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LOT B BATTLESHIP

FAILURE INVESTIGATION REPORT (U)

3 March 1959

DATE OF INCIDENT: 26 Februar
1635 Hours

PLACE OF INCIDENT: Martin-Den
Test Stand

CLASSIFICATION CANCELLED, OR CHANGED
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LOT B BATTLESHIP

FAILURE INVESTIGATION REPORT (U)

3 March 1959

DATE OF INCIDENT: 26 February 1959
1635 Hours

PLACE OF INCIDENT: Martin-Denver
Test Stand D-1

OR CHANGED

DEVELOPMENT TEST ARTICLES: Battleship Tanks BF II (B) 4
Stage II Aerojet Engine
S/N-AJE-00203

840FB
762AC
684TC

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INDEX

I. AUTHORITY

An investigating board was appointed on 27 February 1959, by the Martin Company, Denver Division (Attachment 1) and by the Air Force Plant Representative, Martin Company, Denver Division, Colorado, under the authority granted in Air Force Regulation 62-14, to determine the damage and cause of the emergency generated on Test Stand D-1 during Run D-1-1/2-B-BF-17. Composition of the investigating board is shown in Attachment 2.

II. FACTS AND NARRATIVE

An Aerojet Stage II research and development engine, serial number AJE-00203, battleship tanks BFII(B)4 and associated hardware were exposed to a series of explosions and a sustained fire during run D-1-1/2-B-BF-17 on Test Stand D-1 on 26 February 1959, at 1635 hours. The test followed the completion of the scheduled pre-requisite program for the Lot B Captive program and as such therefore, was the third scheduled full duration sequenced firing of the Stage I and Stage II Titan engines. The test was being performed by the members of the normal D-1 test stand firing crew listed in Attachment 3.

As authorized by Test Directive #D-1-1/2-B-BF-17 (Attachment 4) Stage I engine AJE-00103 and Stage II engine AJE-00203, battleship tanks BFI(B)3 and BFII(B)4 were to undergo propulsion system development tests which called for a full duration sequenced firing on each of the engine assemblies. This run had previously been attempted on the evening of 25 February 1959, but was subsequently aborted early in the countdown when trouble was encountered with the lox fill control system and the run was rescheduled for 26 February 1959.

At 1207 hours on 26 February 1959, the countdown as shown in Attachment 5 was initiated at T-95 minutes. Other than the holds shown in Attachment 6, the count proceeded normally in accordance with the procedures found in the same attachment. Fire/switch one ($87FS_1$) for the Stage I engine occurred at 1639 hours and 25 seconds and at T+127.2 seconds the engine shutdown ($87FS_2$) was initiated by a scheduled actuation of a thrust chamber pressure switch. The shutdown of the Stage I engine was normal. At T+120.0 seconds, the Stage II gas generator fire switch signal ($GGFS_1$) was initiated and the gas generator and auxiliary pump drive assembly (APDA) were started with nominal performance data. At T+130.00 seconds the Stage II thrust chamber fire switch ($91FS_1$) was generated by the staging timer and thrust chamber ignition occurred. At 1.45 seconds later an explosion occurred in the Stage II engine compartment. The source of this explosion was later determined to be the lox side of the Pump Drive Assembly (PDA) and had been caused by a high reverse pressure surge when the thrust chamber valves downstream closed.

The impact of the initial explosion and the impact of flying fragments probably destroyed the action of the lox and fuel prevalves almost immediately and ruptured both propellant systems which allowed the initial fire to be fed by both lox and fuel. All available means of fire fighting were activated from the blockhouse and included CO_2, thrust chamber spray, engine deluge, missile washdown and firex. Commands were given to open propellant tank vents and close the propellant prevalves.

Damage to airborne and ground support equipment hardware was as follows: The Stage II engine was destroyed and ground support equipment, instrumentation, cameras flight control hardware in and around the engine compartment were damaged or destroyed.

No personnel casualties or injuries were sustained and damage to the stand was of a minor nature. No operating test crew errors were experienced.

Photographs of the damage area are contained in Attachment 7.

III. DISCUSSION OF RESULTS

A. Summary

An analysis of available test data and a detailed investigation of the Stage II engine hardware indicated that a major rupture occurred in the lox Pump of the Pump Drive Assembly at 1.45 seconds after thrust chamber ignition causing heavy lox leakage and a subsequent series of explosions and fire. Owing to the shattered and burned condition of most of the engine hardware and the fact that the high speed camera compartment coverage was lost due to the fire, correlation with recorded data was difficult. However, it has been established that the closing of the thrust chamber valves caused a high pressure fluid surge back through the lox system to the Pump Drive Assembly causing the subsequent rupture, explosion and fire.

