NATIONAL TRANSPORTATION SAFETY BOARD
OFFICE OF AVIATION SAFETY
WASHINGTON, D.C. 20594

January 12, 2004

ADDENDUM NUMBER 5 TO THE SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION– AUTOPILOT SERVOMOTOR EXAMINATION

DCA02MA001

A. ACCIDENT

Operator: American Airlines
Aircraft: A300-600R
Location: Belle Harbor, New York
Date: November 12, 2001
Time: 09:16 EDT

B. SYSTEMS GROUP

Chairman Steven Magladry
National Transportation Safety Board
Washington, DC

Member Gerald Gaubert
Bureau Enquetes - Accidents
Paris Le Bourget, France

Member Albert Urdiroz
Airbus France
Toulouse Blagnac, France

Member David Seratt
American Airlines
Tulsa, Oklahoma

C. SUMMARY

On November 12, 2001, American Airlines flight 587, an Airbus Industrie A300-600R, N14053, crashed at Belle Harbor, New York, shortly after takeoff from John F. Kennedy International Airport (JFK), Jamaica, New York. The aircraft was equipped with General

Electric CF6-80C2A5 engines. The airplane had taken off from runway 31 left and had turned southbound when it crashed. The aircraft was operated under the provisions of Title 14 of the U.S. Code of Federal Regulations Part 121 as a regularly scheduled international passenger flight from JFK to Santo Domingo, Dominican Republic. The 2 pilots, 7 flight attendants, and 246 passengers plus 5 lap children on board were killed.

The systems group recovered the yaw autopilot actuator from the accident site and it was moved to NTSB Headquarters in Washington, DC. Group members removed the molten debris attached to the unit. The unit wiring was inspected, but it could not be determined if the unit was correctly wired due to the extensive heat damage. The Systems Group then convened at the manufacturer, Goodrich, in St. Ouen L'Aumone, France to examine and disassemble the unit. The following provides the details of these activities.

D. DETAILS OF THE INVESTIGATION

1.0 Yaw Autopilot Servomotor Description

The yaw autopilot actuator, also referred to hereafter as the autopilot servomotor (APSM) Figure 1, consists of two electro-hydraulic actuators. Both of the electro-hydraulic actuators are housed in a single unit with a common output. One of the electro-hydraulic actuators is referred to as the Driving Body and the other is referred to as the Driven Body. The common output lever is connected through a torque limiter to a bell crank in the rudder frame. For a description of the rudder frame, see the Systems Group Chairman's Factual Report of Investigation. The torque limiter allows the pilot to override the autopilot output. The APSM is designed only to be active with slats extended and with the autopilot engaged. Each Body has two electrovalves (solenoids). One is the Main (Pressure) solenoid the other is the Engagement (Engage) solenoid. Figure 1 shows the location of each of the solenoids.

Figure 2 shows the internals of one of the Bodies (Driving or Driven) in the engaged condition; with both the Pressure and Engage solenoids energized. Each of the solenoids consists of two parts, the solenoid and the solenoid valve. The solenoid is the electrical portion which moves a push rod toward the solenoid valve, when energized. The solenoid valve is a hydro-mechanical component, which ports hydraulic fluid to different outlets depending on the position of its transfer piston. The solenoid valve push rod makes contact with the solenoid valve transfer piston. The Pressure solenoid valves are two ball valves (Figure 3) and the Engage solenoid valves are one ball valves (Figure 4).

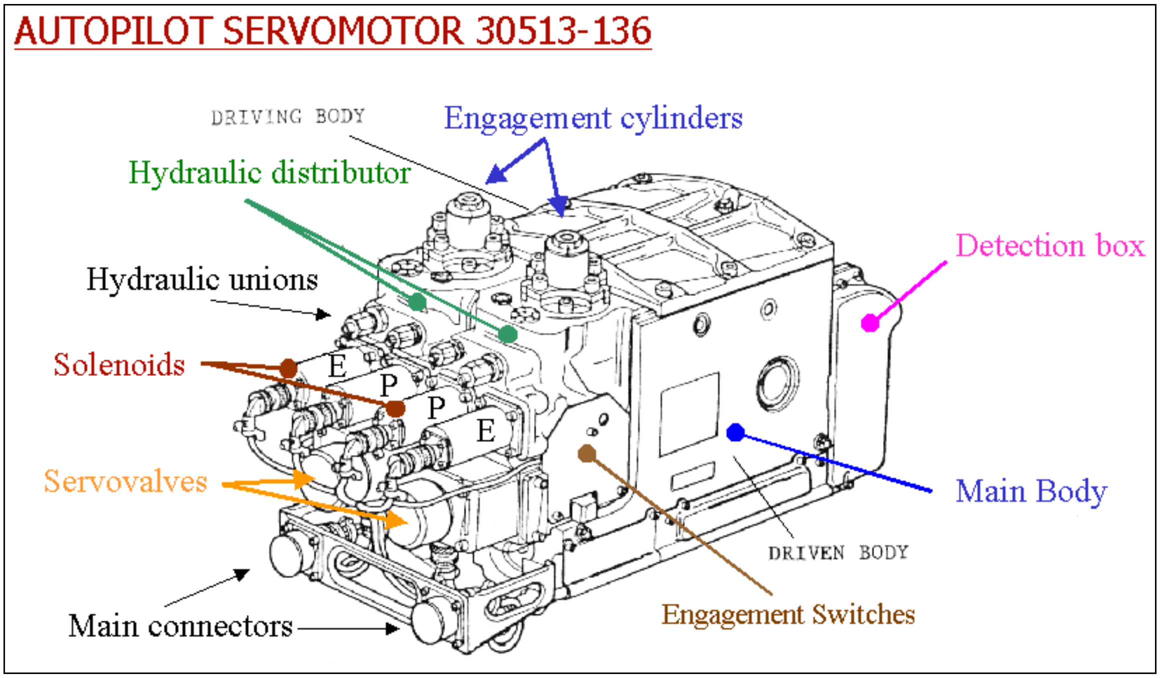

Figure 1. Autopilot Servomotor

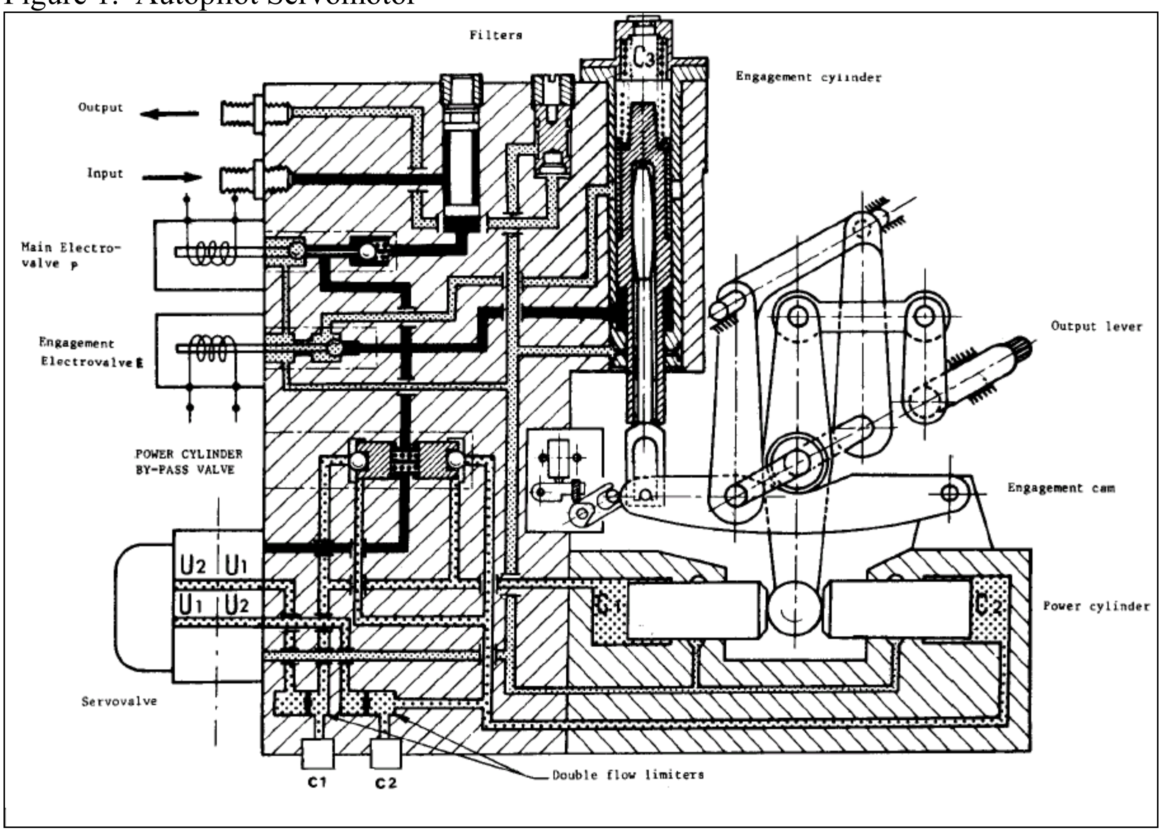

Figure 2. APSM Schematic of one of the Bodies in the Engaged State.

– A transfer piston (A) upon which the solenoid push rod rests.

– A first "low pressure" ball (B) moved by the transfer piston.

– An intermediate needle pin (C).

– A second "high pressure" ball (D).

– A return piston (E) resting on ball (D) under the action of spring (F).

– A liner (G).

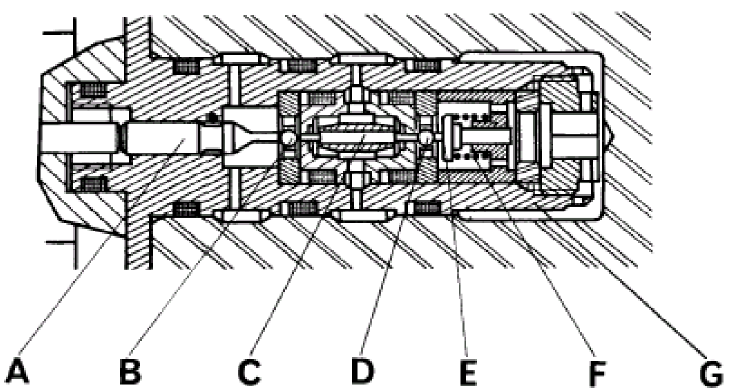

Figure 3. Pressure Solenoid Valve.

– A transfer piston (A) upon which the solenoid push rod rests.

– A ball (B) moved by the transfer piston.

– A liner (C).

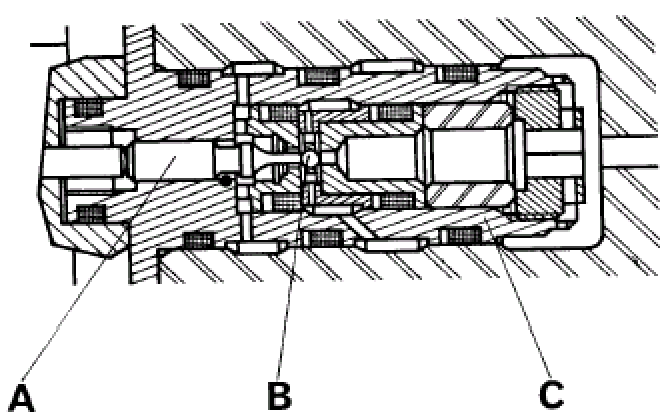

Figure 4. Engage Solenoid Valve.

2.0 Condition of Accident APSM.

The APSM was recovered from the accident site with a large amount of debris attached. The debris consisted of re-solidified molten metal, fiberous material, cables, wires and general debris, Figure 5.

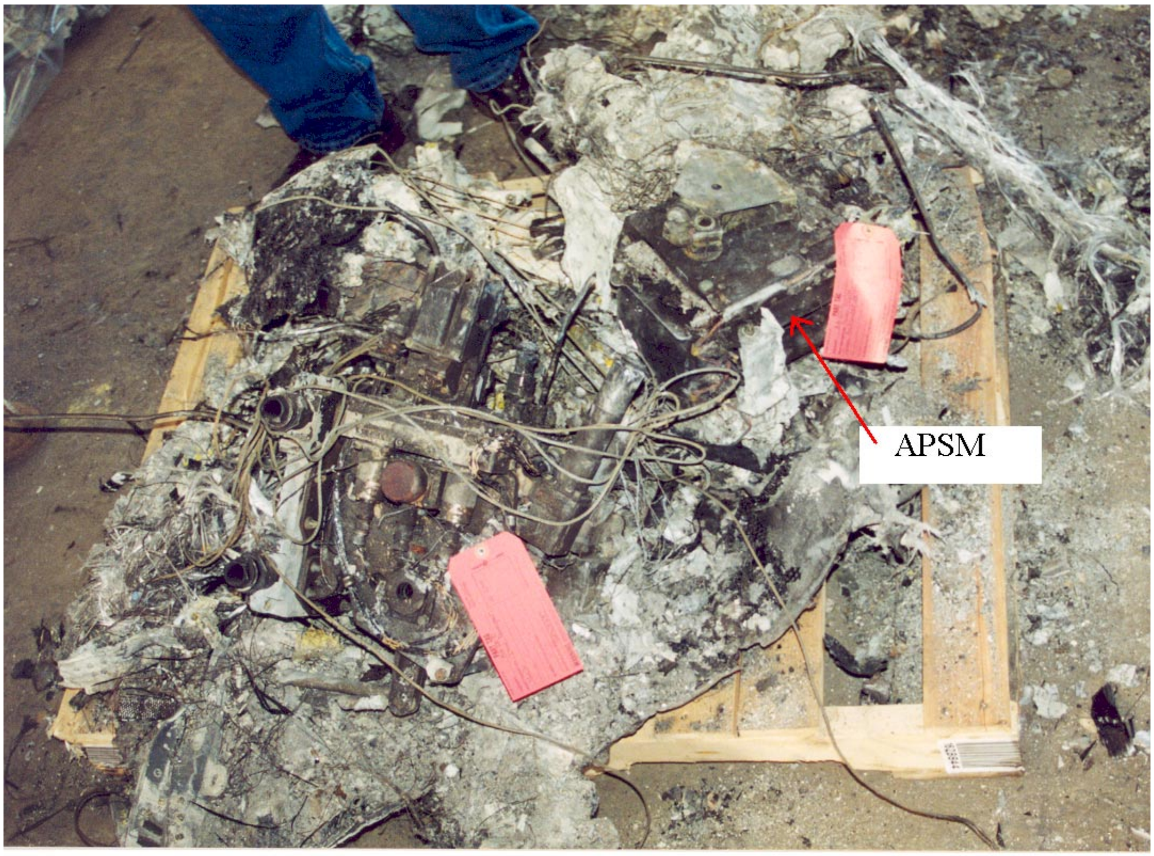

Figure 5. APSM as Recovered from Wreckage.

The APSM was moved to the NTSB Headquarters in Washington, DC. The debris was removed, Figure 6 – 8.


Figure 6. APSM Prior to Removal of Debris.

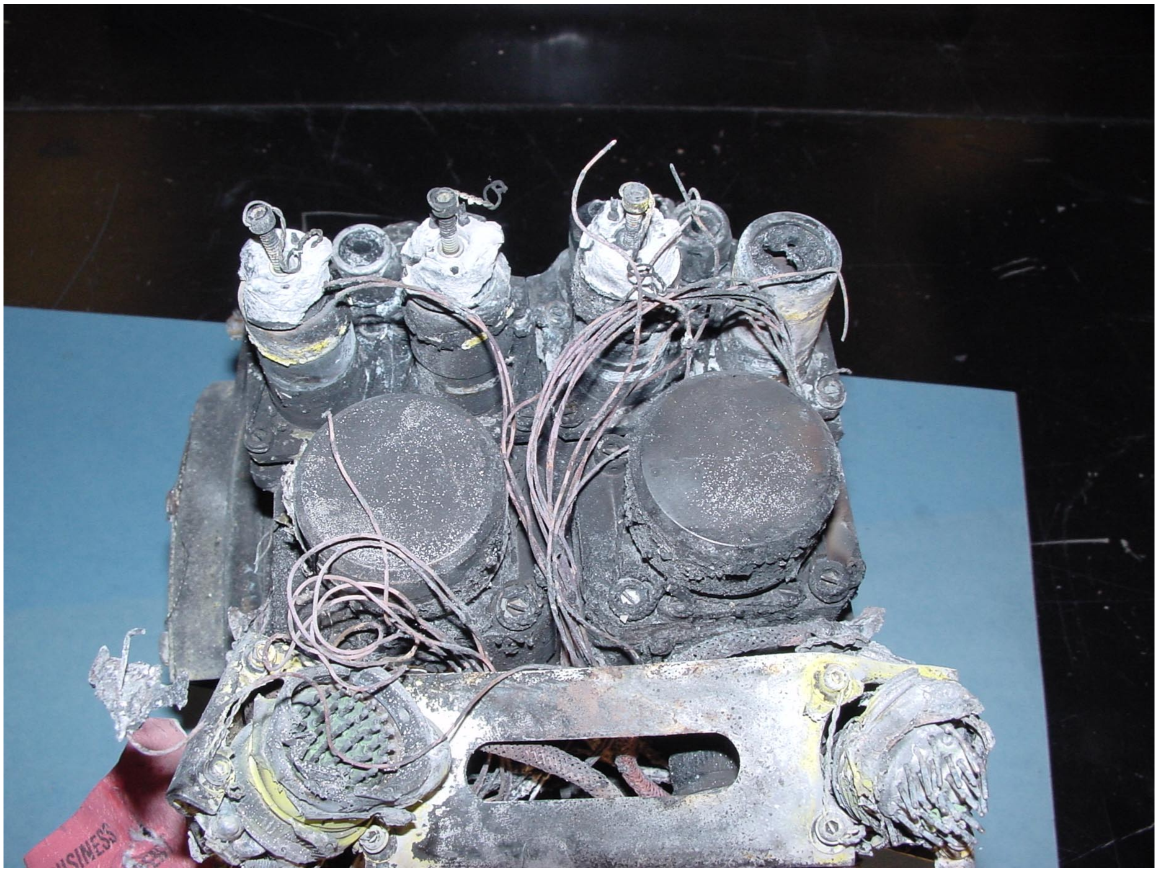

Figure 7. Front of APSM after removal of Debris.

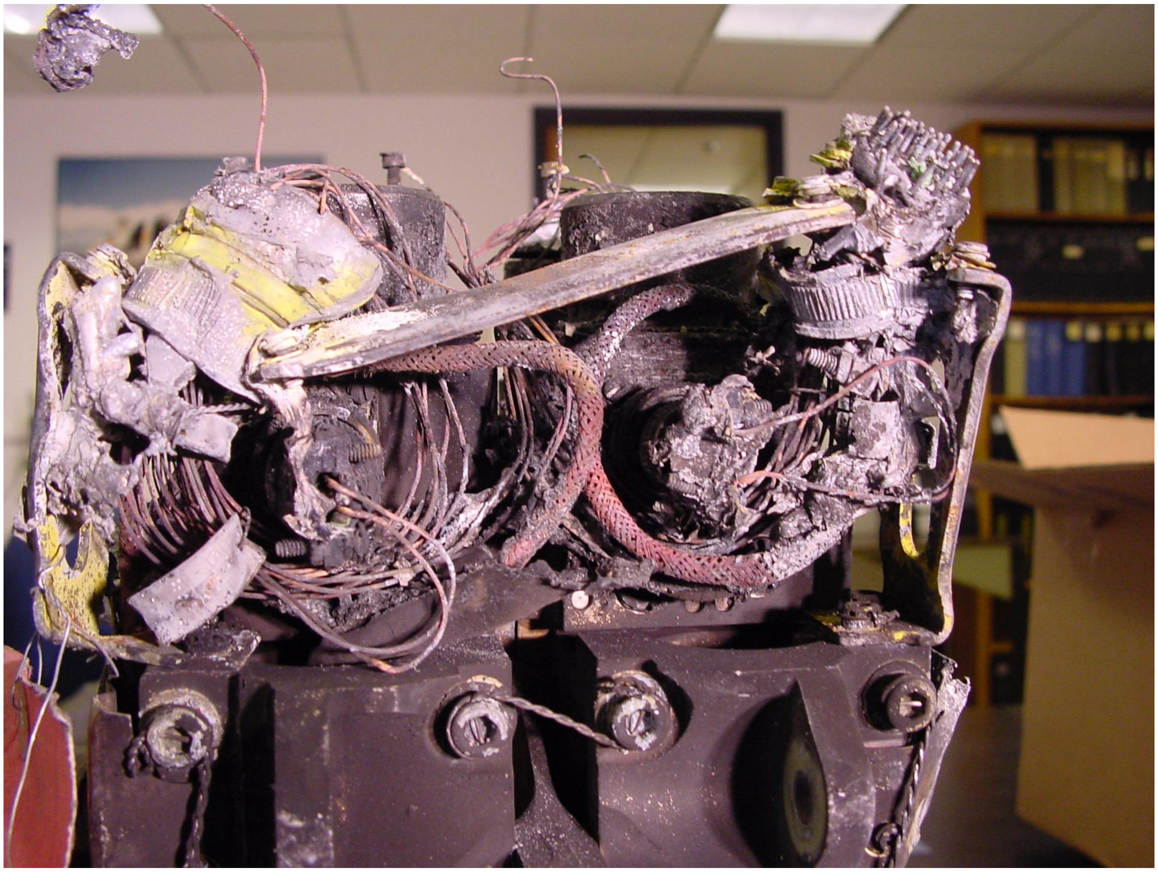

Figure 8. Bottom View of Connectors After Removal of Debris.

3.0 APSM Wiring Inspection

On October 17, 2002, members of the Systems Group convened at the National Transportation Safety Board in Washington, DC to examine the autopilot yaw actuator from the accident aircraft. Examination was conducted in the NTSB Materials Lab.

The APSM was examined and continuity tests performed to verify the wiring paths between the aircraft connectors and the solenoids.

The actuator was observed to be thermally damaged, the plastic wiring looms and wiring insulation was melted. The Driving side connector was intact, while the Driven connector was thermally and impact damaged. The identification plate was recovered from the Driving electrical harness, which confirmed the correct harness P/N 338827-140 was installed. The wires from the connecter were no longer attached to any of the solenoids though some of the wire routing appeared to be unaltered. Figure 9 and Figure 10 show the wire routing of an undamaged APSM.

