: [REDACTED]
 Customer Account Manager: [REDACTED]
 Customer Service Rep: [REDACTED]
 Compliance: [REDACTED]
 Product Integrity Coordinator: [REDACTED]

REASON FOR INVESTIGATION (D2)

Reported Issue: On June 7, 2023, about 1330 central daylight time, a Grumman G-164B airplane, N48485 was substantially damaged when it was involved in an accident near Bloomfield, Nebraska. The pilot was not injured. The airplane was operated as a Title 14 Code of Federal Regulations Part 137 aerial application flight. The pilot reported a loss of engine power during takeoff. He executed a forced landing to an agricultural field off the end of the runway. The airplane sustained damage to the upper and lower right wings.

INVESTIGATION SUMMARY (D4)

Confirmation Text: NOT KNOWN IF REASON FOR INVESTIGATION/RETURN IS CAUSED BY DISCREPANCY FOUND
 Discrepant Item Number: 8070-186
 Discrepancy: PART IS DAMAGED
 Finding: SEIZED OR STUCK
 Conclusion:

S/N 923051 was last shipped from Woodward as model 8070-186 in December 1989. The presence of non-Woodward lockwire indicates that the unit was serviced at another facility since it was last shipped from Woodward. The unit was returned with customer fittings, power lever and speed setting lever linkages, and pressurizing valve assembly still installed. The customer hardware was removed and a visual as-received inspection was performed.

Minor damage was observed on the housing near the Tt2 sensor port and the Pt2 shaft loading cap. The inlet filter and the transfer tube that interfaces with the pump were missing. The power lever and speed setting lever were free to rotate normally. The drive shaft had some friction to rotate but could be turned by hand.

A slave inlet filter and transfer tube were installed and the unit was tested per the applicable TSP. Several test points were out of limits on the Standard Day Acceleration schedule. The start flows were out of limits at 60 pph (Limits: [REDACTED]). This would not contribute to the reported problem. There were two points at Ps3 set conditions of 45 and 65 psia that were low out of limits by 6-7%. Three test points at Ps3 set conditions of 105, 116, and 130 psia were high out of limits up to 17%. On the Standard Day Accel test points with the highest Ps3 set conditions and highest discharge flows, it was observed that the P1-P2 pressure increased with increasing Ps3, up to approximately 100 psid. Normal P1-P2 pressure when the bypass valve is in regulation is approximately 40 to 45 psid.

The start flow on the 15,000 Foot Accel schedule was out low at 36 pph (Limits: [REDACTED]). All other test points on the 15,000 Foot and 30,000 Foot Accel schedules were within limits.

The Hot Day Accel schedule had one test point (Ps3 set condition of 55 psia) that was low by 5% and one test point (Ps3 set condition of 116 psia) that was high out of limits by 16.8%. The Cold Day Accel schedule had two test points (Ps3 set conditions of 45 and 75 psia) that were low by up to 5% and two test points (Ps3 set conditions of 105 and 116 psia) that were high out of limits by up to 18%.

High discharge flow on the Accel schedules would not contribute to the reported loss of power. The lower Ps3 set points (45 to 75 psia) on the Accel schedules correspond to approximate speeds of 62% to 76%. Lean discharge flow at these conditions would not contribute to the reported loss of power at takeoff.

The Underspeed Governor 65% Speed schedule had rich fuel flow of 137 pph (Limits: [REDACTED]). To achieve the required fuel flow the control had to be run at 65.9% speed. The Underspeed Governor 97% Speed schedule had lean fuel flow 153 pph (Limits: [REDACTED] pph). To achieve the required fuel flow the control had to be run at 96.7% speed. The Overspeed Governor had lean fuel flow at both 103.5% speed and 105.8% speed. AT 103.5% speed the fuel flow was 184 pph (Limits: [REDACTED]). At 105.8% speed the fuel flow was 100 pph (Limits: [REDACTED]). The Decel schedule had one test point low out of limits by 5%. These minor out of tolerance conditions are not considered significant.

The majority of test points on the Power Lever schedules were out of limits. The standard day Max Power setting was 383 pph (Limits: 450 to 470 pph) and the standard day Flight Idle setting was 127 pph (Limits: [REDACTED]). It was noted that the lockwire seal was intact on the Max Power adjustment but was missing from the Flight Idle adjustment. Fuel flow responded as expected to changes in Tt2 set conditions but did not respond as expected to changes in Pt2 pressure. On the Pt2 Correction schedule the Max Power setting was low out of limits at Pt2 pressure of 14.7 psia but high out of limits at 4.4 and 8.8 psia. Fuel flow should change proportionately to the change in Pt2 pressure. The Flight Idle setting was in limits at Pt2 pressure of 8.8 psia but low out of limits at 14.7 psia and fuel flow did not change when Pt2 was increased to 17.6 psia.

After completing the ATP, the high Ps3 test points on the Standard Day Accel schedule were rerun to further investigate the high discharge flows and P1-P2 pressures. The discharge flows closely matched the recorded values and the P1-P2 behavior was similar to that observed during the initial run. The test stand needle valve was adjusted to increase Pn pressure but this did not have a significant effect on discharge flow or P1-P2. Discharge flow and P1-P2 appeared to be most sensitive to changes in Ps3 pressure which is the primary input to the Accel schedules.