The remaining portion of this section contains the detailed discussion of failure analysis and damage assessment investigations.

B. Program Aspect

Attachment 7 contains preliminary consideration of the impact of the accident upon the Lot B Captive program. As noted therein, no program or schedule interference will be encountered. Spare tanks, currently available, will be mounted for tandem environmental testing program of the Stage II engine, including degreasing and operational check, following which test the stand will be converted to the CET (Calibrated Engine Test) program on schedule.

C. Data and Failure Analysis

1. Analysis Summary

The Stage II engine as schematically described in Attachment 9 had experienced a normal gas generator starting sequence and the thrust chamber had reached 75% of rated operating pressure when the Thrust Chamber Valves closed prematurely. The turbine pump assembly continued to operate at high output and the resulting high pressure surges ruptured the high pressure lox pump discharge volutes. The propellant tanks drained completely through the severed lines supplying fuel and oxygen for the ensuing fire.

The cause of the Thrust Chamber Valve closure has been reduced to two possibilities from available data and hardware inspection at this time.

a. Mechanical failure of the Thrust Chamber Valve Pressure Sequencing Valve control system causing hydraulic leakage which initiated an apparent overried shutdown. The pressure sequencing valve has been returned to Aerojet-General for further testing.

b. A high "g" load on the Thrust Chamber Valve control system causing the Pressure Sequencing Valve to shuttle to a closed position.

Apparently, either of the above malfunctions initiated a partial shutdown sequence in which thrust chamber operation was terminated while turbo-pump operation continued until destruction.

A listing of the run time sequence for governing features of engine operation appears in Attachment 10 and engine operating run parameters appear in Attachment 11.

2. Mechanical Operation

The Thrust Chamber Valve Pressure Sequencing Valve (AGC 1-206854) is the main control component in the thrust chamber valve control system. As shown in Attachment 12, the valve is a pressure operated four-way pilot valve with a solenoid override feature for quick thrust chamber shutdowns. A belleville and coil spring system maintains the valve in a closed position until fuel actuation pressure overcomes the spring system force.

Rising main fuel pump discharge pressure through Port 1 is sensed by the sequencing-valve actuation piston through internal porting in Cavity D and when the opening pressure of approximately 220 psig is reached, the valve snaps to the open position, admitting fuel pressure through Cavity B and Port 6 to the opening side of the thrust-chamber-valve actuator. Pressure applied through the PSV to the opening side of the actuator opens the mechanically linked thrust chamber valves and permits the flow of lox and fuel from the main pump drive assembly to enter the combustion chamber. The pyrotechnic igniters initiate combustion of the lox and fuel which is then self-sustaining. During a normal thrust chamber shutdown, the hot gas to the PDA turbine assembly is diverted to the vernier ducts by closing the hot gas diversion valve. A micro switch (HGVS) which opens at 10% of the HGV closing travel, energizes the override solenoid in the thrust chamber valve pressure sequencing valve, which then opens, allowing the pressurized fuel in the actuation cavity to vent through Port 4 and 7 to the 3/8" overboard drain line. As the differential pressure across the actuation piston is reduced, the valve spring system force snaps the pressure sequencing valve to the closed position, reversing the vent and pressure passages to the thrust chamber valve actuator. The thrust chamber valve actuator is pressurized closed through Port 5 with the aid of the compressed actuator springs by venting the pressurized fuel overboard through Port 2 and the 3/4" overboard fuel drain line. The closing time for the thrust chamber valves during Aerojet acceptance tests for this engine was .133 and .135 seconds on two successive tests and the valve closure on Run BFB 10(1) was .12 seconds, indicative of a similar shutdown. The pressure sequencing valve has an additional closing feature in the event of an override malfunction. The valve will shuttle to the closed position when the pump discharge pressure drops below approximately 180 psi, which is below the spring pressure, producing a longer decay shutdown with a lengthened thrust chamber valve closing time. A typical thrust chamber valve closure of this type on BFB 3(1) at Denver gave a .33 second closing time.

The data for this run indicates normal time sequence for an override shutdown of the thrust chamber valve control system with fuel discharge pressure assisting in closing the thrust chamber valve actuator.

3. Possible Malfunction Causes

The following is a brief description of other possible malfunctions of the thrust chamber valve actuation system that were considered and that could cause the Thrust Chamber Valves to close.