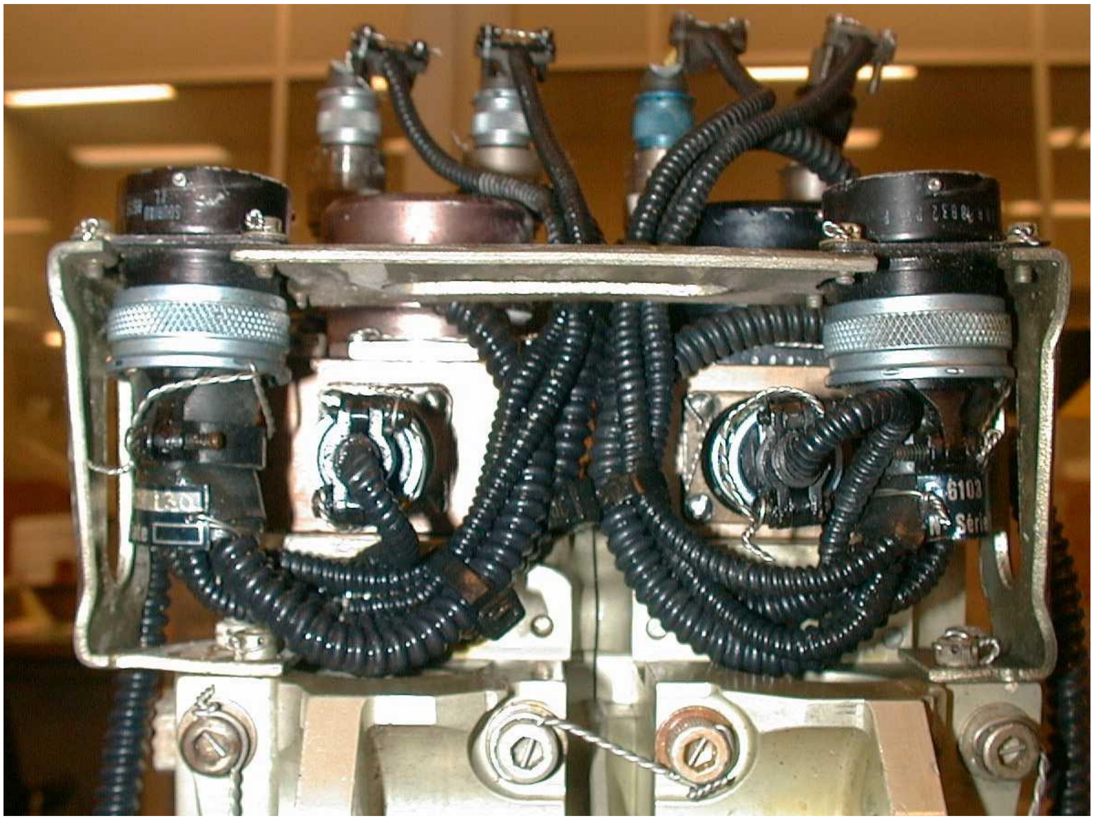

Figure 9. Bottom View of Undamaged APSM

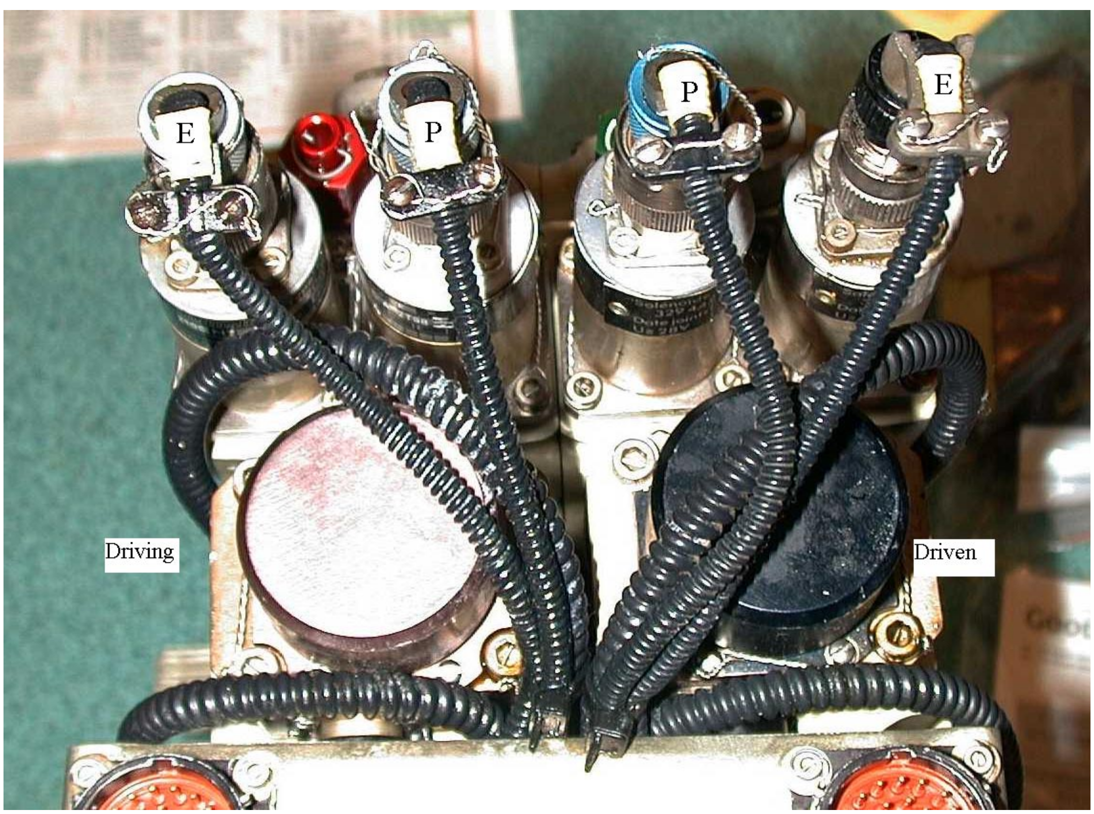

Figure 10. Front View of Undamaged APSM

The wires to the solenoids were labeled from 0 to 8 (#2 not used) as shown in Figure 11. The pin arrangement of the Driving channel connector was verified as correct. Continuity tests identified individual wires leading to the solenoids. The Driving channel's Engage solenoid wiring was positively identified through its proximity to the solenoid (far left in Figure 7). The Driving channel's Pressure solenoid wiring was identified. The position of the wiring made it impossible to identify to which solenoid the wires were connected.

The pin arrangement of the Driven channel connector was verified as correct through identification of pins X and c from the engagement detection microswitch. From that point of reference, relevant pins and individual solenoid wires were identified through continuity tests (Table 1). Pins a and b appear to be paired together as well as pins Y and Z. The position of the wiring made it again impossible to determine to which Pressure solenoid the wires were connected. The Driven channel's Engage solenoid wiring appeared to be from pins a and b through their proximity to the solenoid.

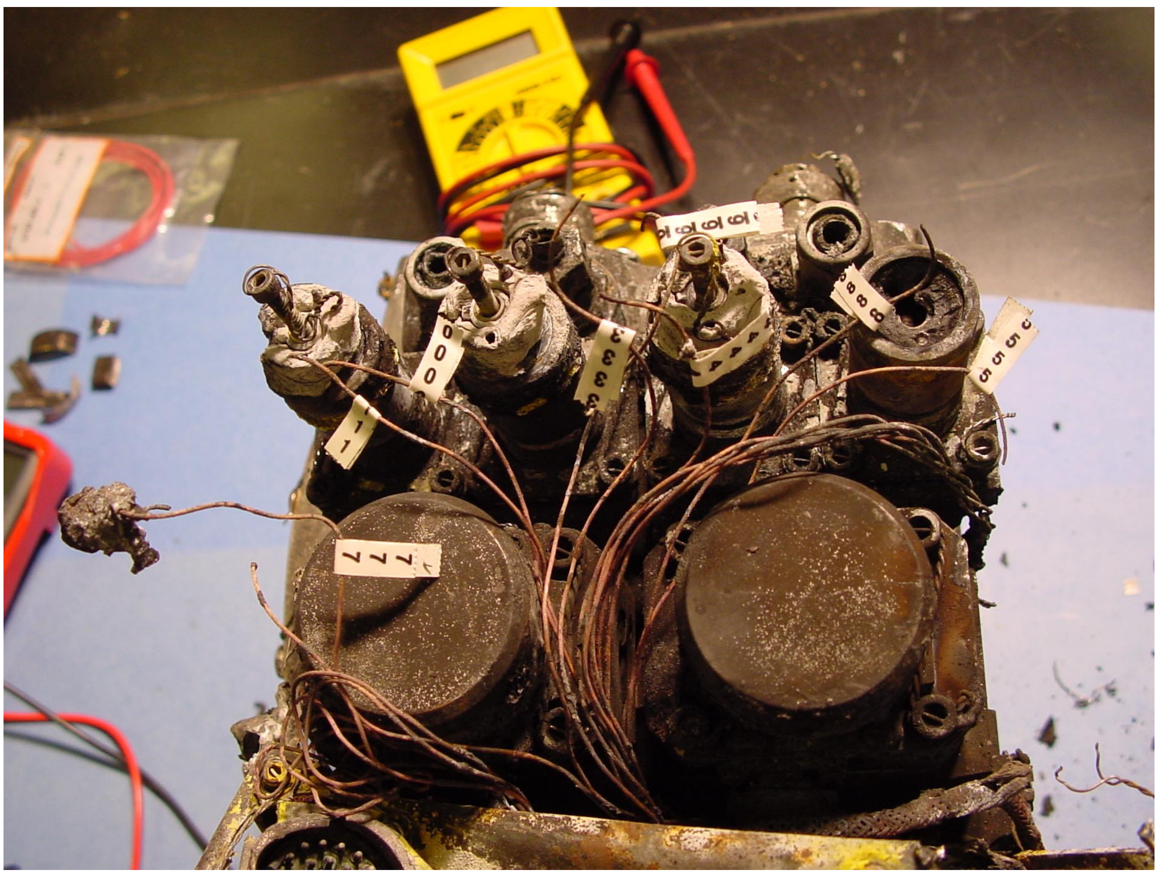

Figure 11. APSM with Wires Labelled.

Driving Connector		Driven Connector	
Wire Label	Pin	Wire Label	Pin
0	a	5	b
1	b	6	Y
3	Y	7	Z
4	Z	8	a

Table 1. APSM Continuity Test Results.

Wire Diagram Pin Assignments:

Y - Pressure Solenoid (+), Z - Pressure Solenoid (-)
a - Engage Solenoid (+), b - Engage Solenoid (-)

4.0 APSM Examination and Teardown

The Systems Group then convened at the manufacturer, Goodrich, in St. Ouen L'Aumone, France, between June 2-3, 2003 to examine and disassemble the APSM. The following assisted the Systems Group:

Goodrich Investigation Team:

Jean-Francois Coillard	Project Manager
Chrystelle Caudron	Engineering
Davy Binois	Product Support
Marc Brescia	Laboratory

Airbus Engineering Support:

Jean-Christophe Brody	Flight Controls Design Office Engineer
Francis Fernandez	Flight Controls Design Office Engineer

The group began with documenting the external condition of the APSM prior to disassembly. Figures 12 through 15 show the condition of the unit. In Figure 12, the torque limiter was shown removed. It was removed in Washington DC, prior to shipping. Figure 13 and 15 showed the Driving side and Driven sides with the engage switch cover plates removed. The cover plates were removed in Washington DC during the continuity checks performed previously.

Figure 12. APSM Driving Side. Torque Limiter Removed (left, Bottom).

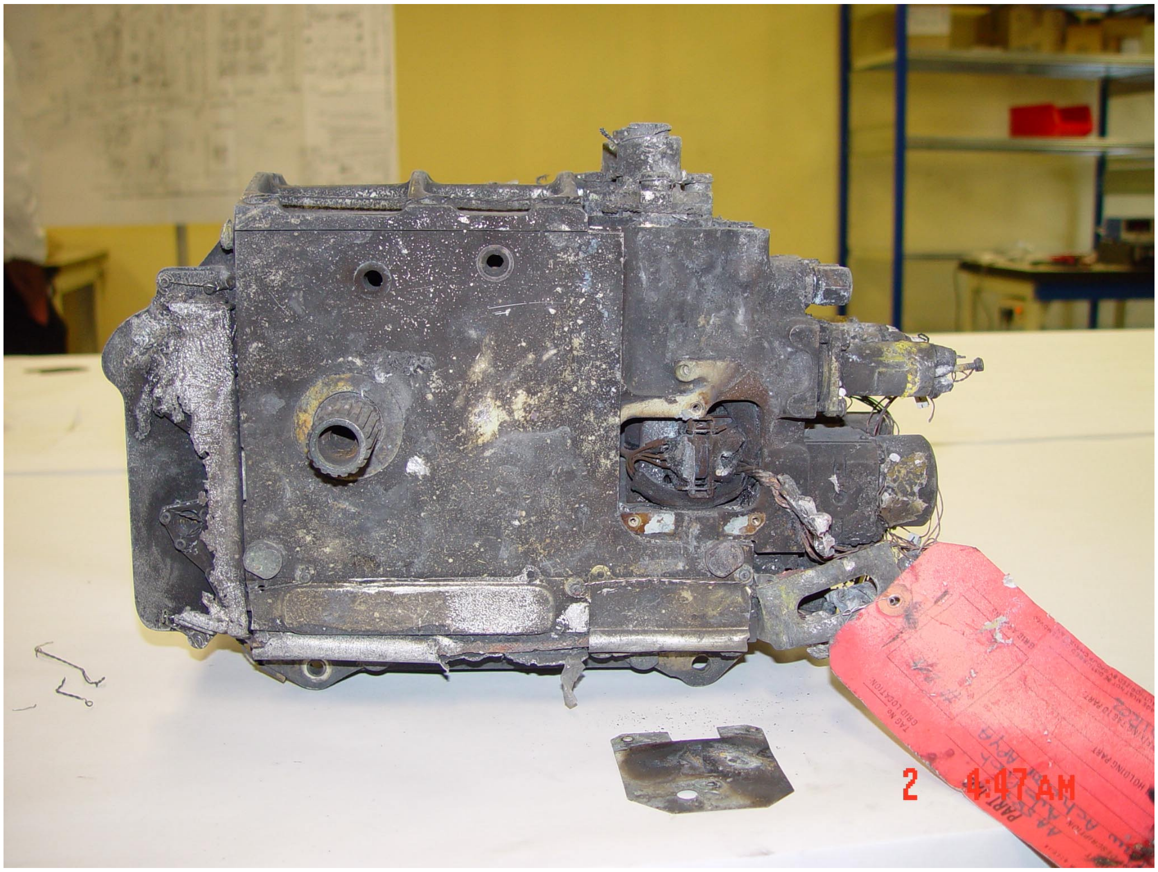

Figure 13. Driving Side of APSM.

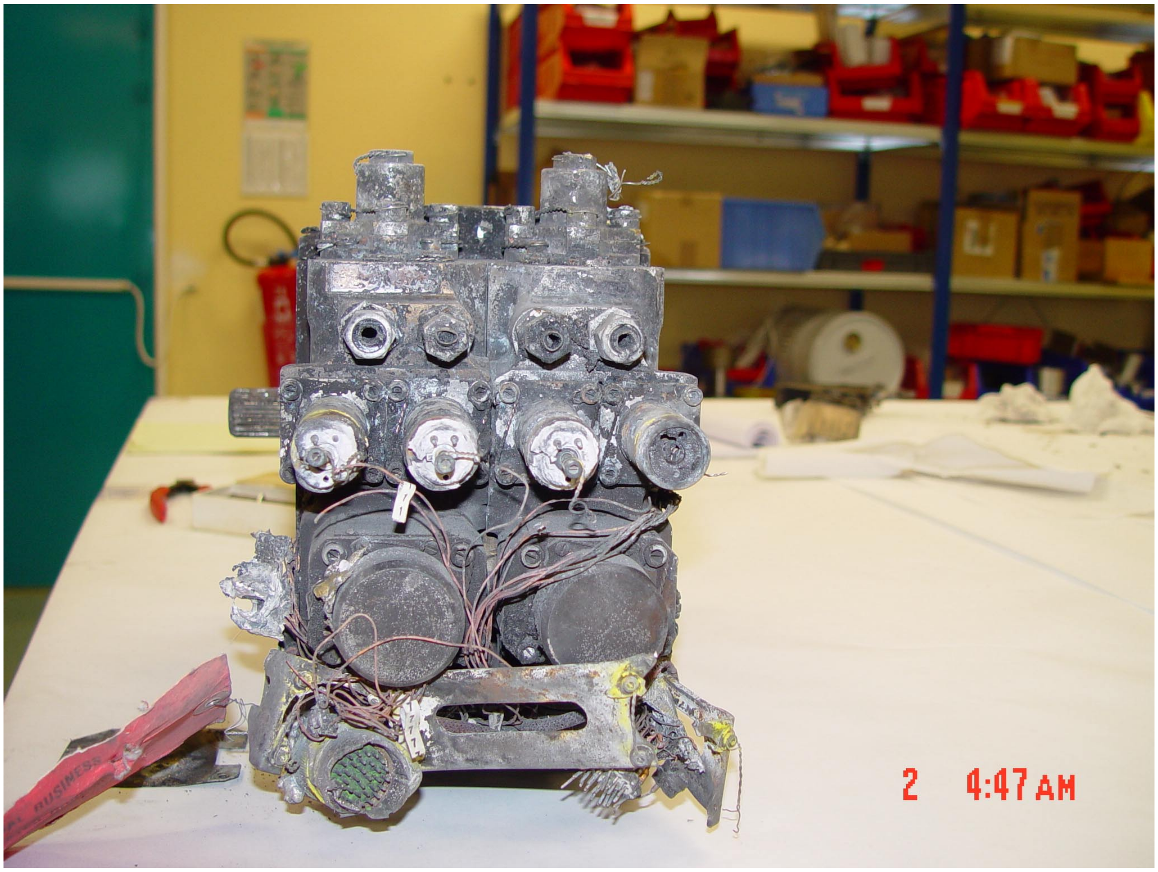

Figure 14. Front of APSM.

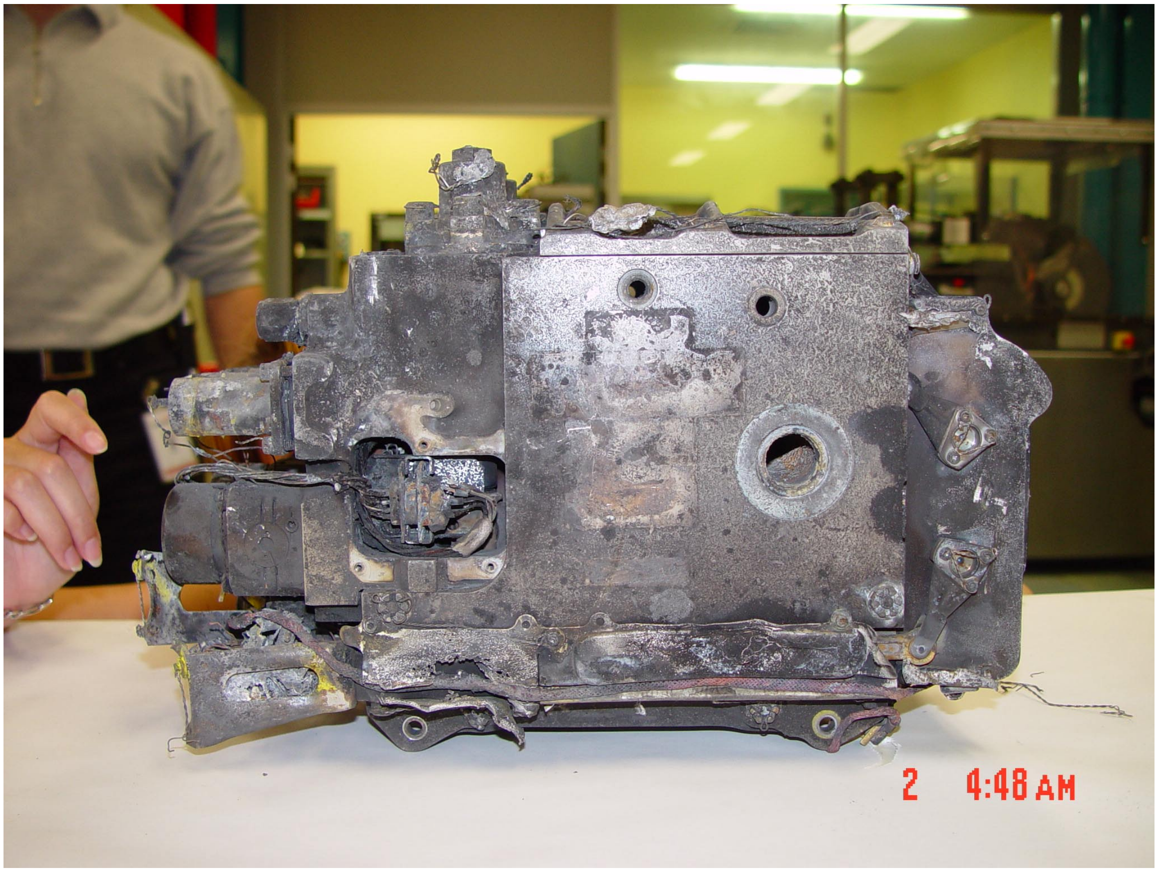

Figure 15. Driven Side of APSM.

All visible part numbers and identification plates were recorded. The following information was obtained:

All Illustrated Parts List (IPL) references are provided in Appendix B.

IPL 1-470E Hydraulic unit (Driving), PN 329 300 – 236, SN CM097, MFD 06/90
IPL 1-440E Hydraulic unit (Driven), PN 329 301 – 236, SN 2105, MFD 06/90

IPL 1-430C Wiring Assembly (Driving), PN 338827-140, MFD 07/90
IPL 1-240D Solenoid, PN 38215-262, SN4125, MFD 2Q 97
IPL 1-240D Solenoid, PN 38215-262, SN4111, MFD 2Q 97
IPL 1-240D Solenoid, PN 38215-262, SN4094 (main Driving)
IPL 1-260A Servovalve Abex (Driving), PN 78068, SN AH-1419, MFD A2Q90
IPL 1-260A Servovalve Abex (Driven), PN 78068, SN AH-1340, MFD A1Q90

Component Disassembly:

On each side, the detection box cover plate and wiring cover plates were removed in order to observe the position of the detection linkage. Appendix A, Figure 1 shows the Driving side with the plates removed.

The Driving detection linkage (IPL 11-150) was observed to be against the stop in the direction of the servovalve. The linkage was in a position which corresponded to a full counter clockwise movement of the output shaft when the clutch is engaged and the cam is in the center of the roller, or when the clutch is disengaged and the actuator is correctly synchronized to a full counter clockwise position of the output shaft.

The Driving side detection box (IPL 2-002), and upper cover plate (IPL 8-70A) were removed, Appendix A, Figure 2.

It was observed that the output shaft (IPL 8-310) is in the full clockwise position against the mechanical stops as observed from the Driving side of the actuator. This corresponds to a left rudder command.

Appendix A, Figure 3 showed the Driven side with the cover plates removed.

The Driven detection linkage was against the stop in the direction of the servovalve. The jack assembly is in a position which corresponds to a full counter clockwise movement of the output shaft when the side is clutched and the cam is in the center of the roller, or when the clutch is disengaged and the actuator is correctly synchronized to a full counter clockwise position of the output shaft.

The Driven side detection box was removed, Appendix A, Figure 4 and 5.

The detection box electrical connectors and wiring were removed, Appendix A, Figure 6.

The Driven side engage piston and switch were observed to be in the un-clutched position, Appendix A, Figure 7.

The Driving side engage piston and switch were observed to be in the un-clutched position, Appendix A, Figure 8.

The Engage switches (IPL 1-280A) were removed, Driving Appendix A, Figure 9 and Driven Appendix A, Figure 10.

Continuity checks were attempted but insulation was lost due to heat damage, Appendix A, Figure 11. Visual examination of the wires routing was not conclusive because of the substantial damage to the connectors.

Wires were cut at the engagement switches and continuity was confirmed between 2 of the 3 pins as documented below in Figure 16. The switches are shown in top view. Appendix A, Figures 12 to 15 are the Driven and Driving switches.