Select test points on the power lever schedule were also retested to investigate the low discharge flows and abnormal response to changes in Pt2 pressure. The standard day Max Power test point was set up and Pt2 pressure was increased to identify how much of a Pt2 bias was required to bring fuel flow up to nominal. No change in fuel flow was observed when increasing Pt2 pressure. An indicator was then installed to follow the axial movement of the inner 3D cam shaft, which moves axially with Pt2 pressure. The indicator moved as expected between Pt2 values of 4 and 11 psia but showed no movement above 11 psia.

The unit was then disassembled. The Pt2 bellows was removed and appeared to be in good condition. The Pt2 amplifier servo was removed so that the 3D cam shaft assembly could be accessed. The cam shaft assembly consists of two concentric shafts. The 3D cam is attached to both shafts with a pin. The outer shaft rotates with Ps3 pressure and the inner shaft moves axially with Pt2 pressure (see Figures 1 and 2). It was noted that the inner shaft could not be pushed by hand.

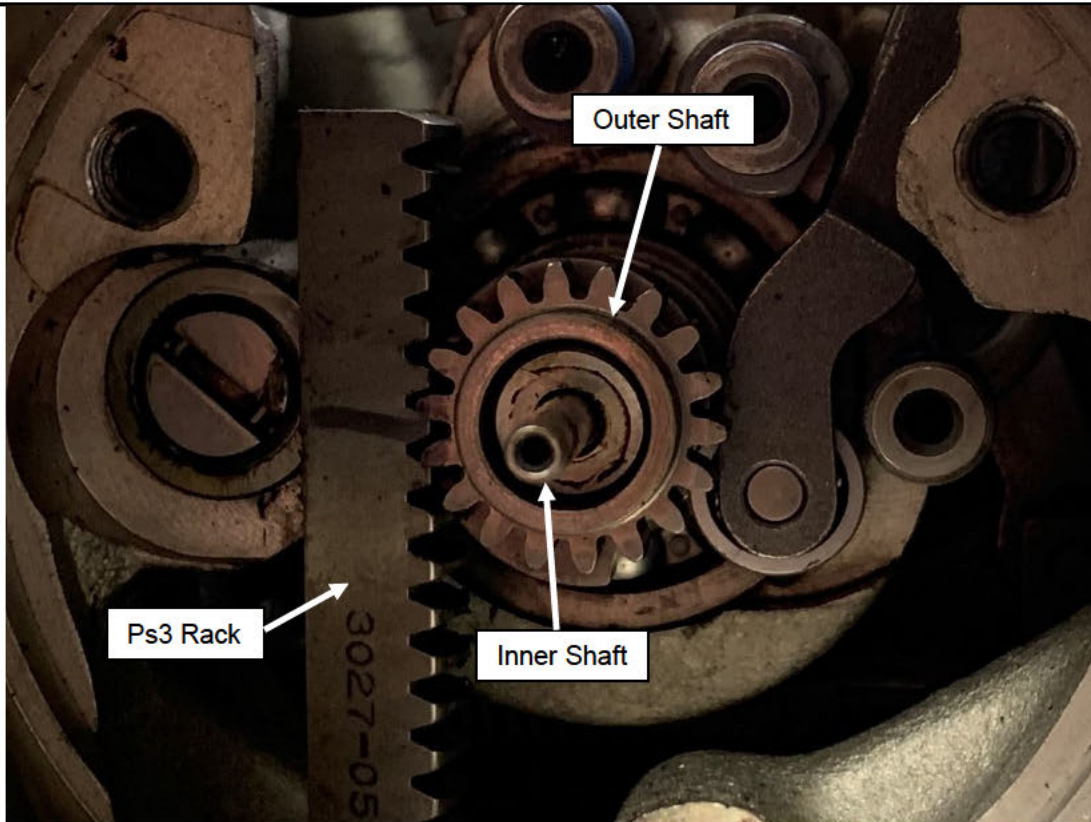


Figure 1. Cam shaft assembly viewed from Pt2 bellows bore with Pt2 amplifier servo removed