The word "failure" as used in these paragraphs is defined to mean a structural fracture of the component listed.

The generalized condition that must exist to cause the TCV to close is that there must be a loss of the opening force on the TCV actuator piston. Since the opening force is generated completely by engine fuel pressure, it follows that a loss of fuel pressure on the opening side of the TCV actuator was the reason for the closing of the TCV experienced on Run BFB-10.

Loss of fuel pressure in the TCV actuator can be the result of a mechanical malfunction within the missile and/or engine fuel systems, or an electrical signal to the PSV override solenoid. Some of the possible malfunctions considered by the investigation are listed below. The listing in some cases represents a generalized category which could not be investigated in detail because of the damaged condition of engine or missile hardware.

a. Mechanical

(1) Failure of the TCV actuator or high pressure plumbing to the actuator from the PSV. No evidence of this type trouble was found.

(2) Failure of the PSV or high pressure plumbing from the main fuel discharge line to the PSV. No evidence of this type failure was found.

(3) Failure of the engine fuel discharge line. This line between the pump and fuel thrust chamber valve was intact.

(4) Failure of the main fuel pump. Fuel discharge pressure did not drop off until after the explosion.

(5) Unscheduled closure of the fuel pre-valve. Fuel prevalve was found to be in the open condition after the fire had subsided.

(6) Any obstruction in the PSV overboard dump lines sufficient to cause hydraulic lock up within the PSV. Functional tests through these lines were satisfactory - recovered components were correctly installed.

(7) Internal leakage in the PSV, particularly in the override piston seals. Aerojet-General is bench testing the valve at Sacramento to investigate the possibility of this type failure.

b. Electrical

Attachment 13 is a schematic showing the thrust chamber valve pressure sequence valve override, the connecting plugs, wiring and the associated portion of the airborne sequencer. The hot gas valve switch and associated electrical circuitry inside the airborne sequencer are shown as they were at FS_1 + 1.27 seconds, the time at which thrust chamber valves started to close.

The possibility of an erroneous electrical signal reaching the thrust chamber valve pressure sequence valve override has been reviewed and appears remote.

The possibility of a 28 volt signal being sent to the override from the P-5 instrumentation connector was investigated and appears impossible. No wires were connected to the pins in the P-5 connector ((g) and (f)) that would be used to record the thrust chamber valve pressure sequence valve override signal. These are the only pins through which a stray signal could be sent from instrumentation or GSE.

The possibility of an erroneous signal to the override solenoid originating in the airborne sequencer was reviewed and also appears quite unlikely. However at this time, closure of just one set of contacts could have initiated the thrust chamber shutdown.

In the event that either of these open sets of contacts in the 2K3 override relay circuit chattered long enough to close the normally open points, a fireswitch signal would have been sent to instrumentation through the P-2 connector, and the 2K12 fireswitch two relay would have been energized also. In order to energize the override without energizing the 2K3 override relay it would be necessary to simultaneously chatter a minimum of two sets of 2K3 points at the same time.

The fact that no chattering of points has been experienced (in the airborne sequencer) during previous Denver testing and that no wires existed in the instrumentation line to plug P-5, pins (8) and (f), seems to indicate that no electrical signal was the cause of the thrust chamber valve pressure sequence valve shuttling thereby causing the thrust chamber valves to close.

4. Pressure Sequencing Valve Disassembly and Test

After isolation of the malfunction to the pressure sequencing valve assembly, which had undergone the compartment fire, Martin-Denver requested immediately disassembly of the valve without a high pressure functional checkout to determine the condition of the internal components at the termination of the test. A schematic of this valve and its history appears in Attachment 12. The history of this PSV, which carries a Development Stamp, has been requested from Aerojet/Sacramento.

After the other inspections were completed the PSV was removed from the engine and partially disassembled on Test Stand D-1. The following personnel were in attendance:

J. Keeley - Martin, Propulsion Engineering

J. Fealey - Aerojet Field Engineer

B. Hall - " " "

R. Sheffer - Martin, Systems Test

Prior to disassembly, photographs were taken of the valve and the following external damage recorded.

(1) Part No. 1-223750-/- S/N 0-9

Aerojet Inspection Stamp $\boxed{600}$

(2) The fuel supply line to the PSV was intact.

(3) Thrust chamber valve actuator (TCVA) lines (opening and closing) were intact.

(4) All other external lines to the PSV were either burned or broken off.

(5) Approximately 50% of the microswitch housing was missile (burned or broken). The override solenoid electrical connector was burned and the wires inside the switch housing were burned through.