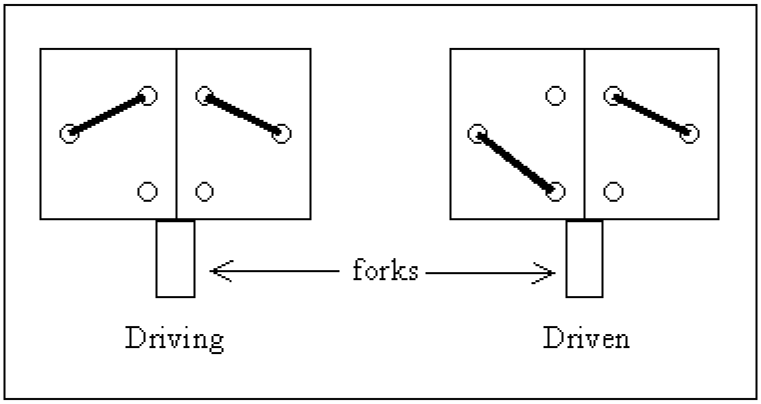

Figure 16. Engage Switch Continuity

The hydraulic units were removed (IPL 5-001 and 5-002), Driving Appendix A, Figure 16 and Driven Appendix A, Figure 17.

The servovalves were removed (IPL 1-260) and heat damage was observed, Driving Appendix A, Figure 18 and Driven Appendix A, Figure 19.

The solenoids were removed (IPL 1-240D), Appendix A, Figures 20 to 25. Upon disassembly, Appendix A, Figures 26 to 32, substantial heat damage was observed on all 4 solenoids as evidenced by the packings that had turned into powder. No foreign debris was found in the solenoids, especially in the bobbin and piston area. The powder was collected into containers.

The solenoid valves (IPL 5-190A and 5-190B) were removed. The push rod protrusion was measured. The results are below. The valves were disassembled, Appendix A, Figures 33 to 38.

Pressure solenoid valves (2 balls)
Driving: Protrusion 0.18 mm
Driven: Protrusion 0.12 mm
Specification for the ball stroke is 0.12 mm to 0.20 mm. Specification for the protrusion in the energized condition is 0.02 mm to 0.04 mm.
The protrusion of the push rod of a solenoid valve from the repair shop was measured to be 0.21 mm.

Engage solenoid valves (1 ball)
Driving: Protrusion 0.32 mm
Driven: Protrusion 0.00 mm
Specification for the ball stroke is 0.12 mm to 0.20 mm. Specification for the protrusion in energized condition is 0,02 mm to 0,04 mm.

The protrusion of the plunger of a solenoid valve from the repair shop was measured to be 0.60 mm.

Upon disassembly of all of the 4 solenoid valves, the packings were observed to be heat damaged but not to the extent that they were powder. All small parts were collected into containers. Goodrich later performed a dimensional check of the solenoid parts. The results are provided in Figure 17 and Table 2.

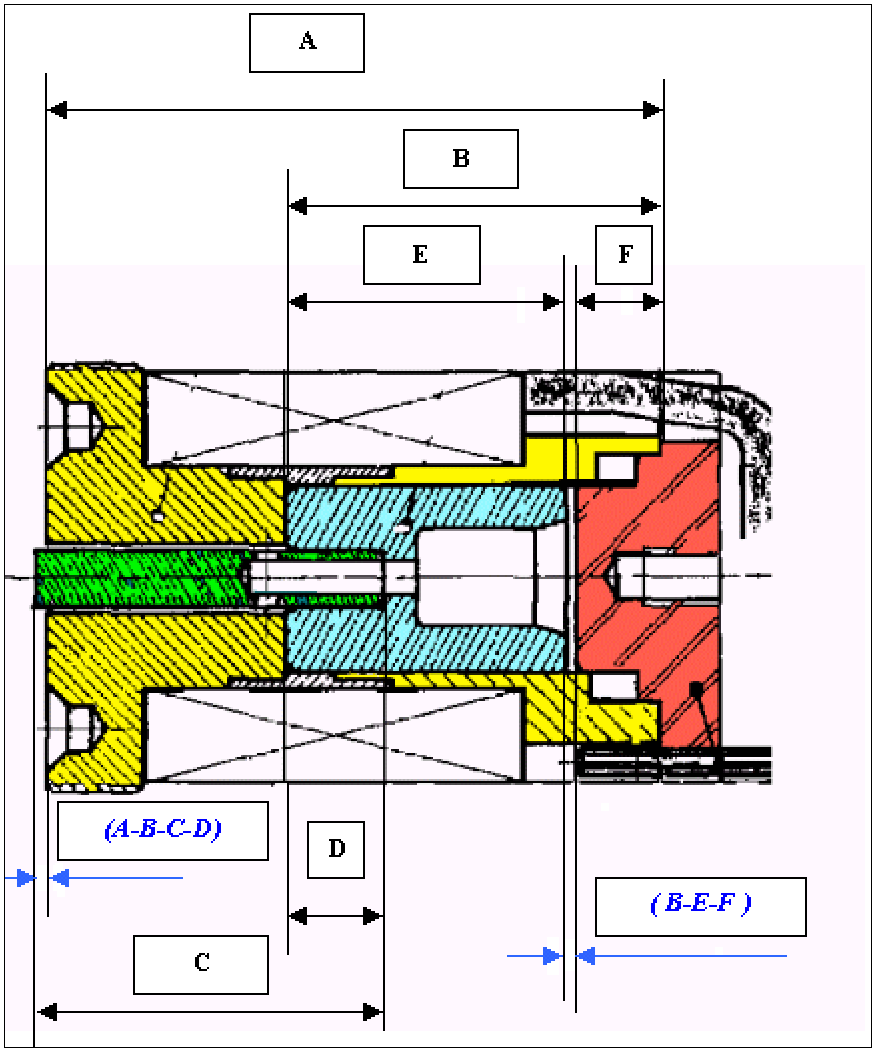

Figure 17. Dimensional Check of APSM Solenoids

DIMENSION	SPECIFIED	Pressure driving	Pressure driven	Engage Driving	Engage Driven
A	31.9 +/- 0.1	31.93	31.92	31.95	31.95
B	19.35 +/- 0.1	19.33	19.33	19.35	19.34
(A – B)	***12.75 max / 12.35 min***	***12.6***	***12.59***	***12.6***	***12.61***
C	18.5 + 0.1 / + 0.2	**17.66**	**17.63**	**17.67**	**17.66**
D	5 +/- 0.1	4.97	4.97	4.99	4.99
(C - D)	***13.8 max / 13.5 min***	***12.69***	***12.66***	***12.68***	***12.67***
(A – B – C - D)	***1.45 max / 0.75 min***	***0.09***	***0.07***	***0.08***	***0.06***
B	19.35 +/- 0.1	19.33	19.33	19.35	19.34
E	14.5 - 0 / - 0.05	14.50	14.48	14.48	14.48
F	4.4 +/- 0.06	4.32	4.40	4.36	4.24
(B – E – F)	***0.66 max / 0.29 min***	***0.51***	***0.45***	***0.51***	***0.62***

Table 2. Dimensional Check of APSM Solenoids

Note: For Dimension C and Dimension (A-B-C-D) the specified value is not achieved because C is subsequently machined per drawing 38215-262 (Appendix C, Figure 3) so that the pushrod protrusion is 0.08 +/- 0.01 mm.

A dimensional check of the Engage solenoid valves was made, Appendix C, Figure 1. The transfer pistons (IPL 13-130A) is shorter than specified in the drawing. The Driving one was measured to be 17.61 mm, the Driven was 17.70 mm. The specified length is 18 +/- 0.1mm. However, the pistons are subsequently machined to achieve the dimension 0.02 to 0.04 mm protrusion with the piston in the fully retracted position per drawing 340241-212 (Appendix C, Figure 1).

The engagement jacks were removed (IPL 6-010) and disassembled, the Driving, Appendix A, Figure 39 and Driven Appendix A, Figure 40. The springs (IPL 6-110 and 6-120) were tested (Appendix C, Figures 4 and 5 respectively). Spring constants were measured to be as per the specifications. The free heights were shorter than specification.

The covers of both detection boxes were removed, Appendix A, Figures 41 to 46. Severe heat damage was observed. The gearing was not free to move due to the damage.

The torque limiter was partially cleaned of melted metal, and the torque required to move the output to maximum travel was measured. The output could not reach full travel. The results are provided in Figure 18.

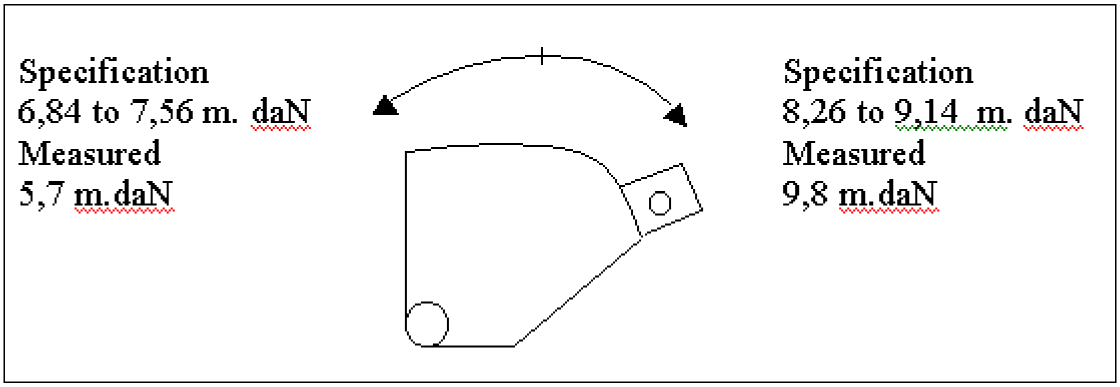

Figure 18. Torque Limiter Test Results

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Aerospace Engineer

APPENDIX A

TO

ADDENDUM NUMBER 5 TO THE SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION– AUTOPILOT SERVOMOTOR EXAMINATION

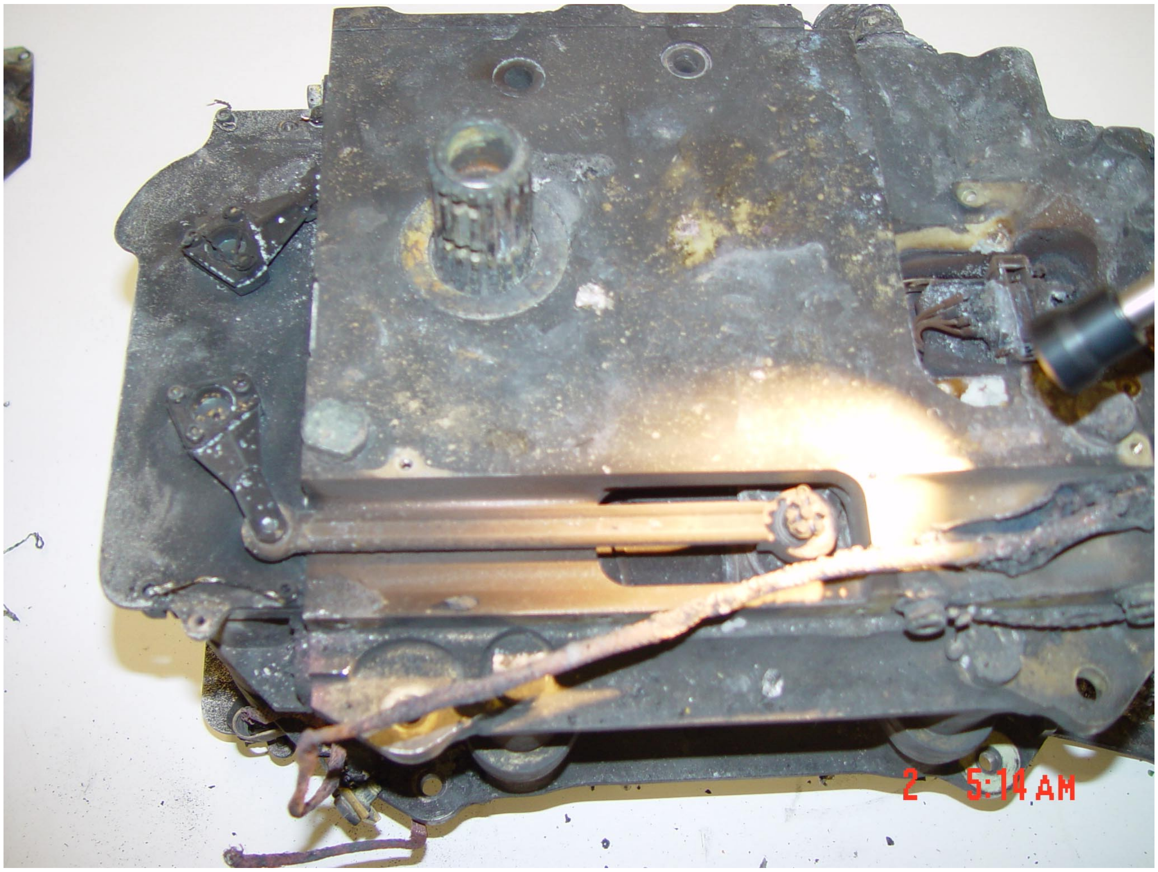


Figure 1. Position of Driving Detection Linkage.

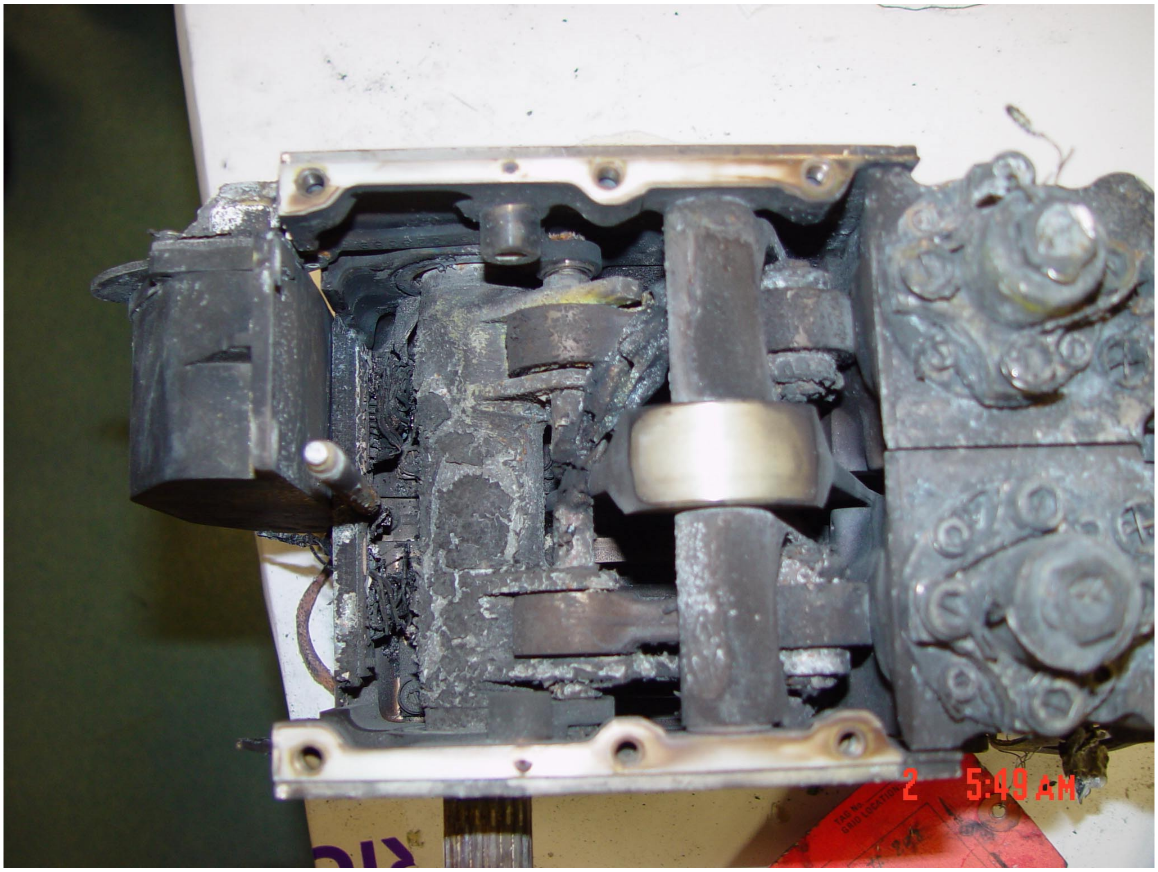


Figure 2. View of Internal Linkage Looking Down.

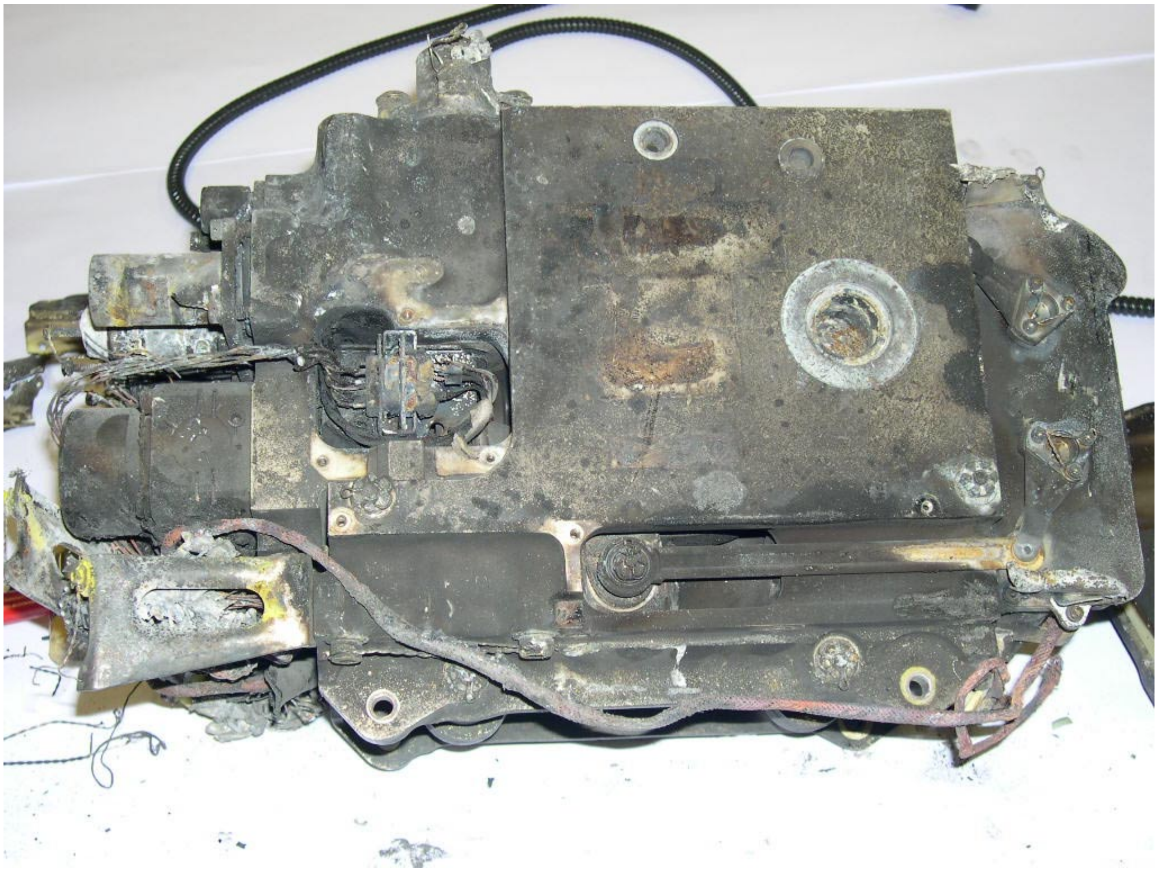


Figure 3. Driven Side With Cover Plates Removed.

Figure 4. Driven Side Detection Box Removal.

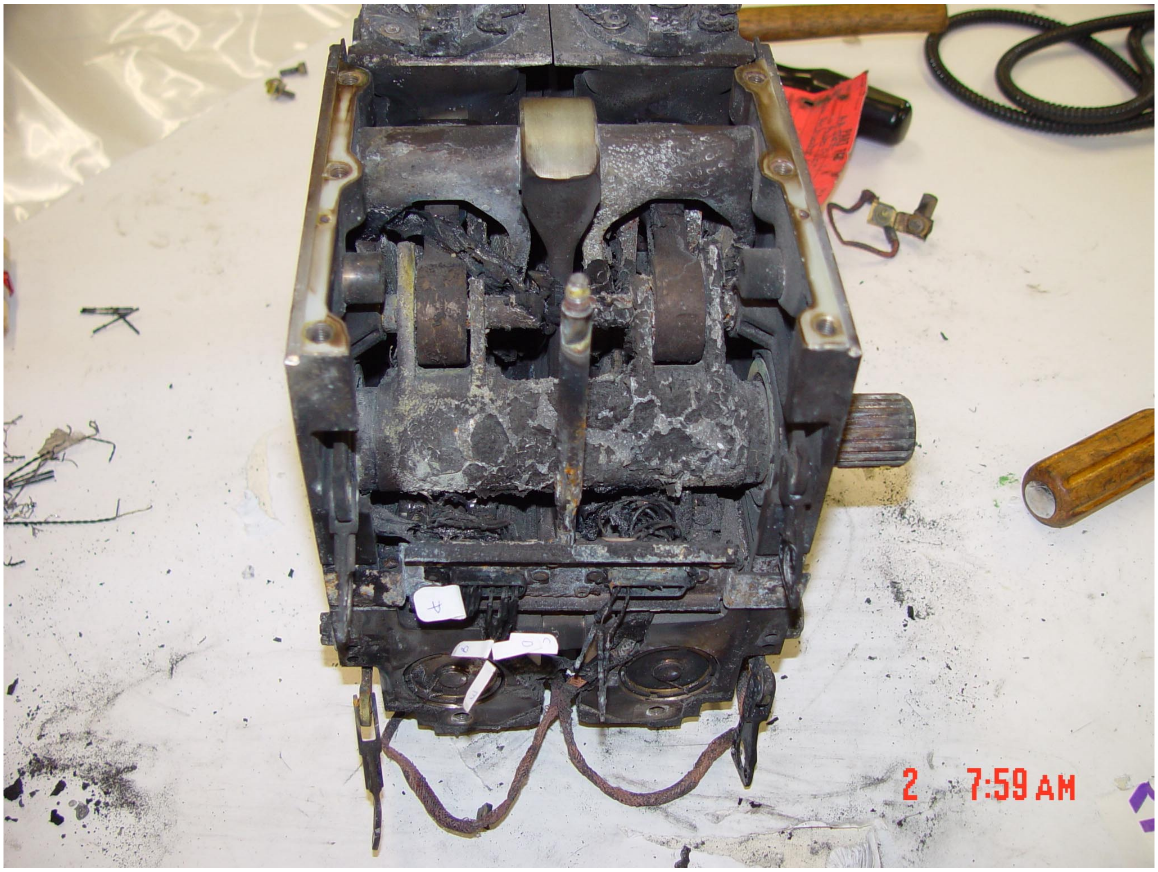


Figure 5. Linkage With Detection Boxes Removed.

Figure 6. Detection Box Wiring.

Figure 7. Driven Side Showing Engage Piston and Switch in Un-Clutched Position.

Figure 8. Driving Side Engage Piston and Switch in Un-clutched Position.