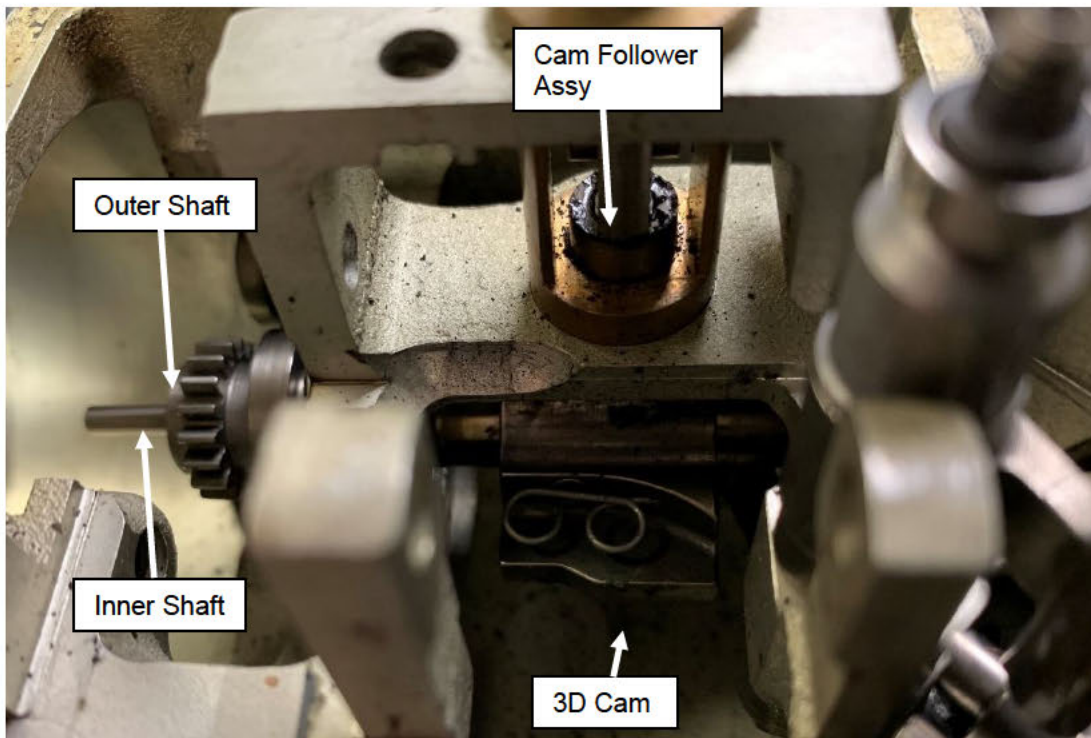


Figure 2. Cam shaft assembly viewed from cover with linkage assembly removed

Further disassembly was then performed to allow the cam shaft assembly to be removed. No abnormal damage or wear was noted during the disassembly. The 3D cam must be disassembled from the cam shaft in order to remove the cam shaft from the housing. The cam could not be pulled off the cam shaft with normal force. After team discussion it was decided to machine the housing to extract the shaft assembly instead of applying extra force to remove the cam from the shaft. The housing was machined and the cam shaft was removed with the cam seized in place.

The axial position of the 3D cam relative to the cam shaft was measured and a stackup was performed to calculate the corresponding Pt2 pressure. The Pt2 pressure was calculated to be 15.2 psia based on the measured cam position. This does not correspond to the observed cam position during as-received testing. It is believed that the cam was driven into this position by the loading spring during disassembly. During normal operation the axial position of the 3D cam is set by the Pt2 bellows assembly. The Pt2 bellows expands or contracts based on Pt2 pressure and this movement is transferred to the Pt2 amplifier servo by a metering pin in the bellows. The Pt2 amplifier servo hydraulically amplifies the movement of the metering pin to move the inner cam shaft. The loading spring provides a force to keep the inner cam shaft loaded against the Pt2 amplifier servo piston. When fluid pressure is removed from the control the inner cam shaft is pushed by the loading spring in the increasing Pt2 direction until the Pt2 amplifier servo piston is stopped by the metering pin in the bellows. During disassembly, once the Pt2 bellows is removed the inner cam shaft can then be pushed further in the increasing Pt2 direction. Therefore the seized position of the cam after disassembly does not correspond to its position during as-received testing.

The cam shaft assembly was sent to the NTSB for materials analysis (report # CEN23LA232). The assembly was visually inspected and photographed prior to any disassembly. The assembly consisted of the cam shaft, 3D cam, bearing, and a remnant of the housing (see Figure 3). The housing remnant was sectioned and removed along with the shim that was installed between the bearing and housing (see Figure 4). Compounds exhibiting a dull black and yellowish-orange color were observed between the cam and shaft. The compounds were extracted and collected for analysis. The assembly was then cleaned with acetone in an ultrasonic bath. Inspection under magnification found evidence of deformation and damage on the shaft and the bushing inside the cam where the bushing inner surface was in contact with the cam shaft.



Figure 3. Cam shaft assembly sent to NTSB

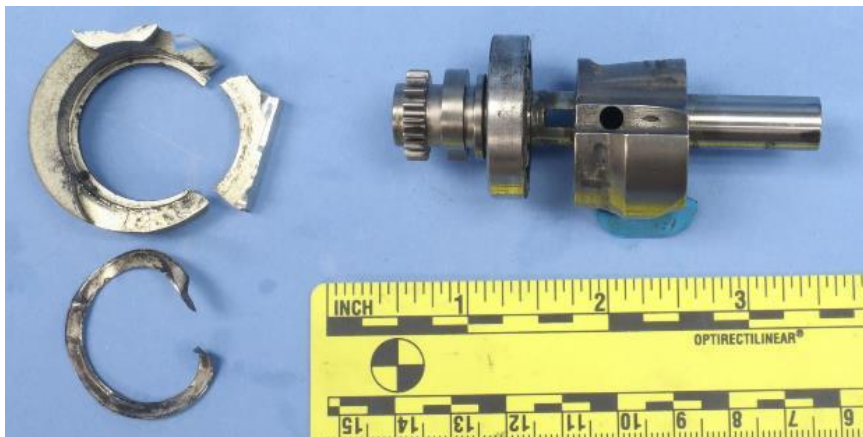


Figure 4. Cam shaft assembly after removal of housing remnant

The cam shaft was then sectioned between the bearing and the cam. Once sectioned, the cam readily slid off the shaft. The shaft was cleaned in an ultrasonic bath of acetone and the areas of damage were inspected. There were two areas of damage identified on the shaft, one on the edge of each slot. The damaged areas both exhibited an indentation at the slot face which were found to align with each other axially (see Figures 5 and 6). The damage on the slot identified as Slot 1 had a circular indentation pattern. The diameter fitted to this indent was approximately 0.14 inches (see Figure 7). The damage on the slot identified as Slot 2 had an impression that was angled and flat with an interior distance of 0.094 inches (see Figure 8).