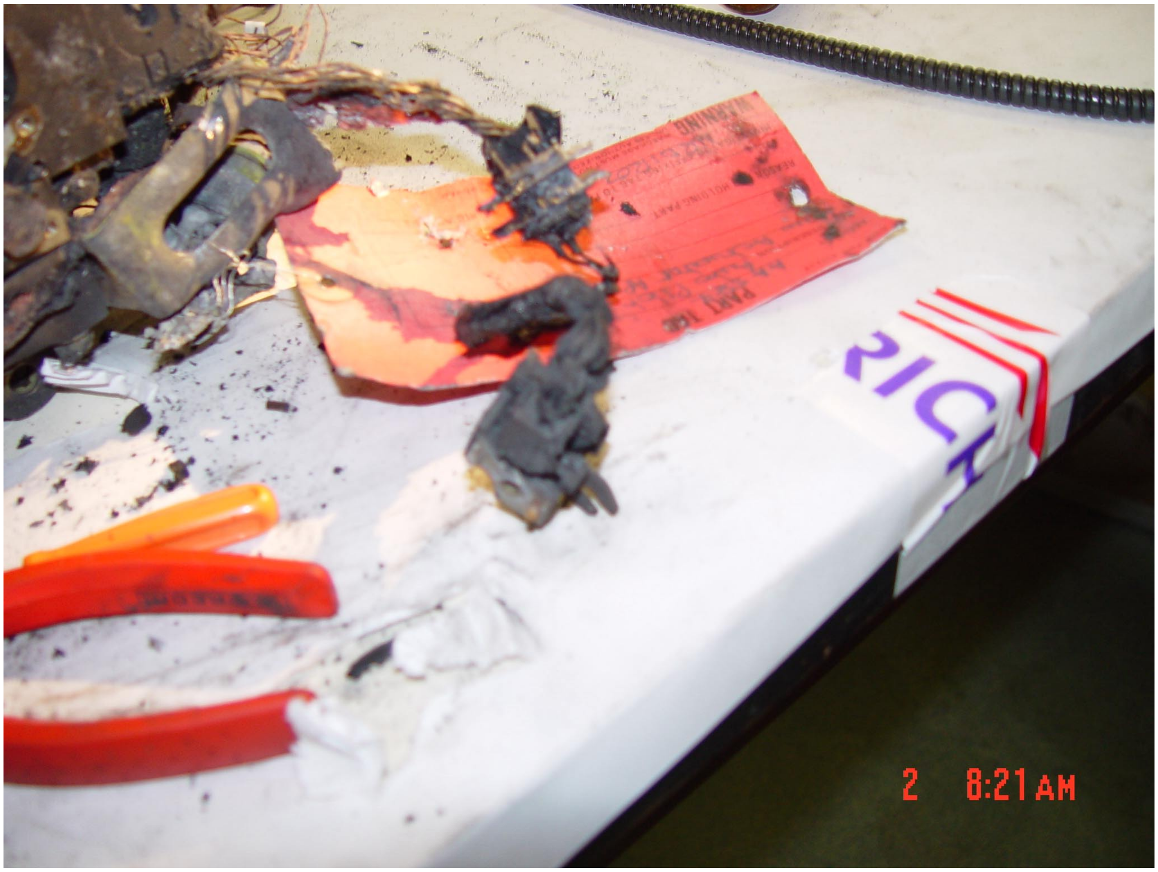


Figure 9. Driving Side Engage Switch and Wiring.

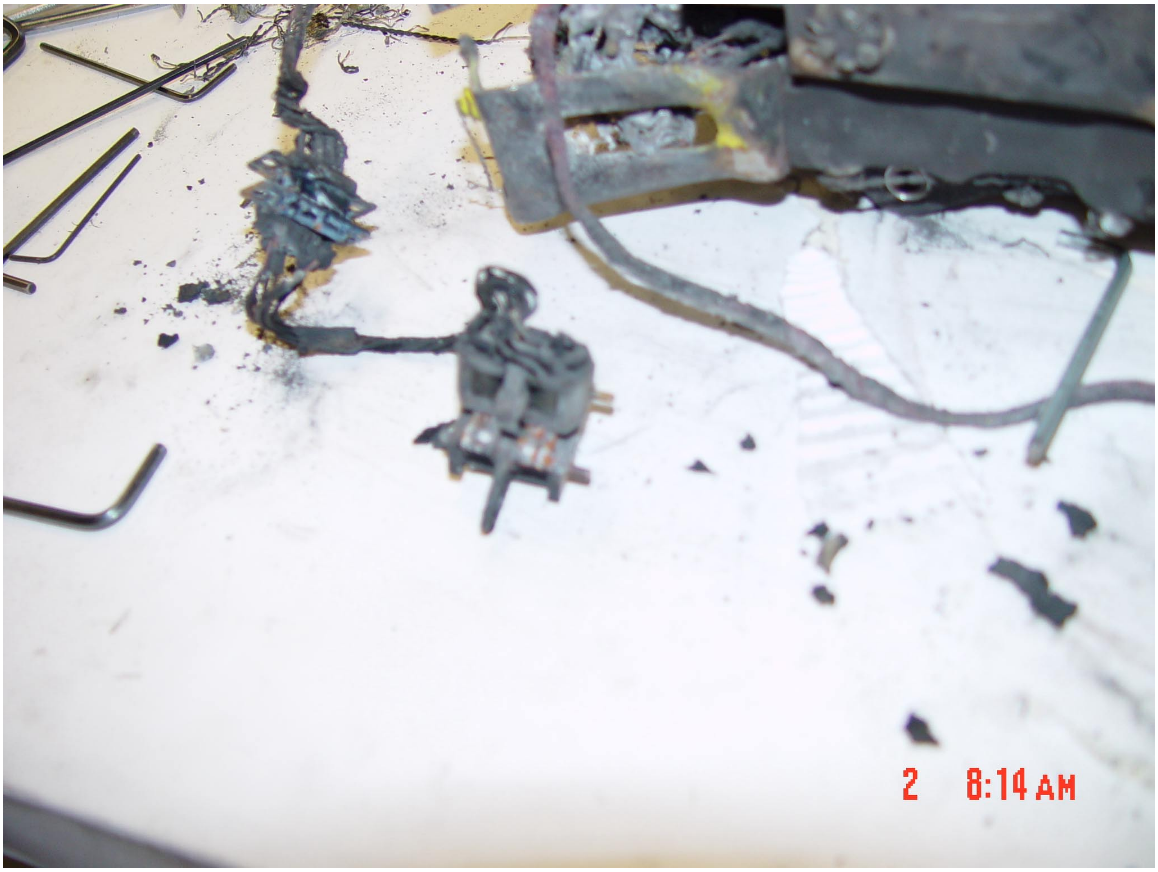


Figure 10. Driven Side Engage Switch and Wiring.

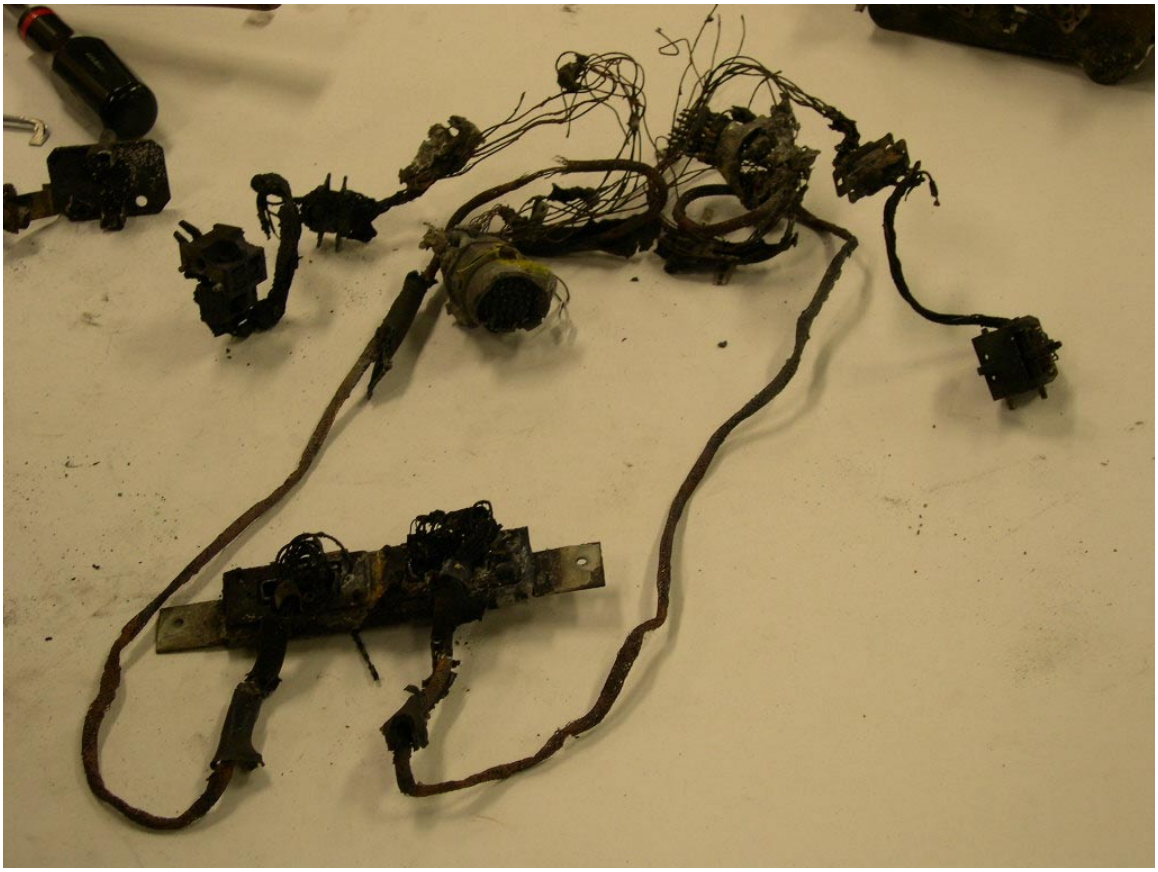


Figure 11. APSM wiring.

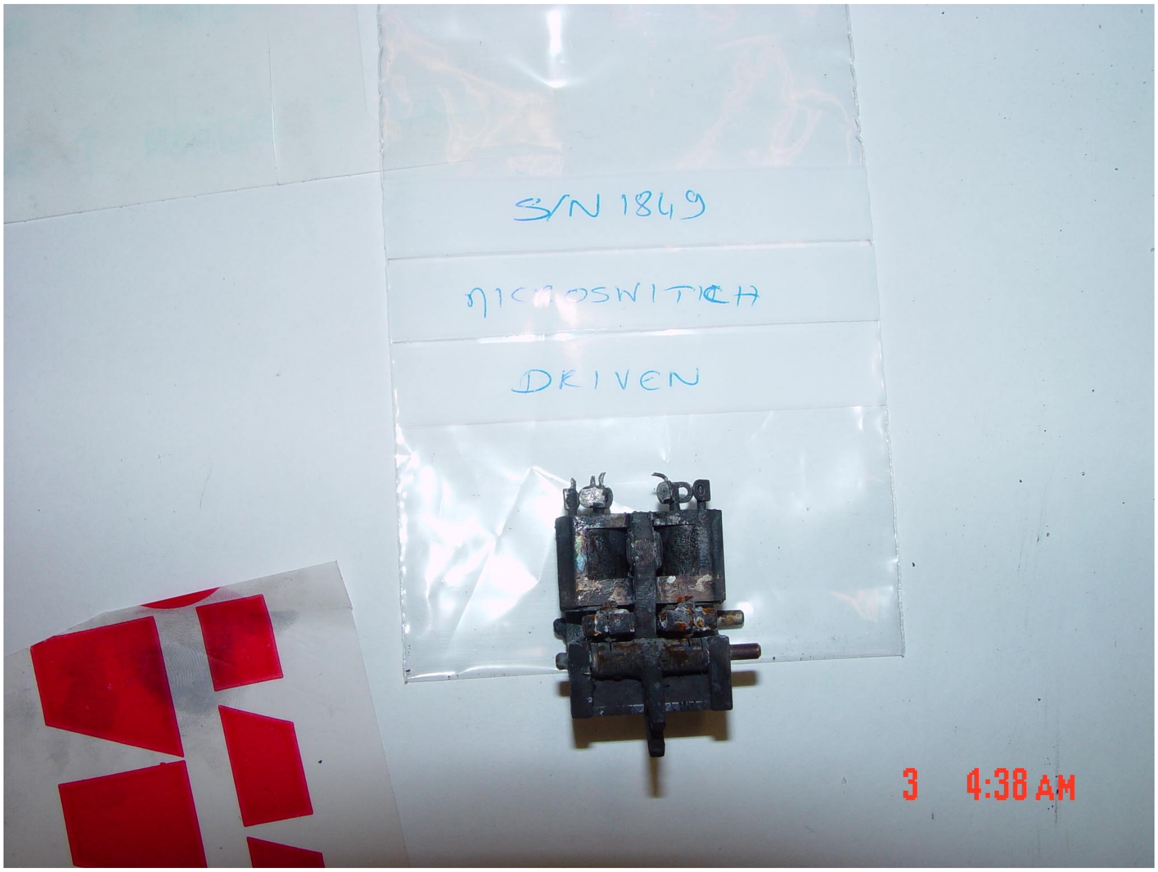


Figure 12. Driven Side Engage Switch.

Figure 13. Driven Side Engage Switch.

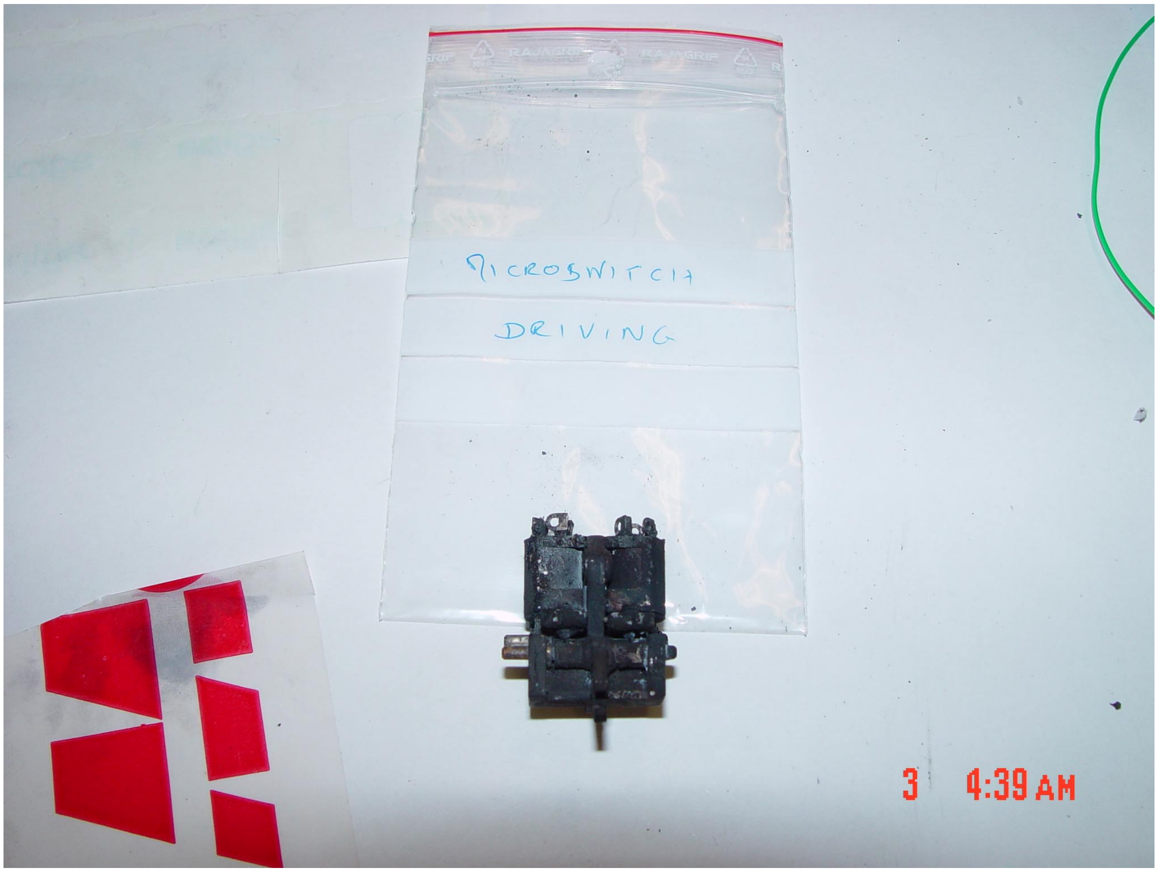


Figure 14. Driving Side Engage Switch.

Figure 15. Driving Side Engage Switch.

Figure 16. Driving Side Hydraulic Block.

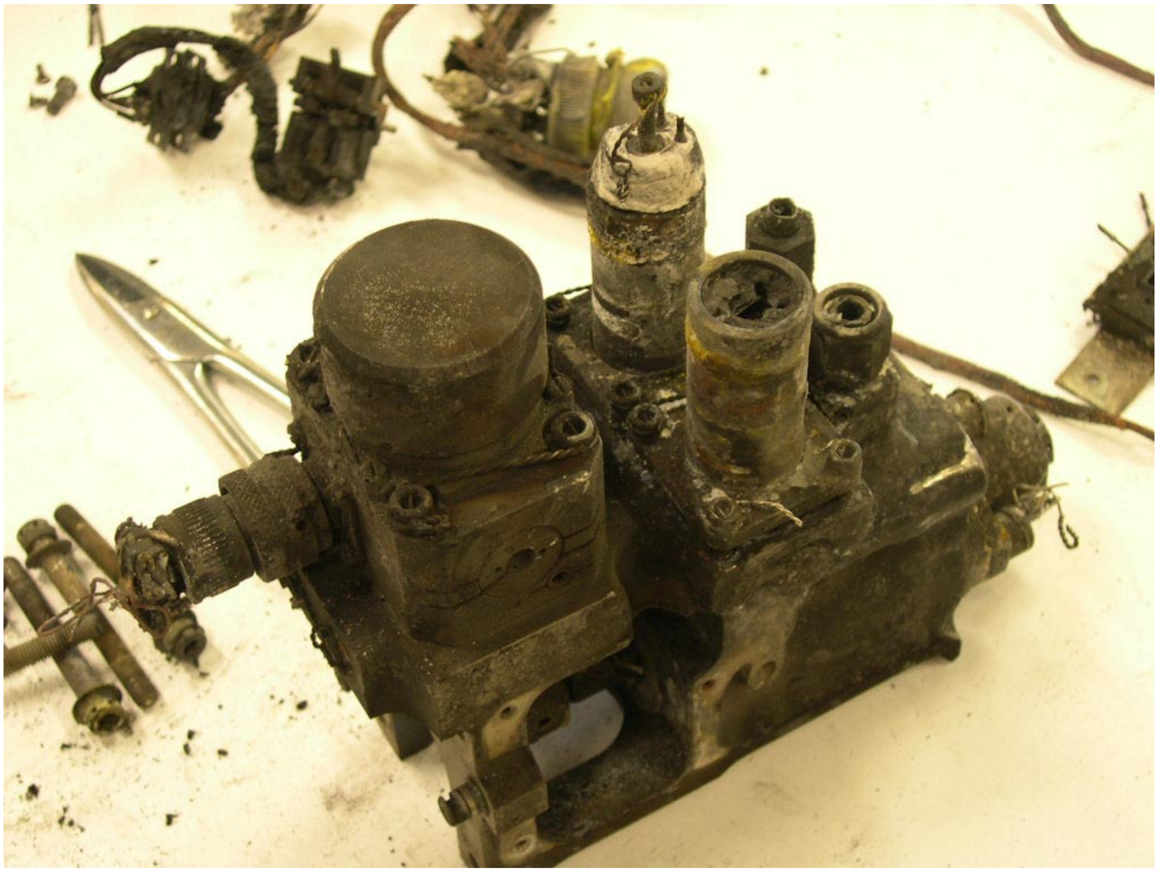


Figure 17. Driven Side Hydraulic Block.

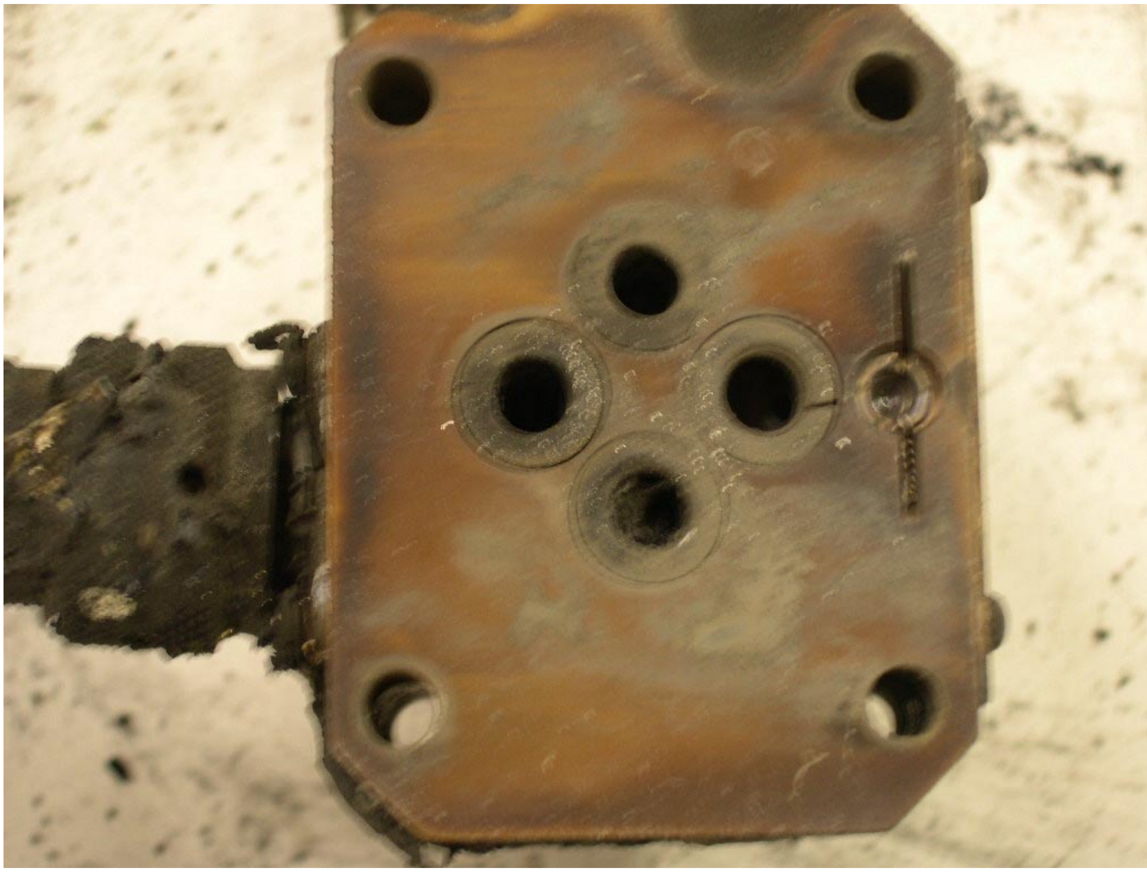


Figure 18. Driving Side Servovalve

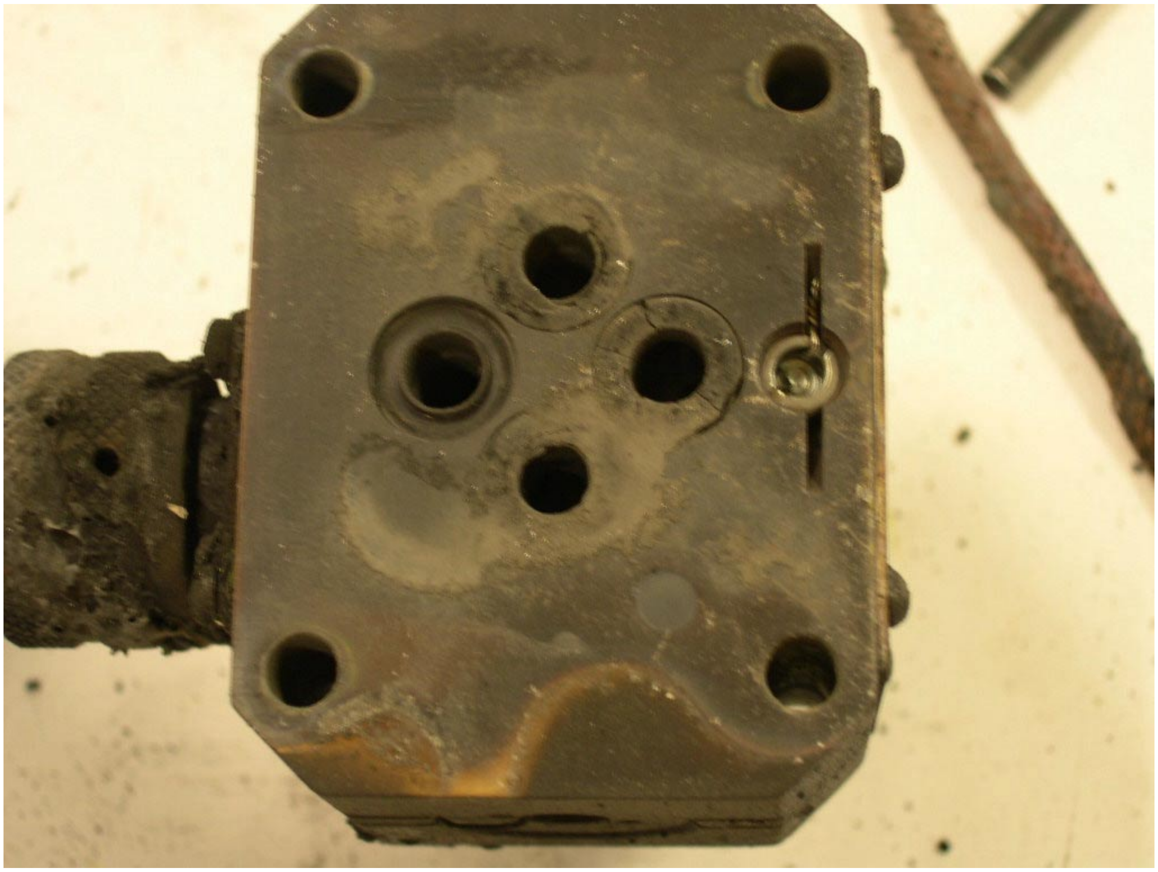


Figure 19. Driven Side Servovalve.

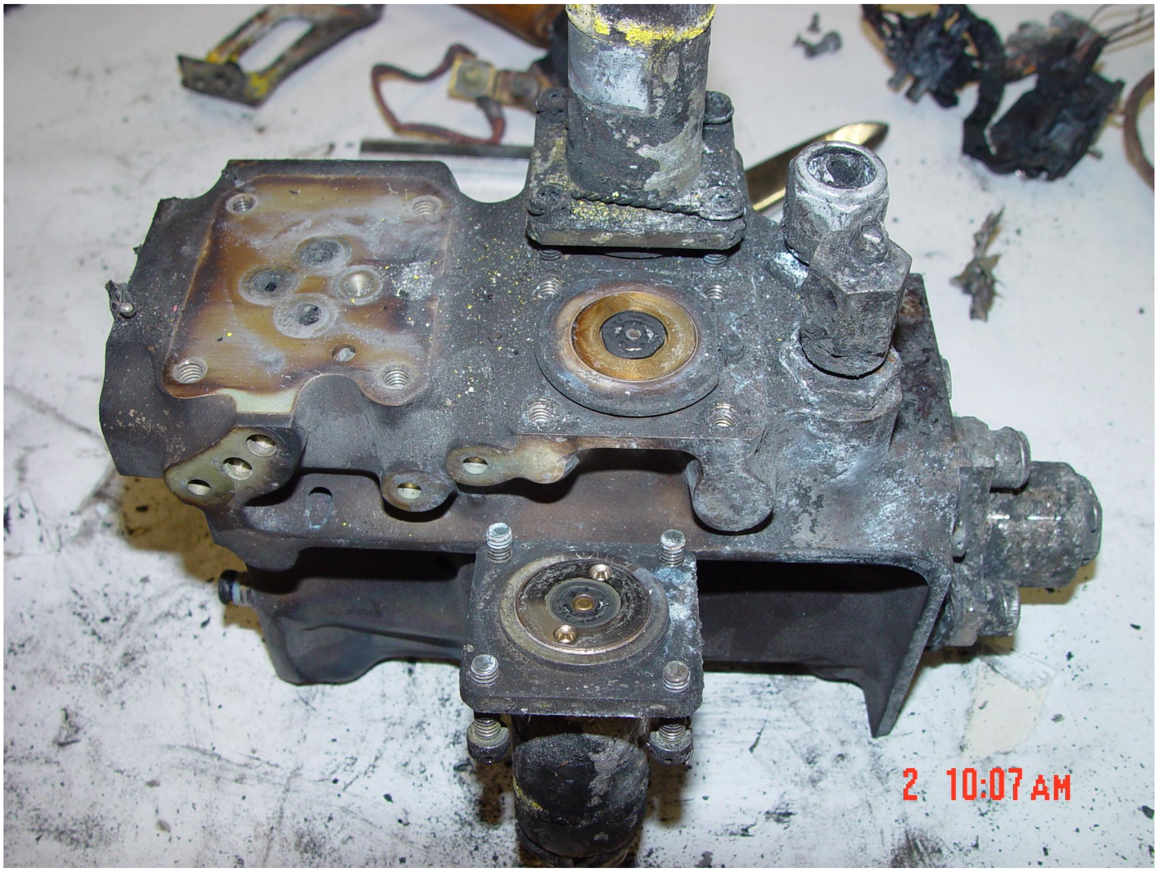


Figure 20. Driving Side With Pressure Solenoid Removed.

Figure 21. Driving Side With Engage Solenoid Removed.

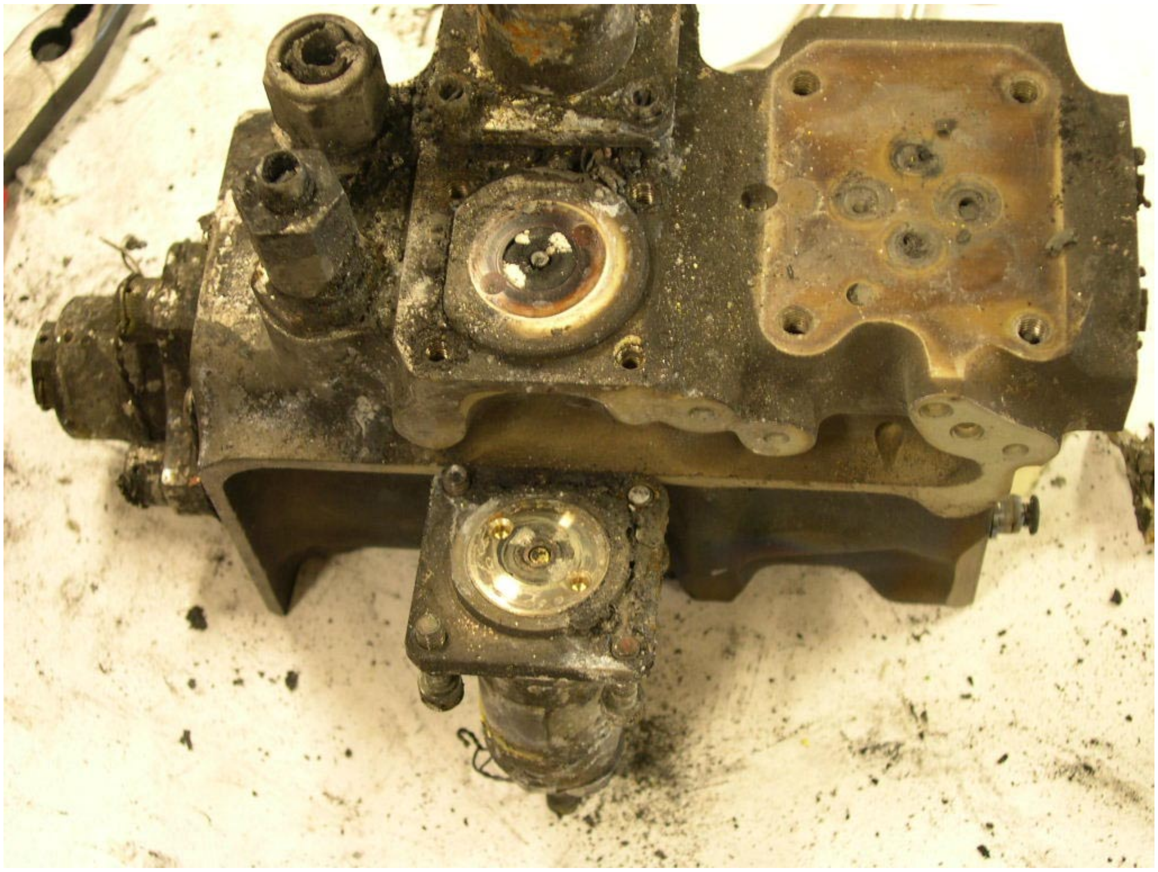


Figure 22. Driven Side With Pressure Solenoid Removed.

Figure 23. Driven Side With Pressure Solenoid Removed.

Figure 24. Driven Side Pressure Solenoid.

Figure 25. Driven Side With Engage Solenoid Removed.

Figure 26. Driving Pressure Solenoid.

Figure 27. Driving Pressure Solenoid.

Figure 28. Driving Pressure Solenoid.

Figure 29. Driven Pressure Solenoid.

Figure 30. Driven Pressure Solenoid.

Figure 31. Driving Engage Solenoid.

Figure 32. Driven Engage Solenoid.

Figure 33. Driving Pressure Solenoid Valve.

Figure 34. Driving Pressure Solenoid Valve.

Figure 35. Driven Pressure Solenoid Valve (bottle label incorrectly).

Figure 36. Driven Pressure Solenoid Valve (bottle label incorrectly).

Figure 37. Driving Engage Solenoid Valve.

Figure 38. Driven Engage Solenoid Valve.

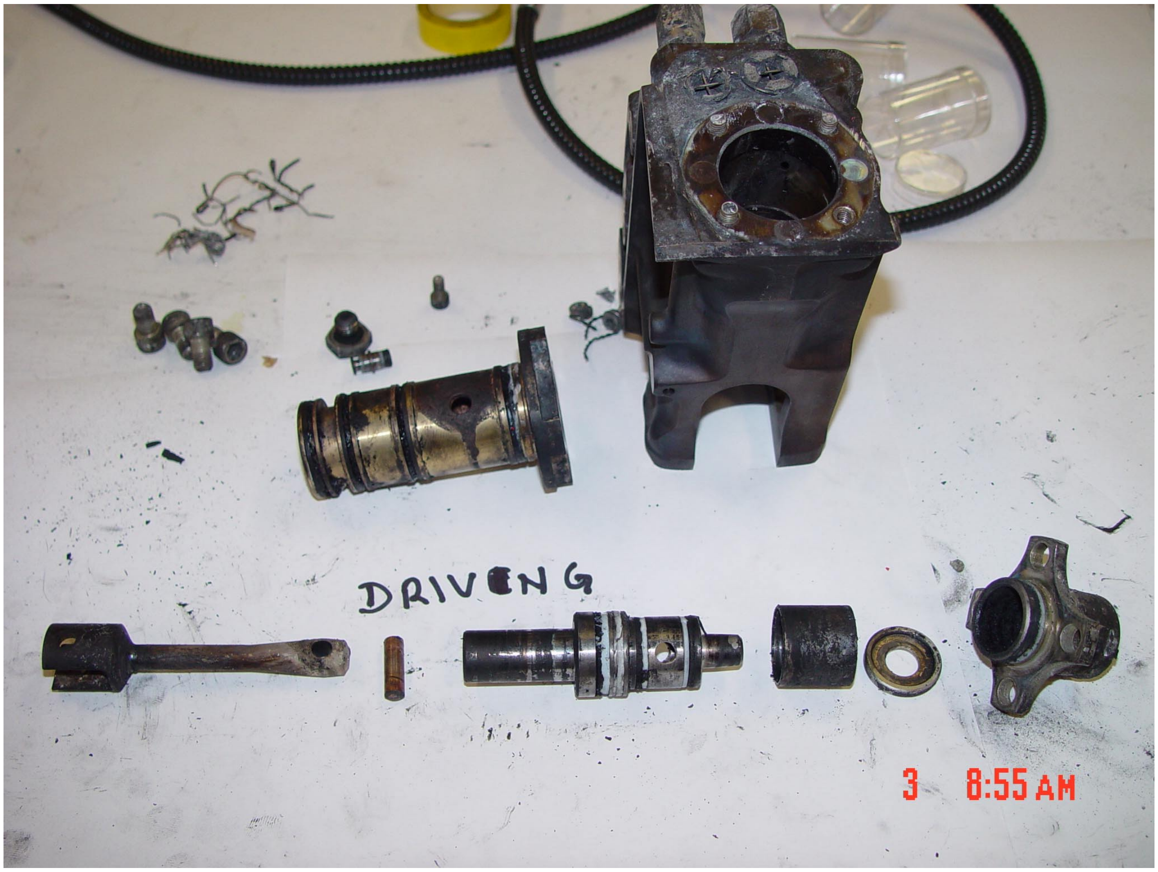


Figure 39. Driving Side Engage Clutch Piston.

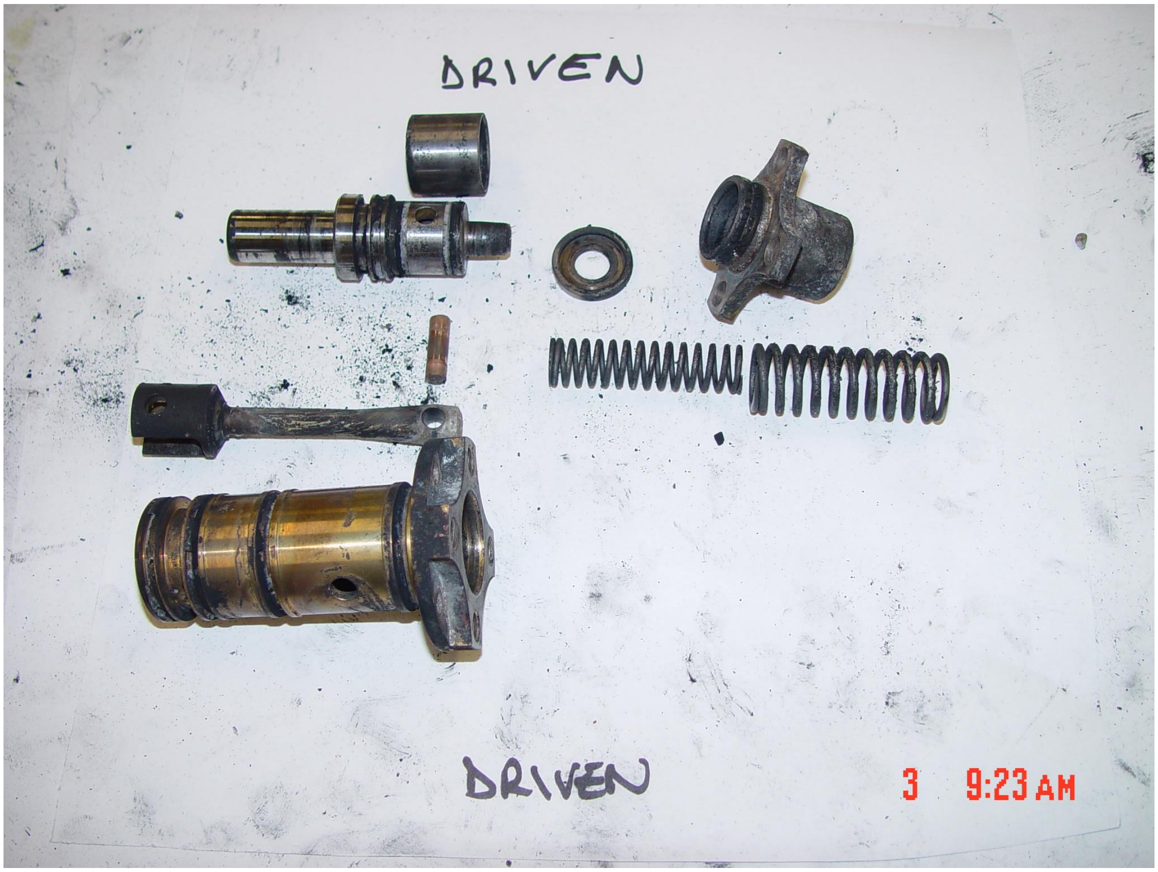


Figure 40. Driven Side Engage Clutch Piston.

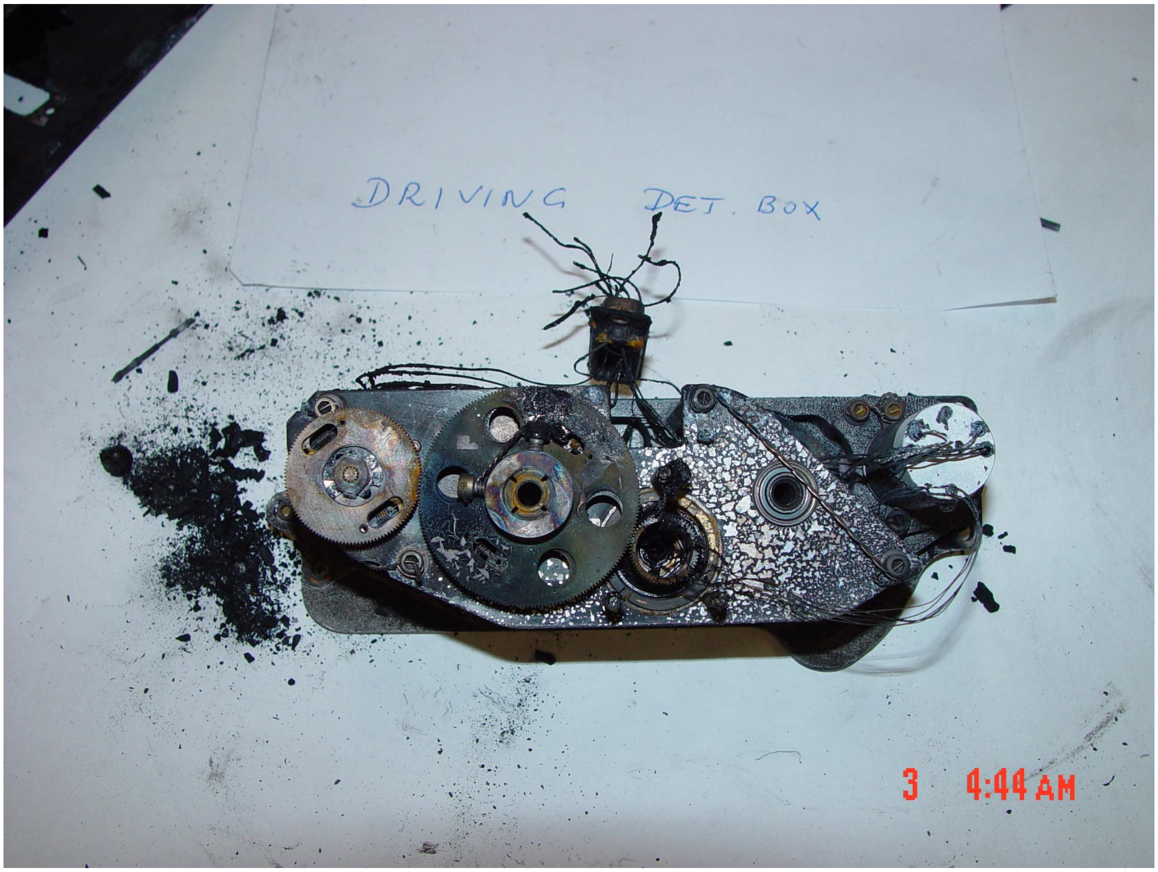


Figure 41. Driving Detection Box.

Figure 42. Driving Detection Box.

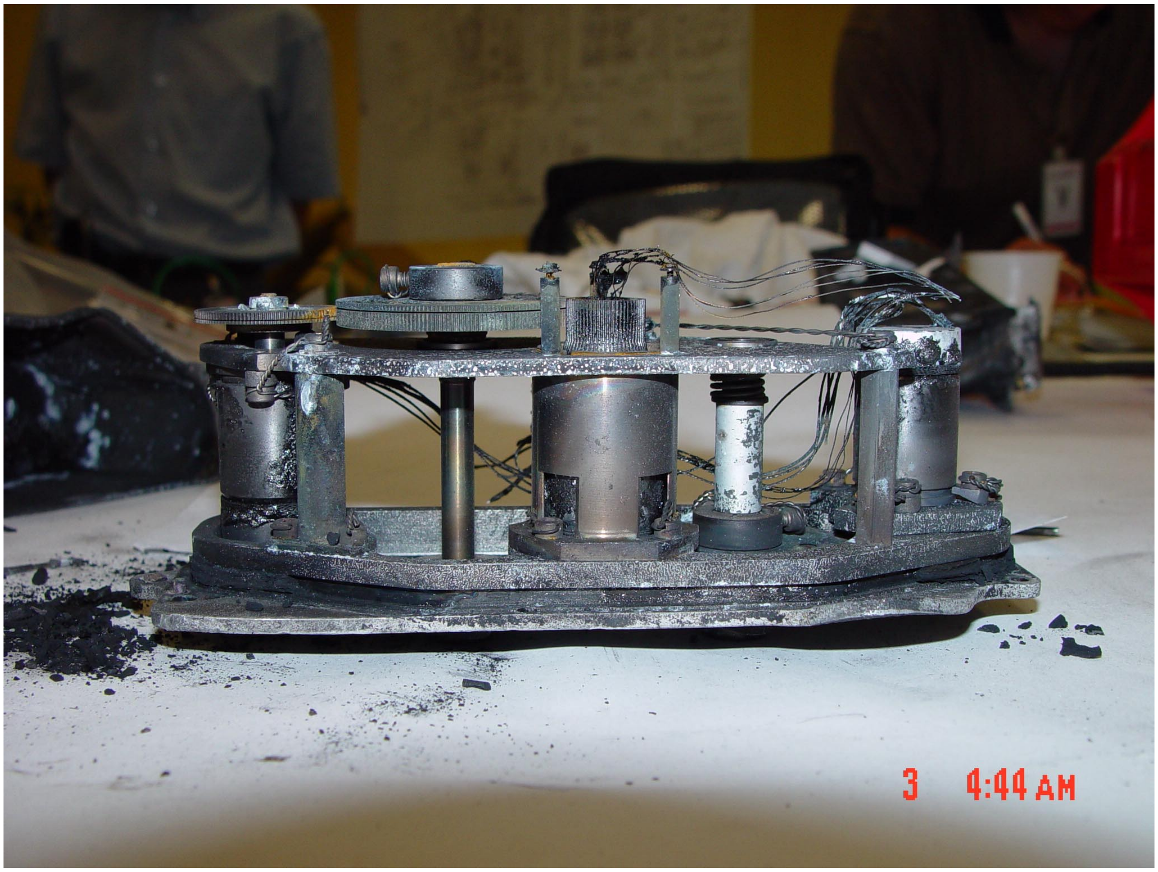


Figure 43. Driving Detection Box.