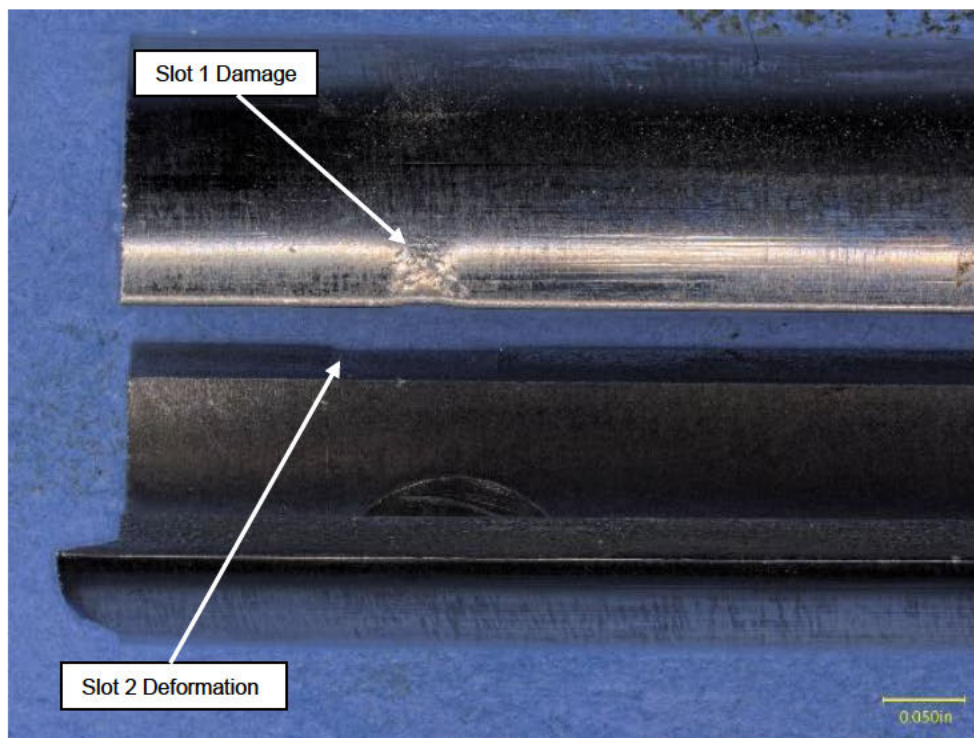


Figure 5. Damage on cam shaft viewed from Slot 1

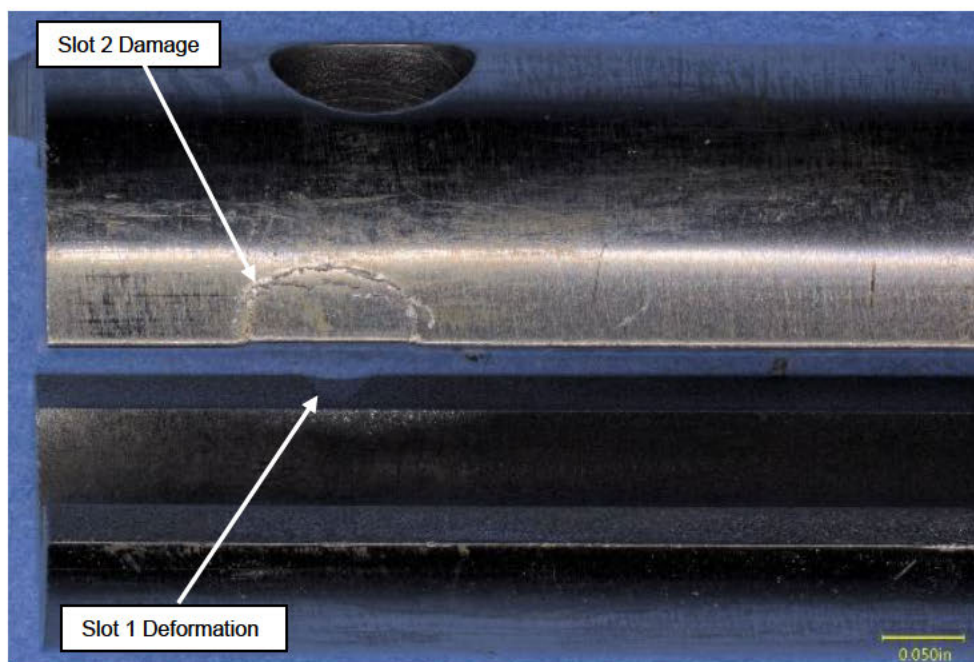


Figure 6. Damage on cam shaft viewed from Slot 2

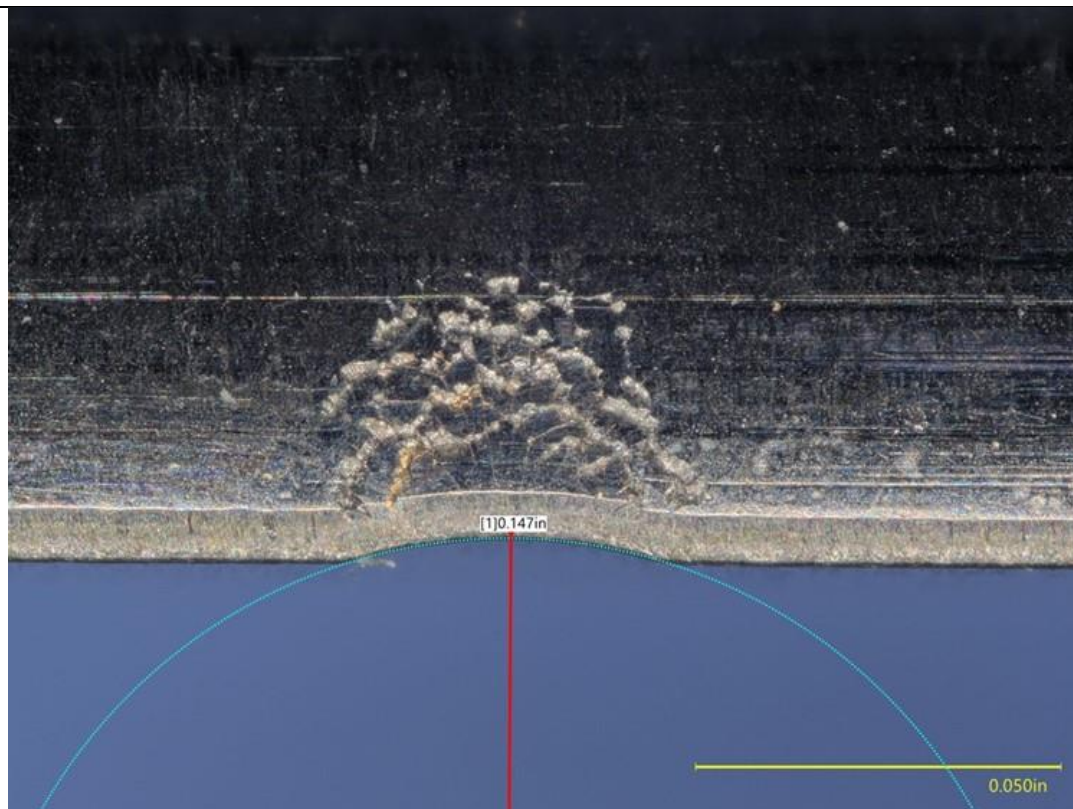


Figure 7. Damage on Slot 1

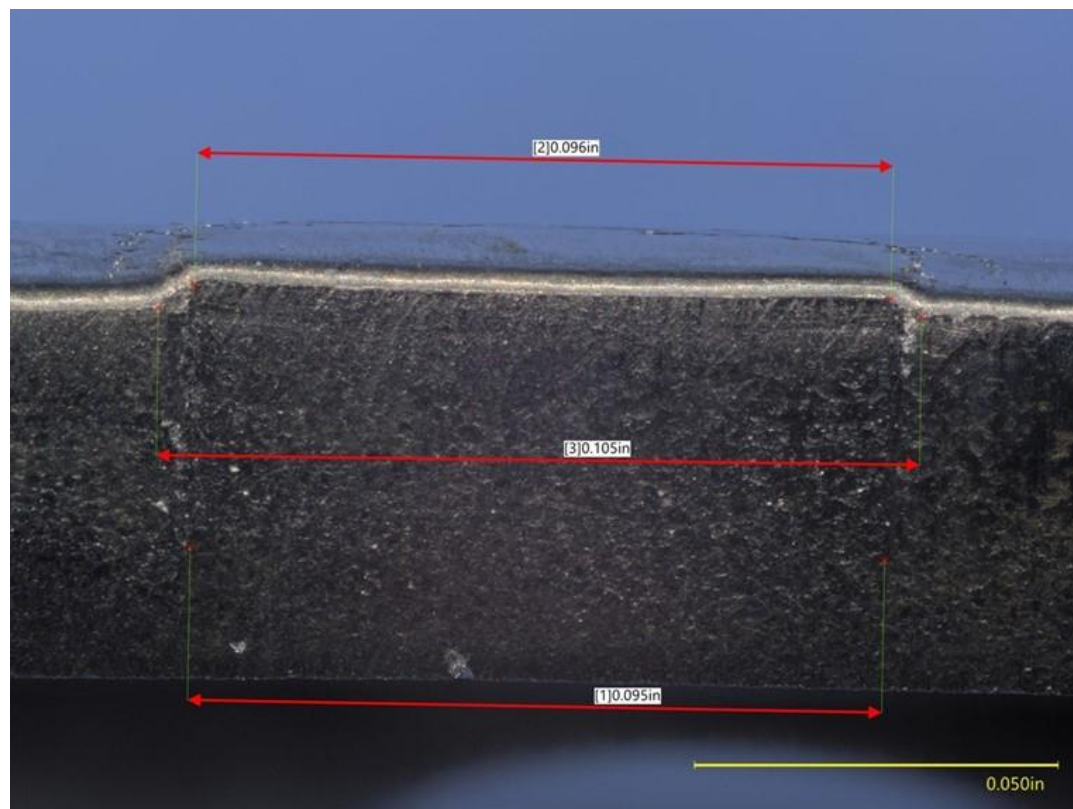


Figure 8. Damage on Slot 2

The shaft was examined using a SEM, which confirmed cracking pattern and localized areas of spalled material consistent with cleavage fracture. This type of fracture on this material is consistent with the higher hardness and lower ductility properties typical of a nitride surface. Examination using EDS found material composition consistent with 17-4 precipitation-hardened stainless steel and nitrogen content typical of nitriding processes. Some of the spalled areas contained material with a higher atomic number. This material was found to have a composition consistent with C660 copper alloy that is prescribed for the mating bushing.