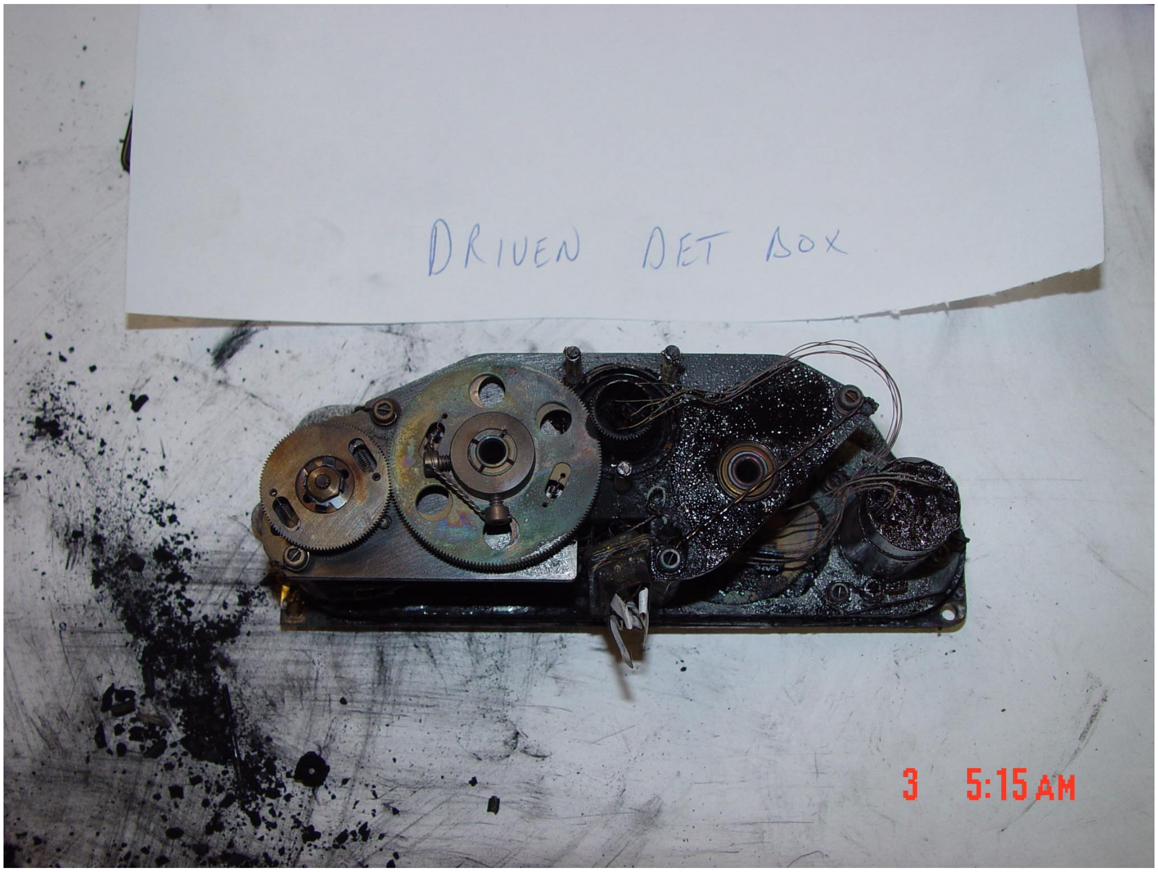


Figure 44. Driven Detection Box.

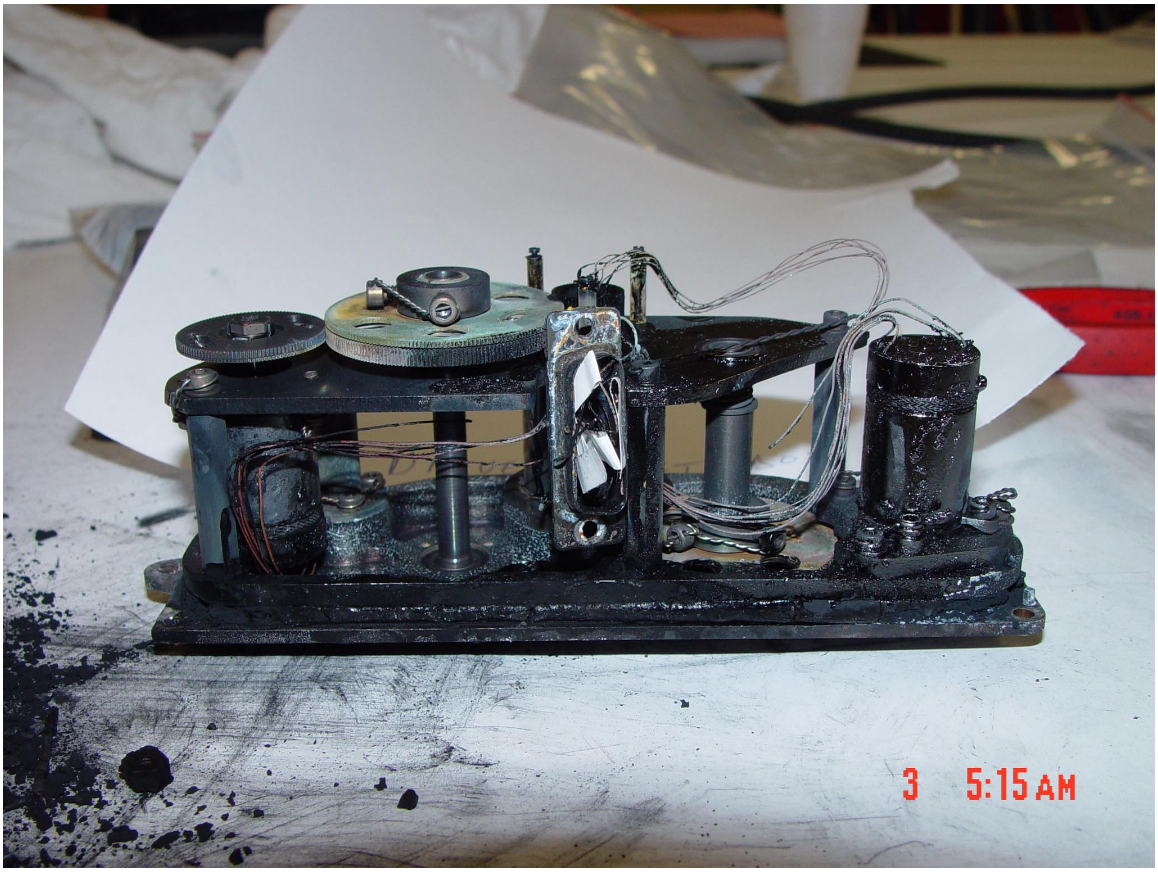


Figure 45. Driven Detection Box.

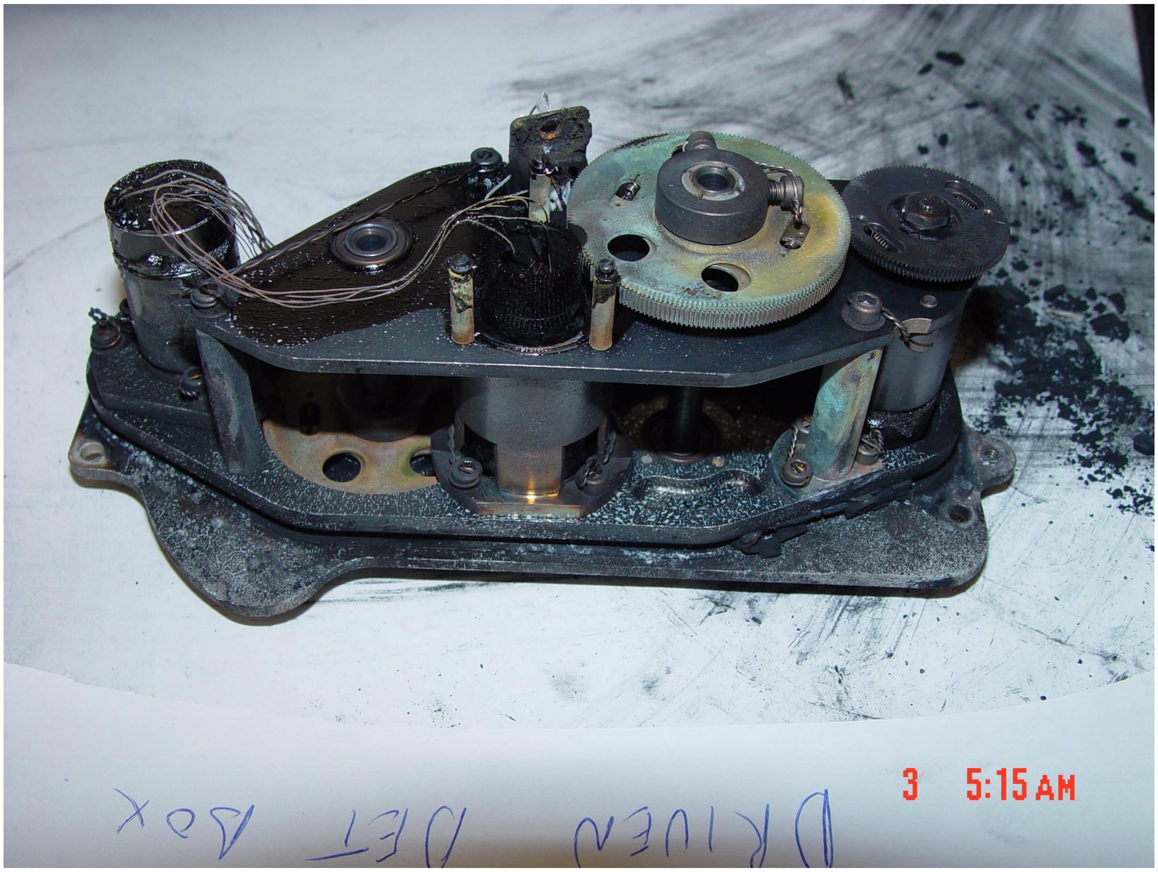


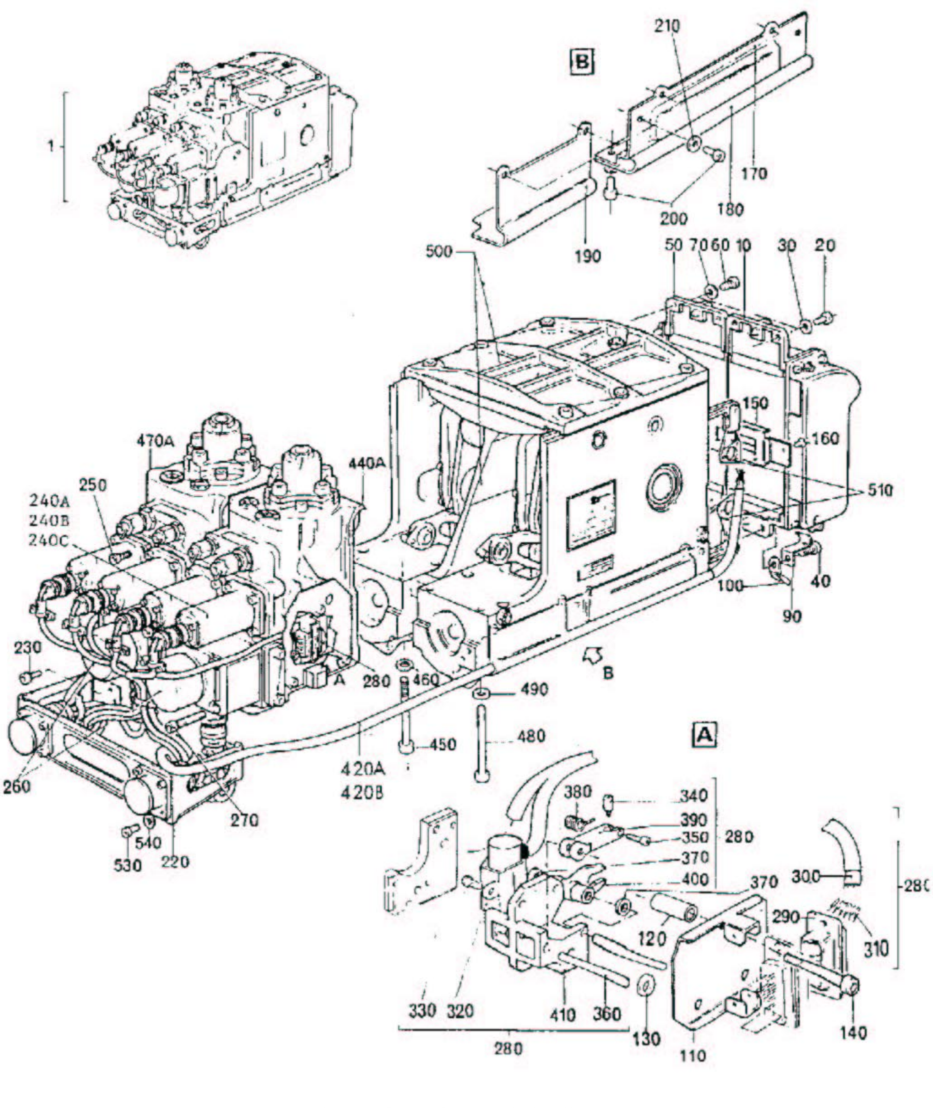
Figure 46. Driven Detection Box.

APPENDIX B

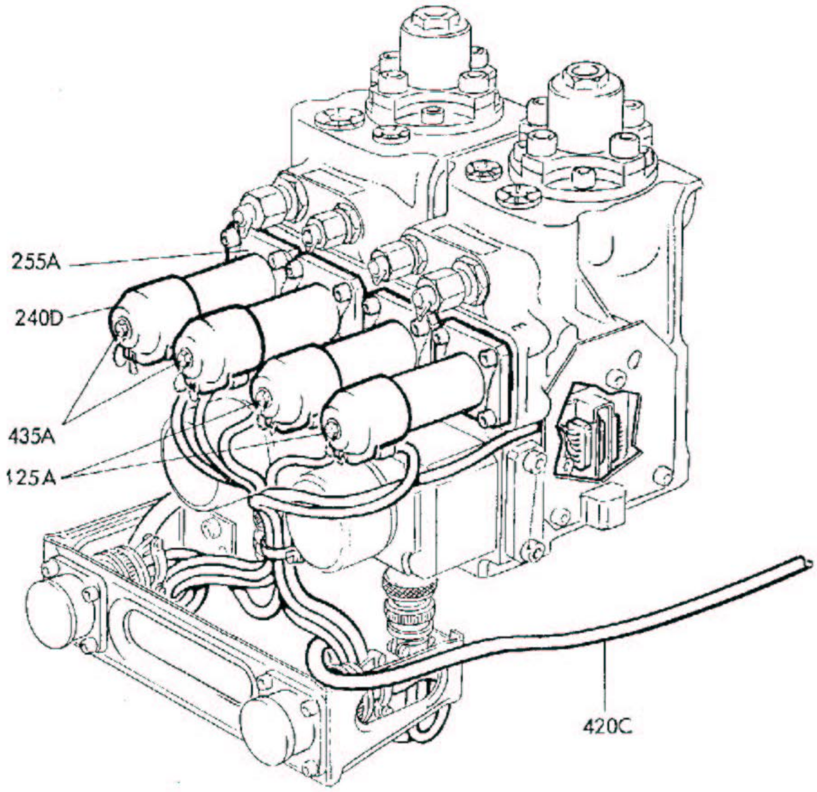
TO

ADDENDUM NUMBER 5 TO THE SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION– AUTOPILOT SERVOMOTOR EXAMINATION

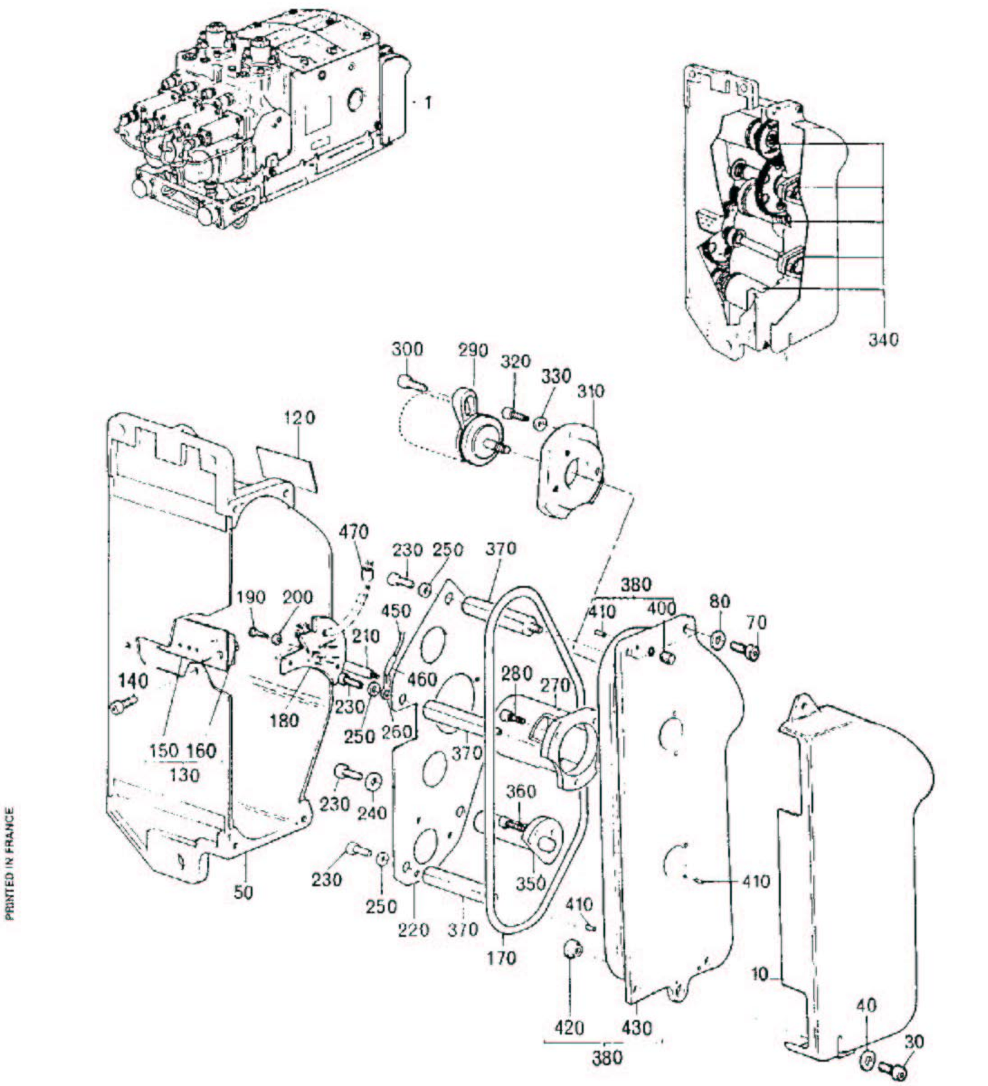
LUCAS AEROSPACE
COMPONENT MAINTENANCE MANUAL
30513