The bushing exhibited longitudinal witness marks consistent with the dimensions of the slots in the mating camshaft. Outward deformation of the edge of the bushing coincided with the most pronounced longitudinal wear marks (see Figure 9).



Figure 9. Witness marks on ID of cam bushing

The bearing removed from the shaft was inspected and no abnormal damage or wear was observed. The bearing was able to rotate freely. All material collected from the bearing, shaft, and bushing surfaces was analyzed using FTIR and found to be consistent with Aeroshell 17 grease.

The 3D cam pin, 3D cam follower, and Ps3 rack, previously disassembled at Woodward, were then examined closely for any damage related to the findings from the NTSB Materials Lab inspection. The 3D cam pin is installed through the cam and through the slots in the cam shaft such that the cam will rotate with the shaft but can move axially within the slot. The 3D cam pin has two diameters and an area with four machined flats (see Figure 10). When assembled the smaller pin diameter is installed through the slot identified as Slot 1 and the area with four machined flats is installed in Slot 2. Damage was observed on the corners of the flats and the width of the flat was found to match the measured width of the deformation in Slot 2. No significant damage was observed on the smaller pin diameter. The pin diameter is 0.124 inches which is similar to the deformation measured in Slot 1.

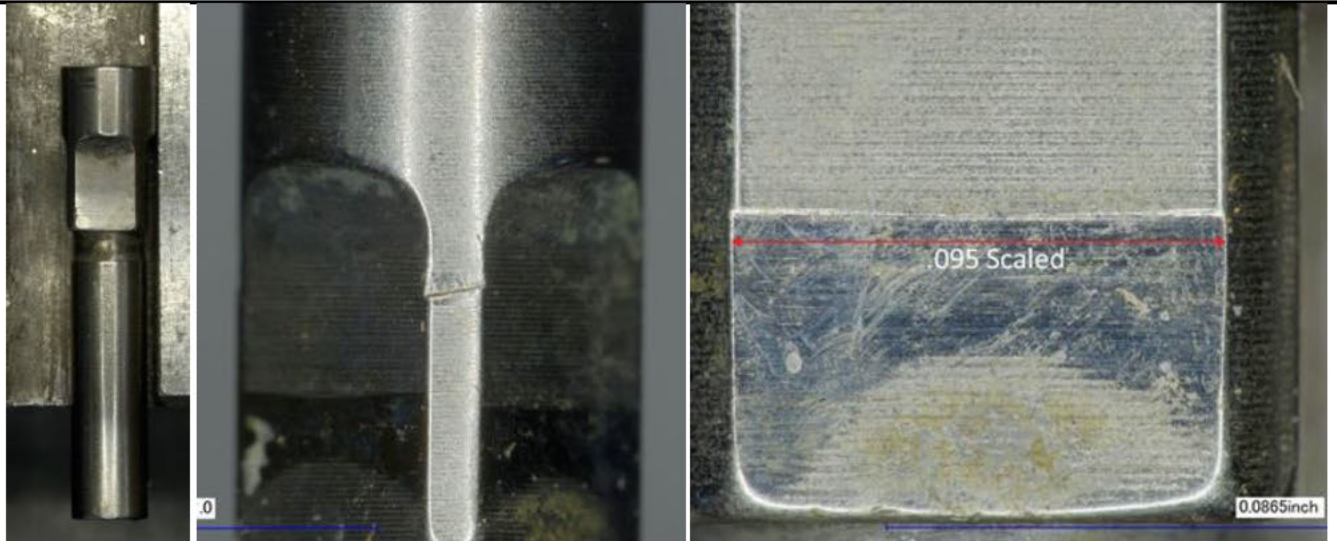


Figure 10. Damage on 3D cam pin

The cam follower assembly was visually inspected under magnification and a flat spot was observed on one of the threads of the cam follow adjuster (see Figure 11). The deformation on the thread is consistent with side loading of the adjuster.



Figure 11. Damage on cam follower thread

Visual inspection of the Ps3 rack found one tooth with damage and deformation (see Figure 12). The deformation was on the face of the tooth consistent with a high load in the increasing Ps3 direction.

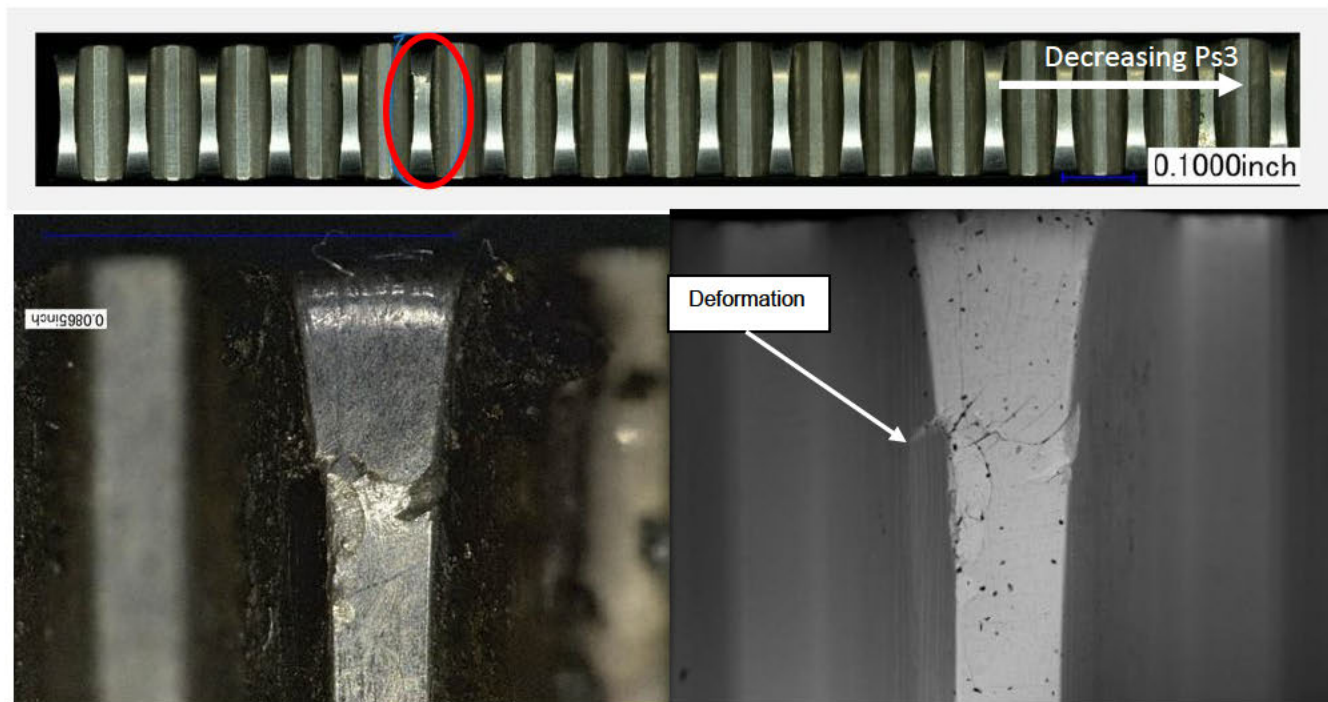


Figure 12. Damage and deformation on tooth of Ps3 rack

The damage observed on the cam shaft, pin, cam follower adjuster, and Ps3 rack tooth is consistent with side loading of the 3D cam against the cam follower assembly. One scenario that can cause this kind of damage is if Ps3 pressure is increased beyond the normal range and the 3D cam rotates such that the cam follower leaves the active cam surface. Since the cam follower is spring loaded against the cam surface, if the cam rotates too far in the increasing Ps3 direction the cam follower will drop down and be loaded against the inactive surface of the cam (see Figure 13). When Ps3 is decreased the inactive face of the cam will load against the cam follower. This is most likely to occur during assembly bench setting or during test calibration when the main cover is not installed since the cover includes a stop screw to limit the travel of the Ps3 rack in the increasing direction. However the damage observed on the cam shaft corresponds to side loading in the increasing Ps3 direction and therefore cannot be explained by this scenario.

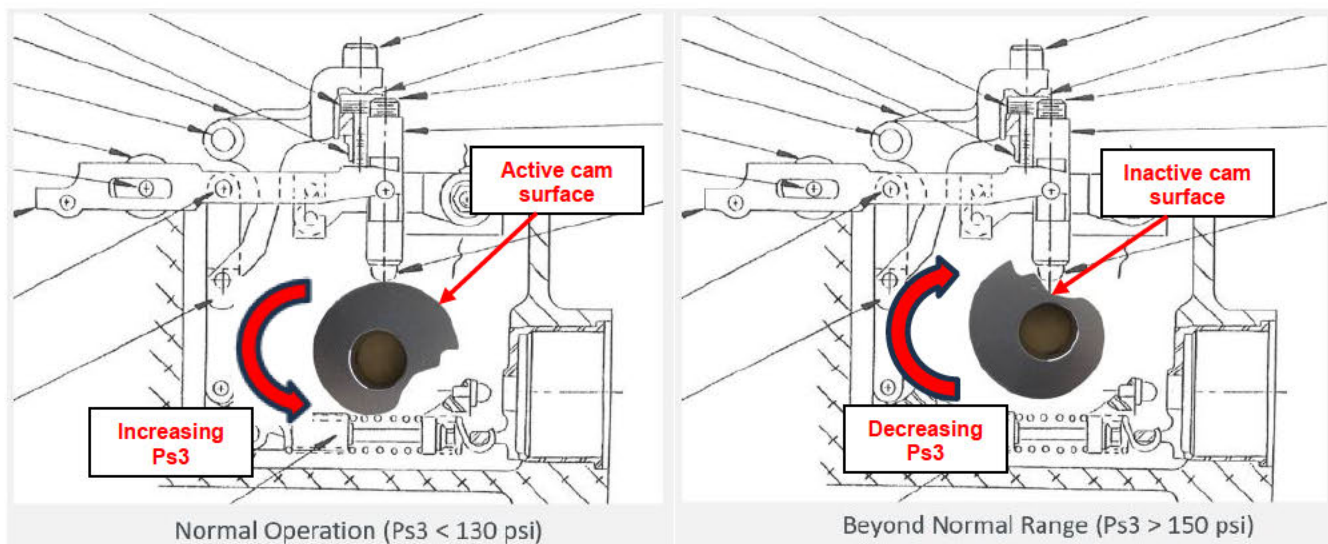


Figure 13. Illustration of rotating the 3D cam beyond its normal range

The most likely scenario to explain side loading in the increasing Ps3 direction is that the 3D cam was installed incorrectly during assembly. If the cam was installed on the cam shaft with the incorrect orientation then the normal rotation of the cam shaft in the increasing Ps3 direction would result in side loading the inactive cam face against the cam follower. This would likely be caught during assembly bench settings and the unit could not be calibrated in this configuration.