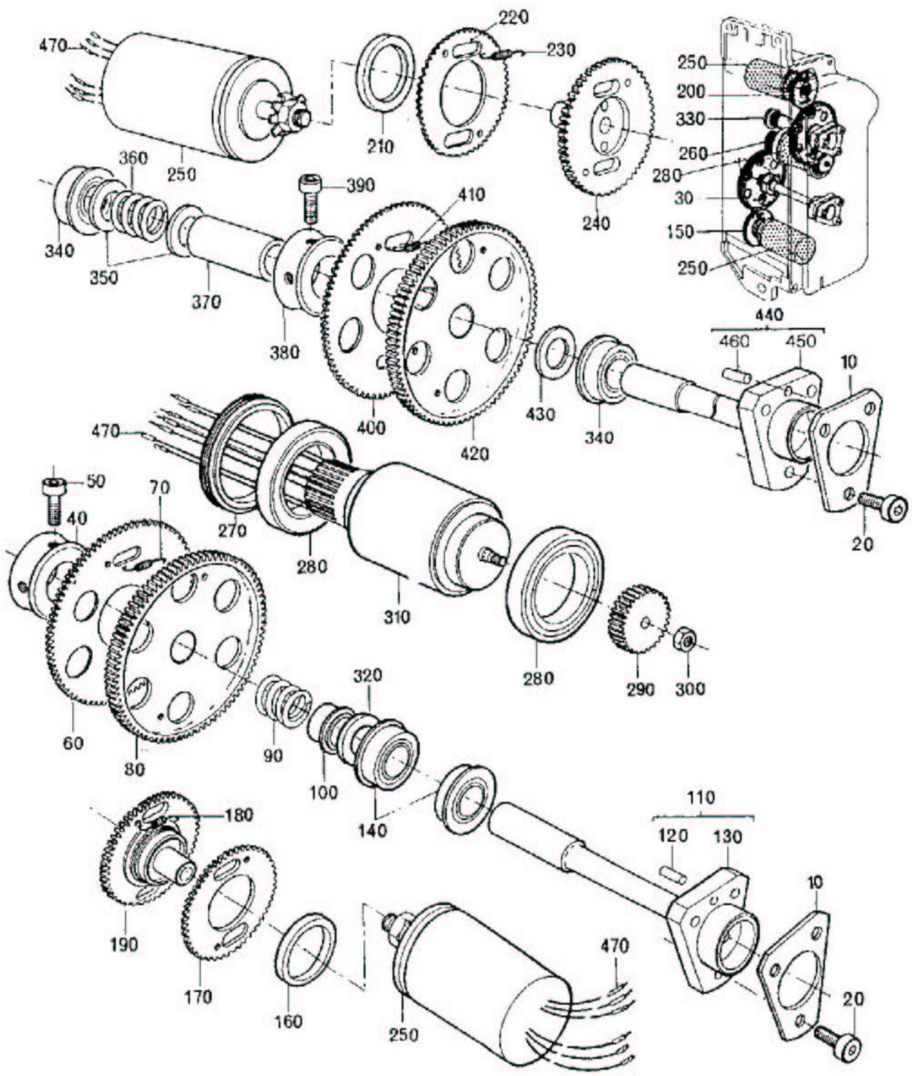
AUTOPILOT SERVO–MOTOR
Figure 1



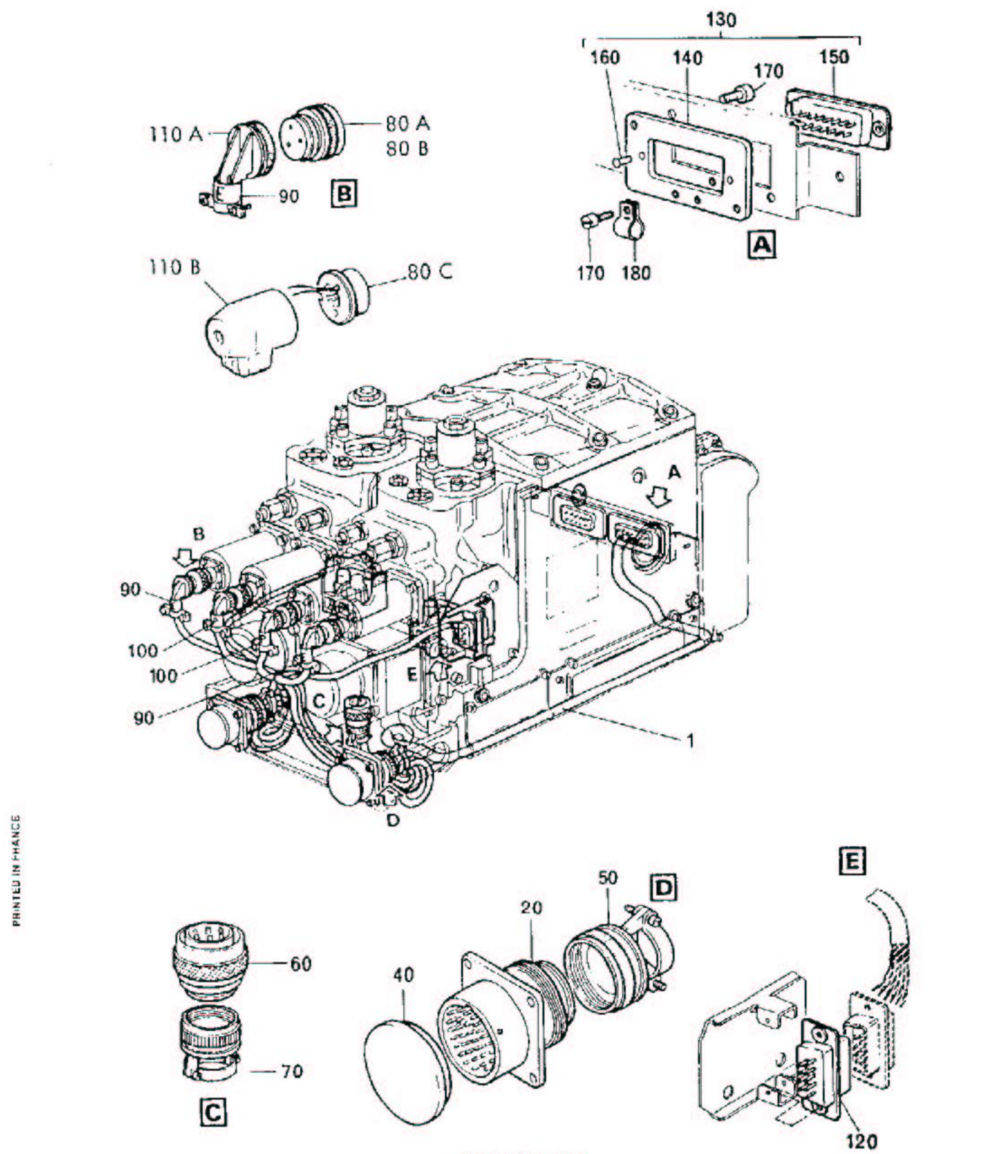
AUTOPILOT SERVO-MOTOR
Figure 1A



BOX, DETECTION
Figure 2

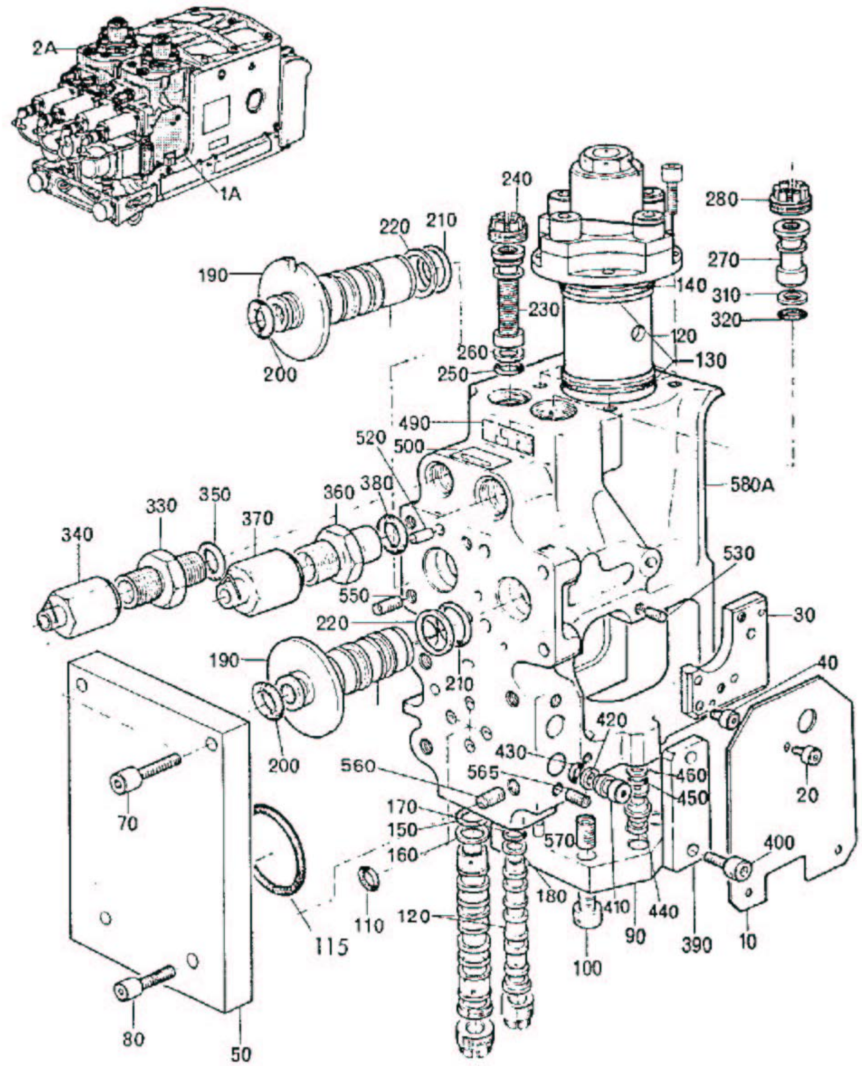


WHEEL, PIN
Figure 3



ASSY WIRING
Figure 4

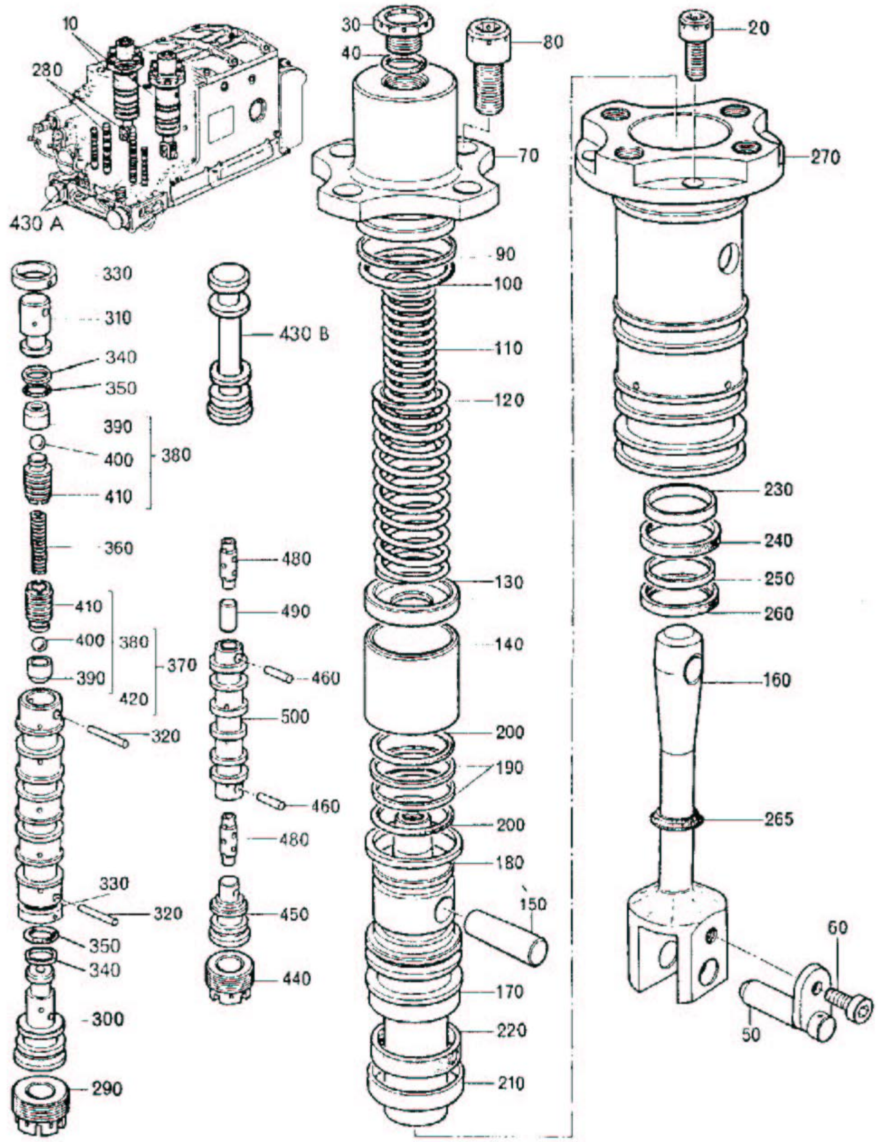
LUCAS AIR EQUIPEMENT
COMPONENT MAINTENANCE MANUAL
30513