ROOT CAUSE (D4)

Origin of Cause: OTHER

General Cause: PRODUCT ISSUE

Cause: Other

Root Cause:

It is not known by Woodward if the low discharge flows on the standard day power lever schedules would cause the reported problem. The low flows on the power lever schedule were caused by binding of the 3D cam on the cam shaft, which prevented axial movement of the cam for Pt2 pressures above 11 psia. Binding of the 3D cam on the cam shaft was a result of damage and deformation on the slots of the cam shaft. Root cause for the damage could not be conclusively identified but the most likely cause is side loading due to mis-assembly of the 3D cam on the cam shaft. The unit was last shipped from Woodward in 1989 and has been serviced at another facility since that time therefore it is not believed that the damage was caused by Woodward.

CORRECTIVE ACTION PLAN (D5)

General Corrective Action: CUSTOMER INTERACTION

Specific Corrective Action: OTHER

Corrective Action:

The discrepancy found was not a result of a Woodward action. It is the responsibility of the customer to determine the cause and the appropriate corrective action to resolve the issue.

CUSTOMER HONEYWELL ENGINES & SYSTEMS			INVESTIGATION NO 1193831
CUSTOMER ORDER Crash Investigation		WOODWARD SALES ORDER 3907447	WOODWARD WORK ORDER C872179
CUSTOMER REJECTION DOCUMENT (CAR,QN RFA DMR,ETC.) N/A		WARRANTY DISPOSITION N/A	PRODUCT STATUS 1 RCVD
PROGRAM/ENGINE TYPE GARRETT SMALL PROP GOVERNOR		ITEM RECEIVED 210736	ENGINE MFR. MODEL RECEIVED N/A
PROGRAM CODE 83344 SML	SERIAL NUMBER 1113178	ITEM SHIPPED 210736	ENGINE MFR. MODEL SHIPPED 869120-9
PARENT ITEM NUMBER 210736	PARENT ITEM SERIAL NUMBER 1113178	FIRST SHIPPED 13-JUL-1999	LAST SHIPPED 28-FEB-2001
CUSTOMER SERIAL NUMBER N/A	APPLICATION N/A	VESSEL TYPE & VESSEL NUMBER N/A N/A	SITE & LOCATION GRID ID N/A N/A
TIME/CYCLES SINCE NEW, OVERHAUL, OR REPAIR			
DATE REPORT OPENED 21-DEC-2023		DATE PART REMOVED N/A	DATE RECEIVED 05-DEC-2023
TEAM MEMBERS (D1)			
Product Engineer: [REDACTED]		Customer Account Manager: [REDACTED]	
Customer QA Engineer: [REDACTED]		Customer Service Rep: [REDACTED]	
Tech Advisor/Reviewer: [REDACTED]		Product Integrity Coordinator: [REDACTED]	
REASON FOR INVESTIGATION (D2)			
Reported Issue: HONEYWELL CONTACT: [REDACTED], PRODUCT INTEGRITY/CONSULTING AIR SAFETY INVESTIGATOR On June 7, 2023, about 1330 central daylight time, a Grumman G-164B airplane, N48485 was substantially damaged when it was involved in an accident near Bloomfield, Nebraska. The pilot was not injured. The airplane was operated as a Title 14 Code of Federal Regulations Part 137 aerial application flight. The pilot reported a loss of engine power during takeoff. He executed a forced landing to an agricultural field off the end of the runway. The airplane sustained damage to the upper and lower right wings.			
CONTAINMENT/IMMEDIATE ACTIONS (D3)			
INVESTIGATION SUMMARY (D4)			
Confirmation Text: DID NOT CONFIRM REASON FOR INVESTIGATION/RETURN Discrepant Item Number: NA Discrepancy: No Discrepancy Found Finding: No Findings Conclusion: The unit was received and an as received visual inspection was conducted. During the inspection it was determined the max speed lever and connecting hardware were customer hardware. There were no other findings that would have prevented running an As Received Test. After the visual assessment, the unit was as received tested. All test points were found within limits except the following. "Maximum RPM" was out of limits high at 3865 rpm (Limits: [REDACTED]) "Minimum RPM" was out of limits high at 3560 rpm (Limits: [REDACTED]) "Arm Travel - Max to Min" was out of limits low at 20 degrees (Limits: [REDACTED]) The Max RPM, Min RPM, & Arm Travel test points are common field adjustments and the presence of non-Woodward lockwire indicate an adjustment was performed in the field. In summary, the unit had evidence of being adjusted in the field resulting in the out of tolerance conditions during testing. Even though there were a few test points outside of limits they would not have precluded normal governor operation.			
ROOT CAUSE (D4)			
Origin of Cause: FIELD / END CUSTOMER (OWNER) General Cause: No Problem Found Cause: No Problem Found or Identified Cause Notes:			
CORRECTIVE ACTION PLAN (D5)			

Specific Corrective Action: No Direct Action, Continue to Monitor
Corrective Action:

CORRECTIVE ACTION IMPLEMENTATION (D6)

Corrective Action Status: NO ACTION