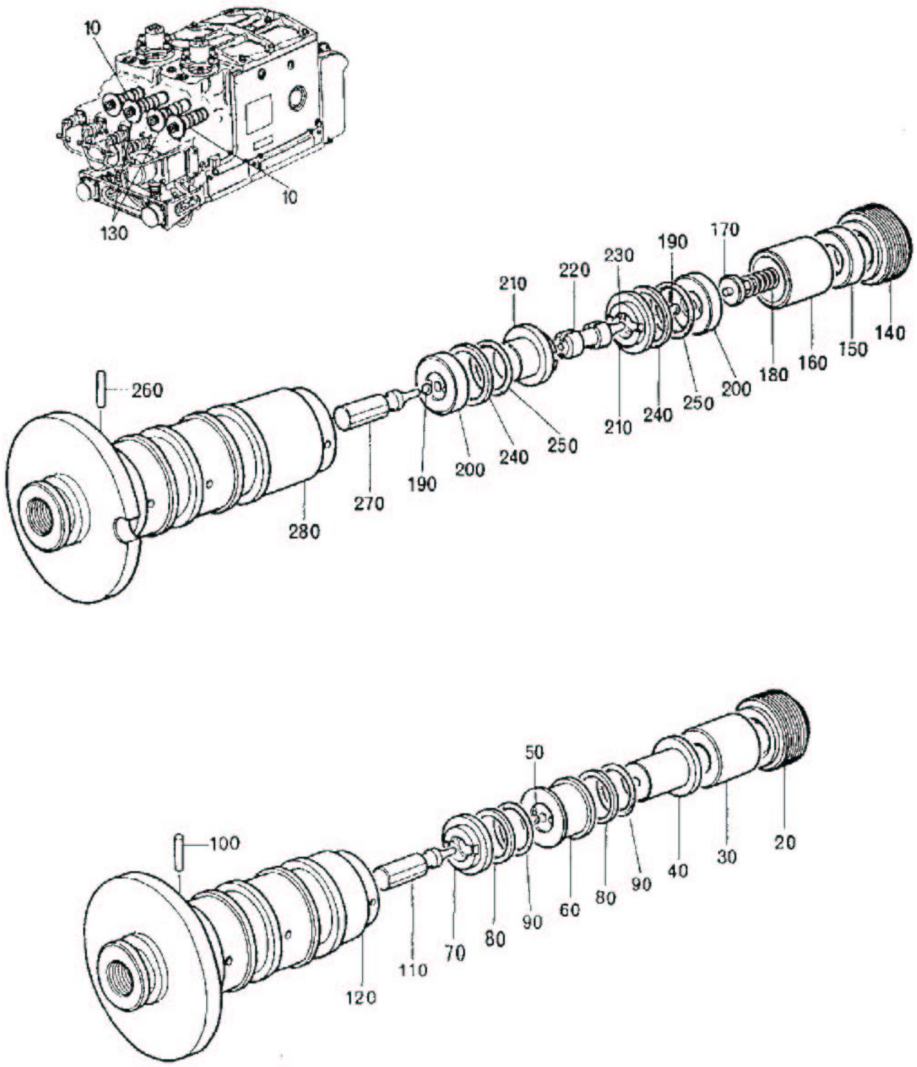
PRINTED IN FRANCE

ASSY UNIT HYDRAULIC

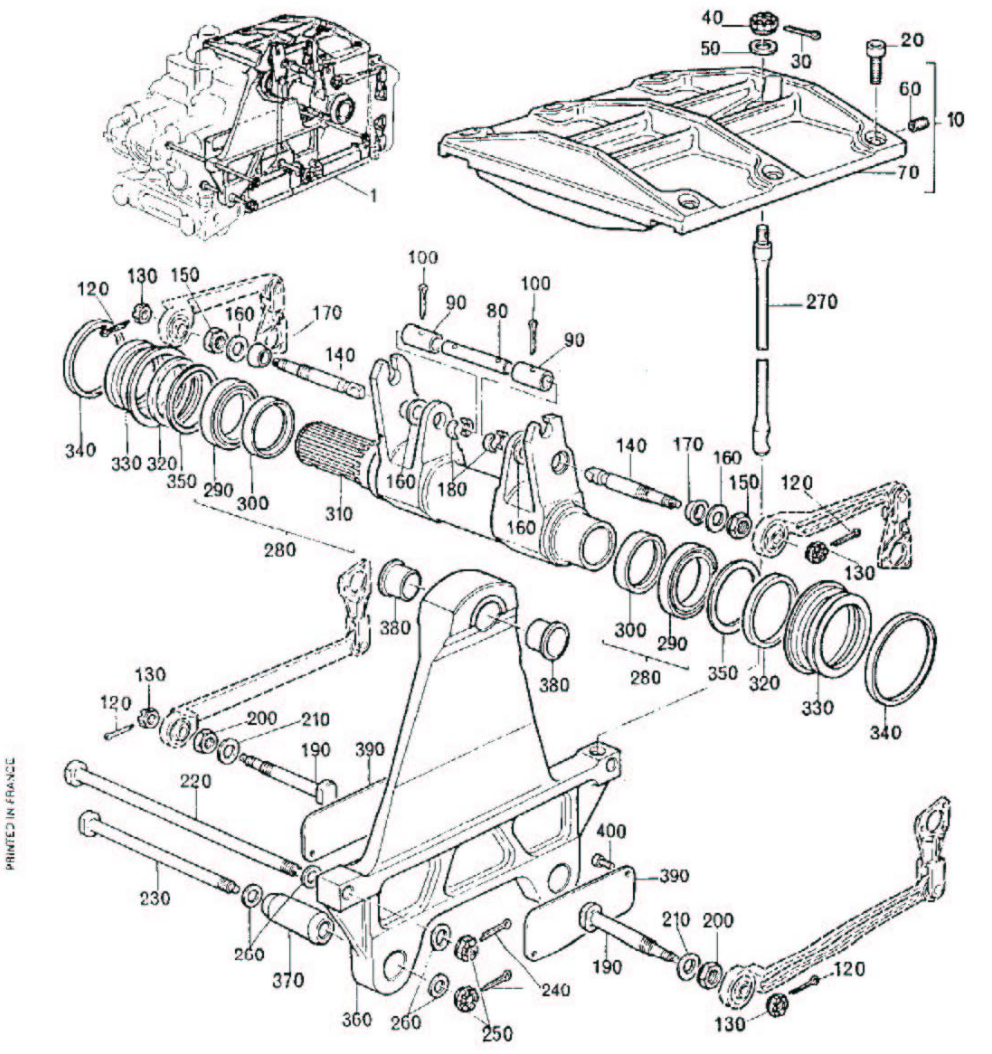
Figure 5



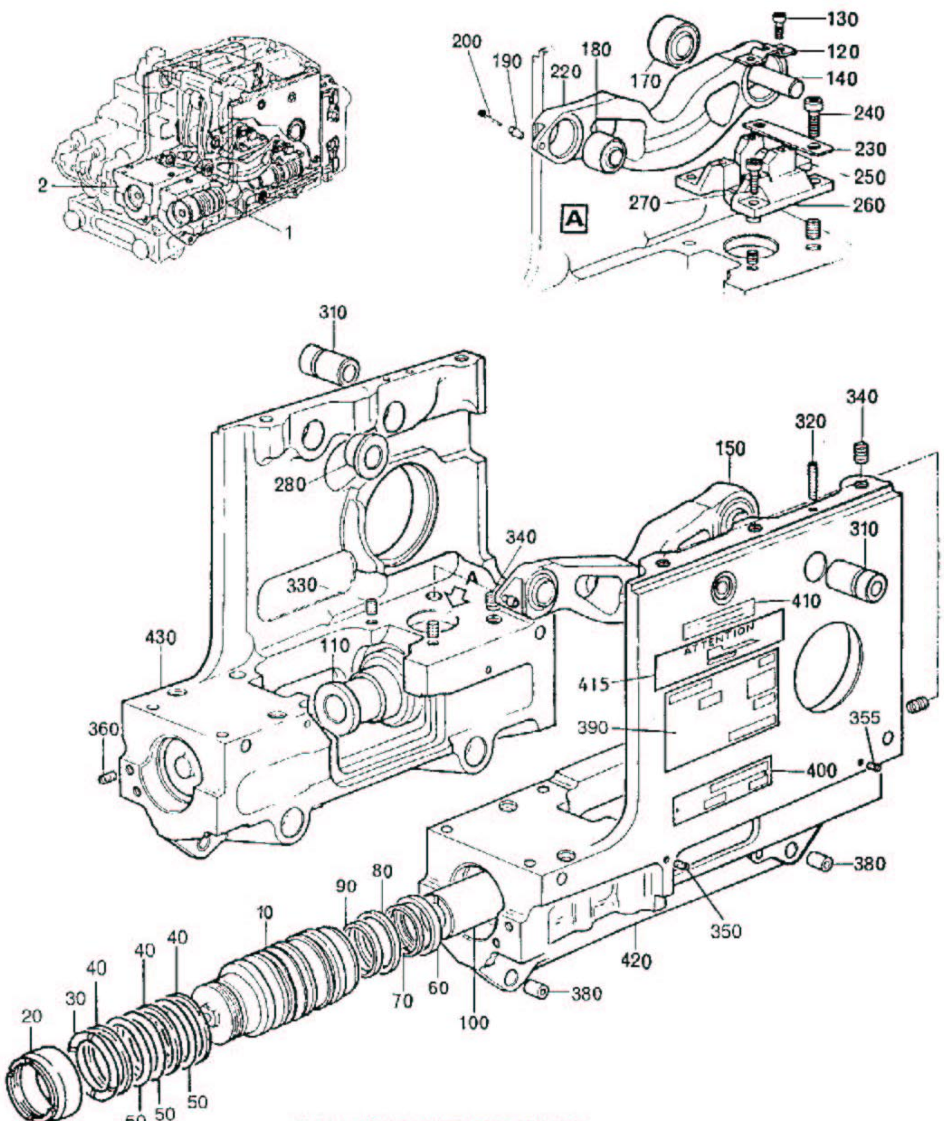
JACK, BY-PASS, LIMITER FLOW
Figure 6



VALVE, SOLENOID
Figure 7

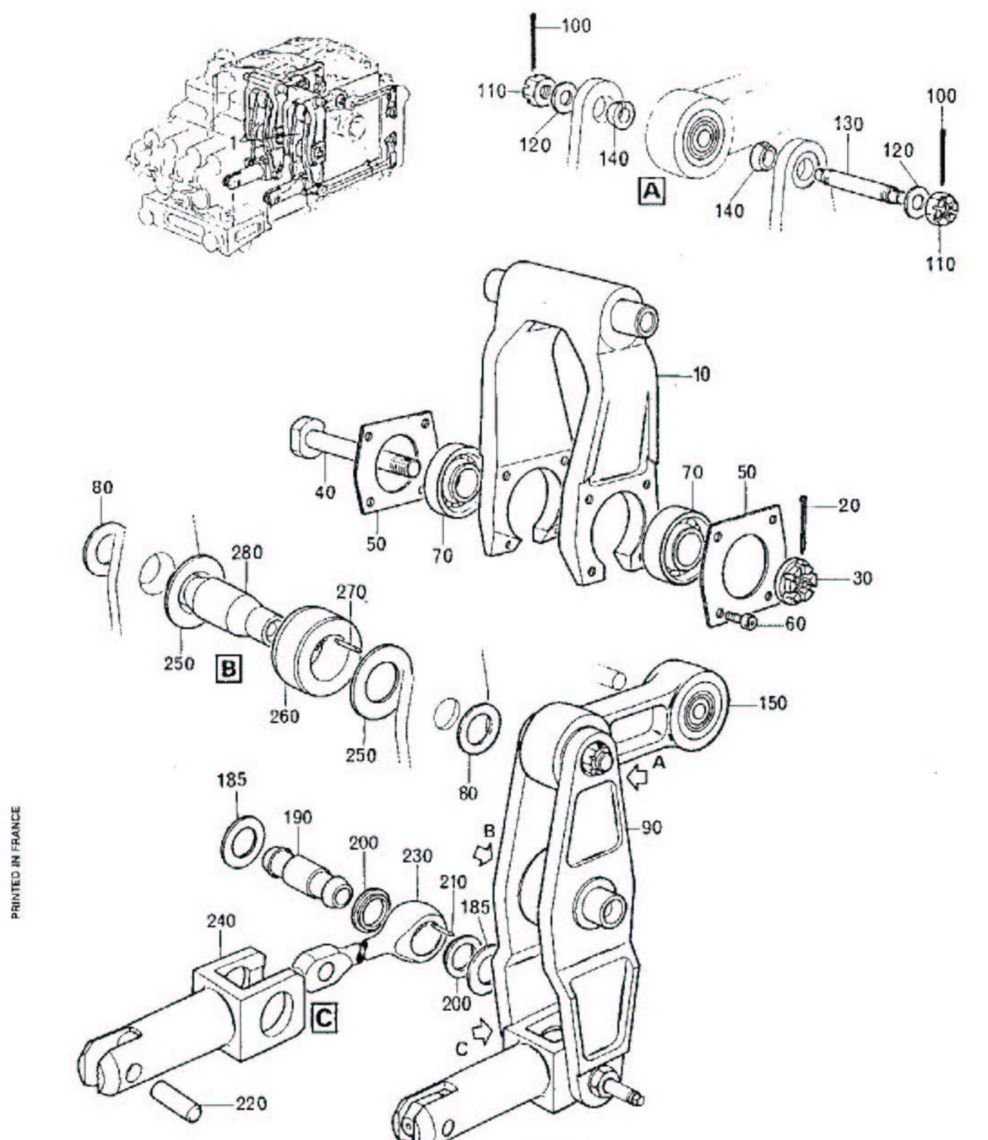


ASSY UNIT MECHANICAL
Figure 8

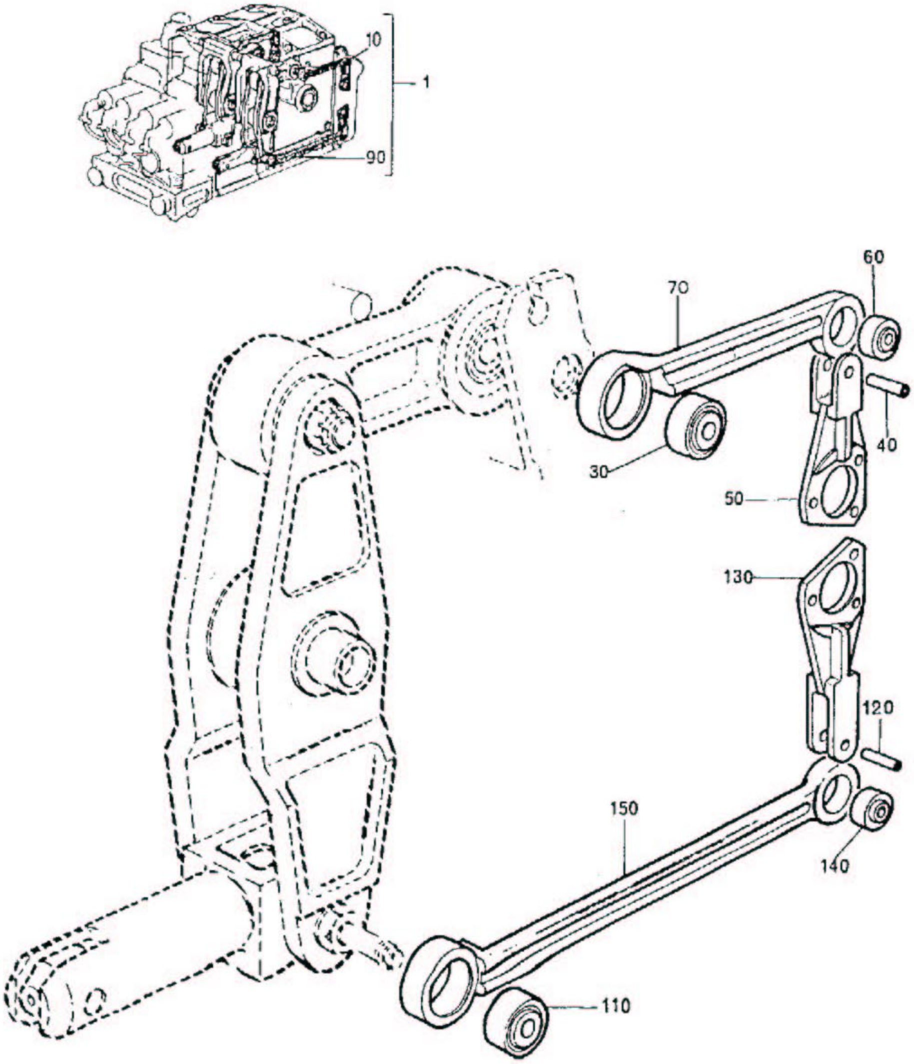


SUB–ASSY UNIT MECHANICAL
Figure 9

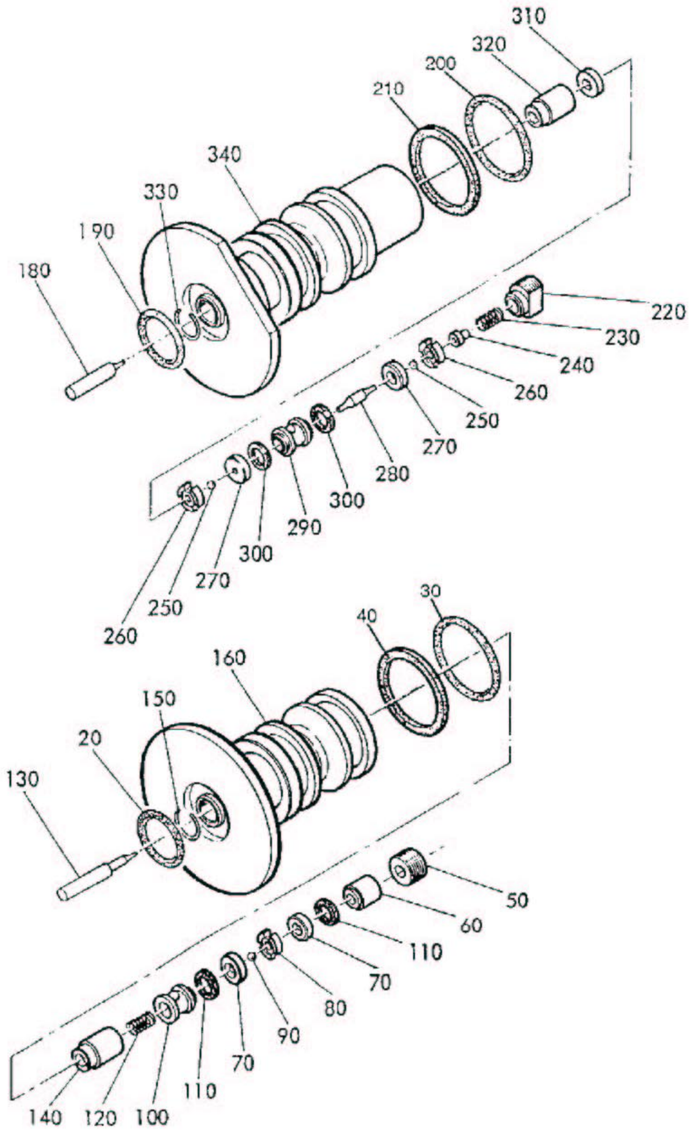
LUCAS AEROSPACE
COMPONENT MAINTENANCE MANUAL
30513



ASSY LINKAGE
Figure 10



LINKAGE, DETECTION
Figure 11



VALVE, SOLENOID
Figure 13

APPENDIX C

TO

ADDENDUM NUMBER 5 TO THE SYSTEMS GROUP CHAIRMAN'S FACTUAL REPORT OF INVESTIGATION– AUTOPILOT SERVOMOTOR EXAMINATION

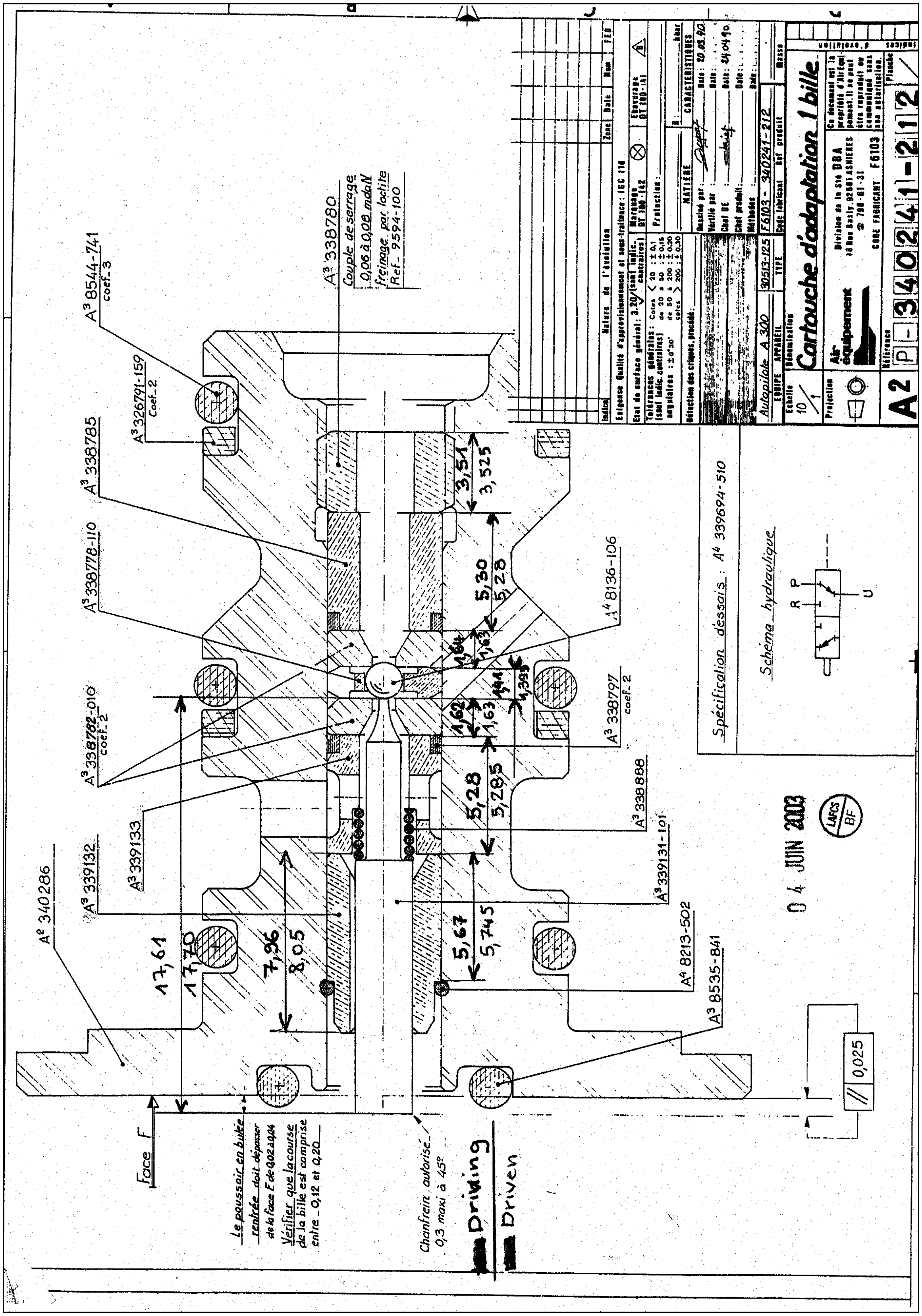


Figure 1. Engage Solenoid Valve (1 Ball).

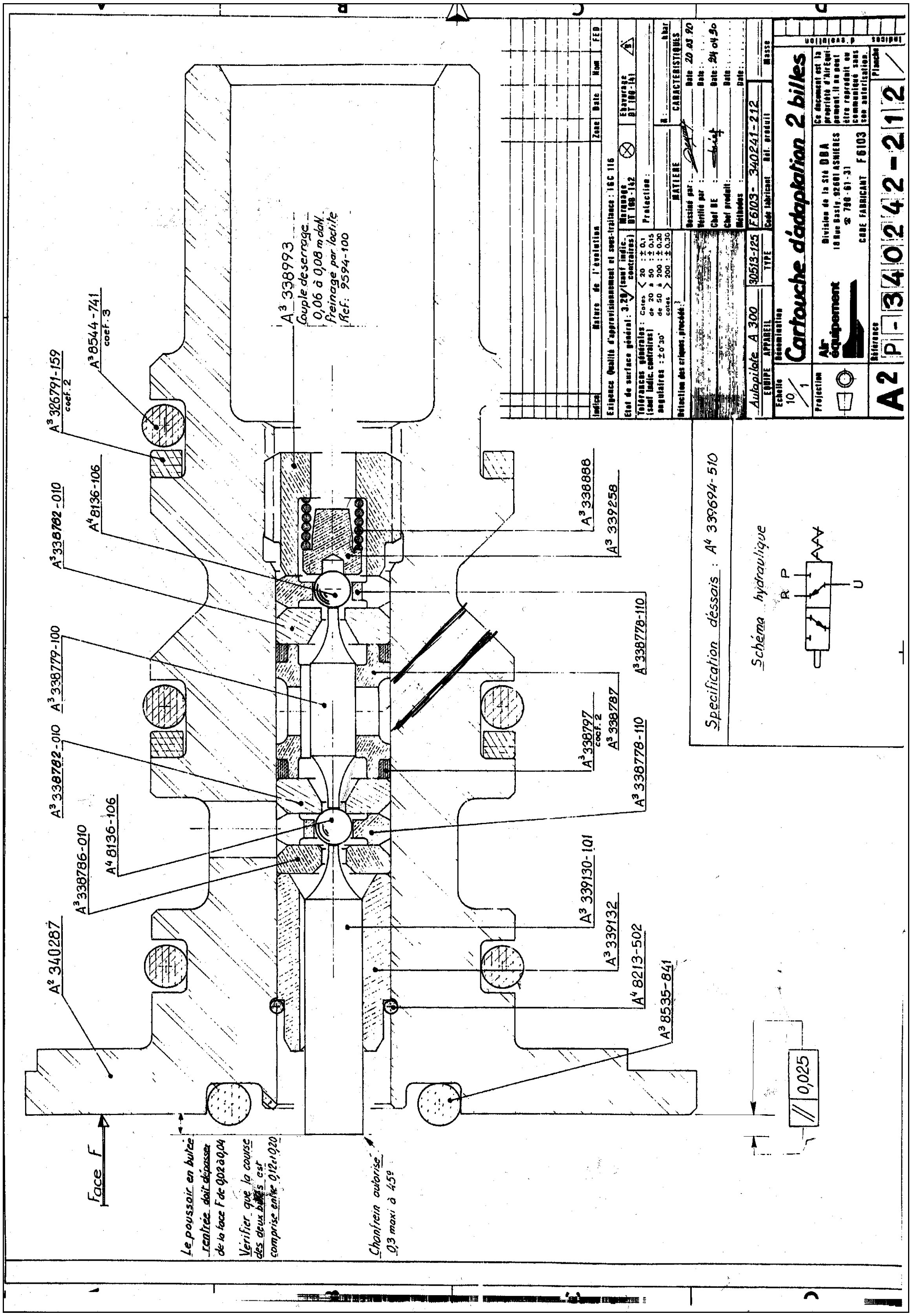


Figure 2. Pressure Solenoid Valve (2 Ball).

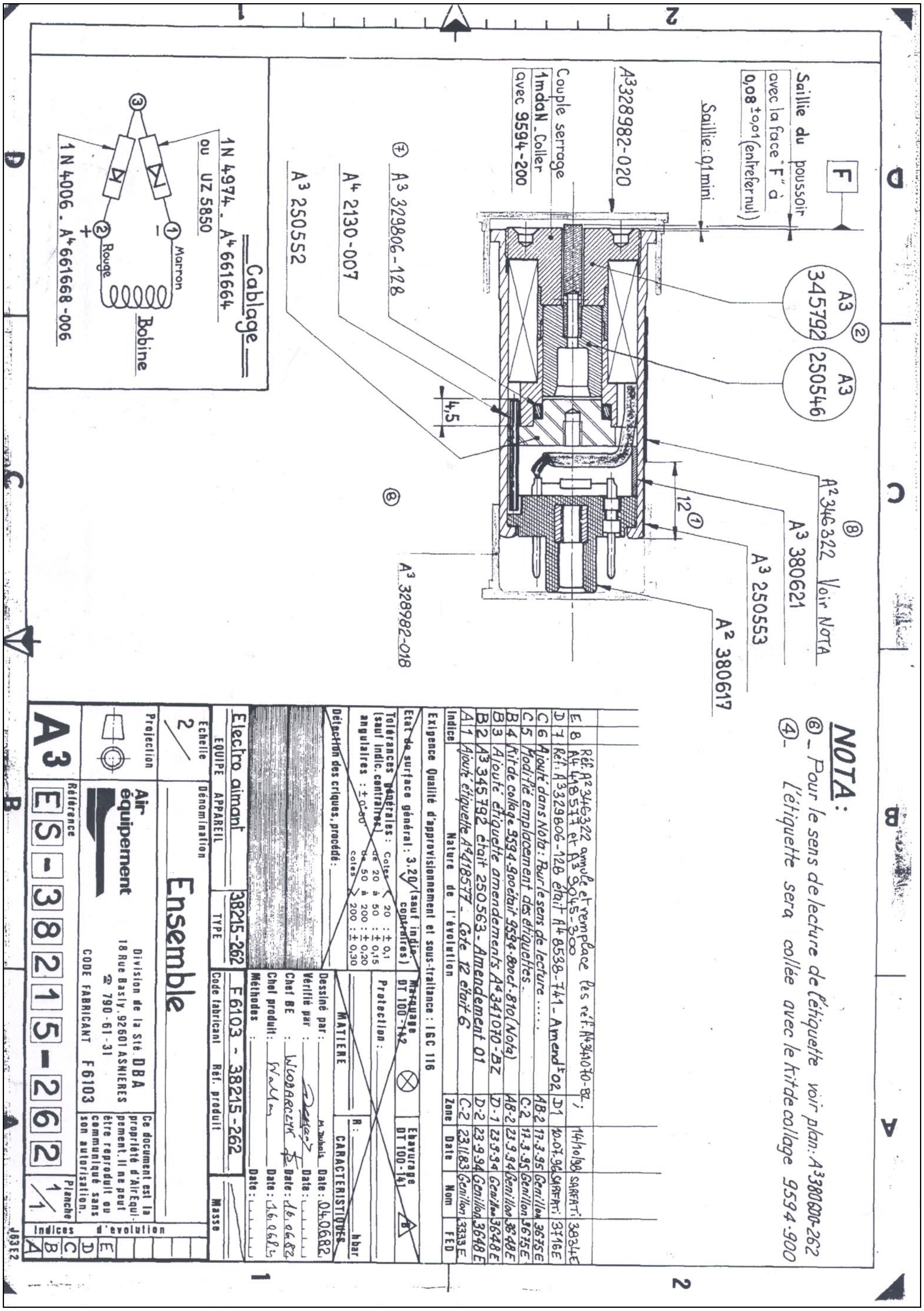


Figure 3. APSM Solenoid Drawing

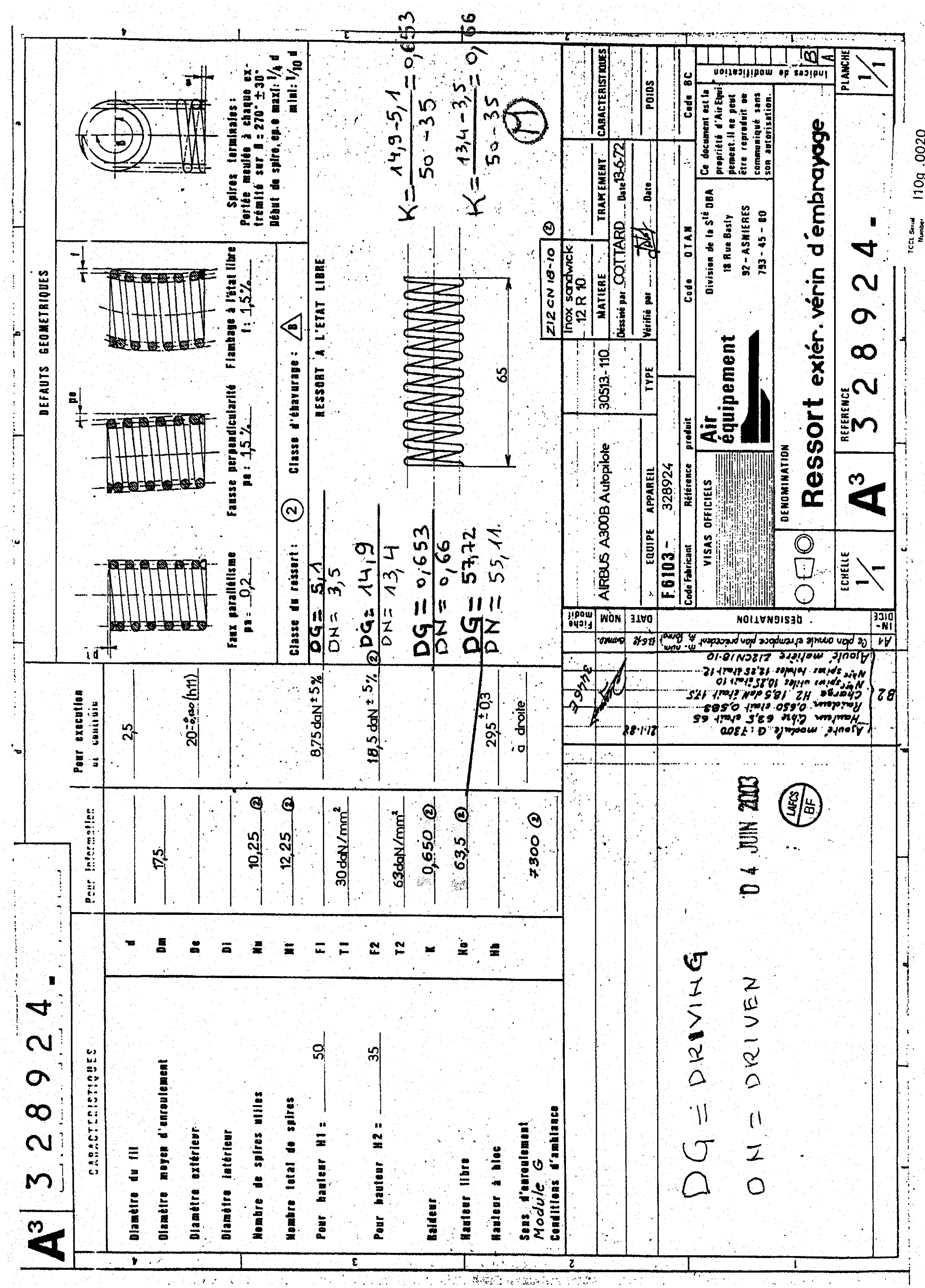


Figure 4. Dimensional Check of Engagement Spring.

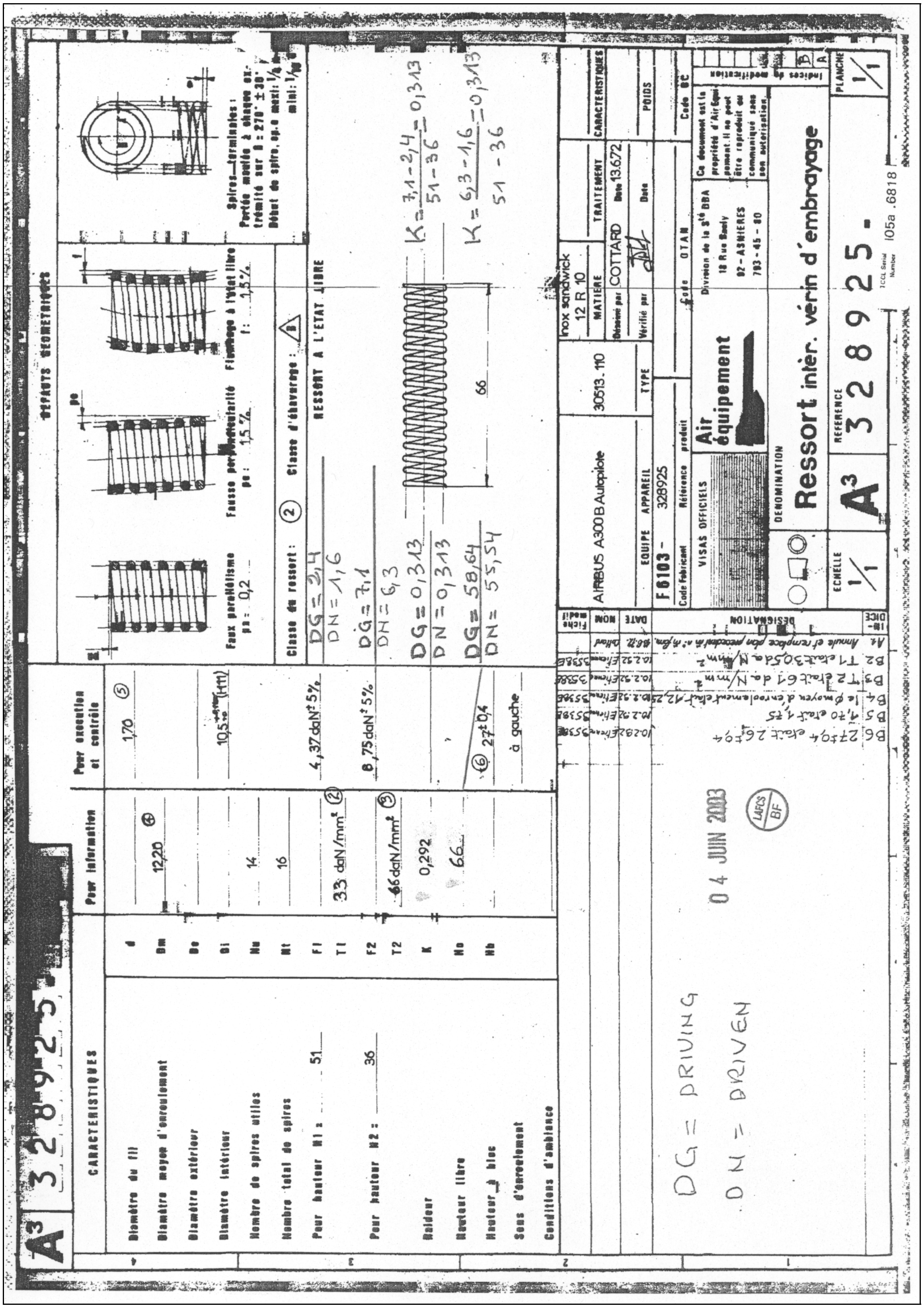


Figure 5. Dimensional Check of Engage Spring.