SPACE SHUTTLE RELATED MAINTENANCE EXPERIENCE WITH THE X-15 AIRCRAFT

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INTRODUCTION

The X-15 airplane was a rocket-engine-powered research vehicle which made many flights to 250,000 feet altitude and higher and to Mach numbers greater than 5. In maintaining the airplane, many small repair items were required between flights. Although each item might not be significant in itself, the total number of items required a significant amount of maintenance time. The time at which a problem occurred or was found in relation to the preflight activity which had already been accomplished would sometimes cause an otherwise minor discrepancy to have a major effect on the flight schedule.

This paper discusses the maintenance activity between X-15 flights and the number and types of repair items which would be related to space shuttle requirements. The increased size and complexity of the shuttle systems will magnify the number of repair items, making the required turnaround time difficult or impossible to achieve unless careful consideration is given to problem prevention and access for system repair and maintainability.

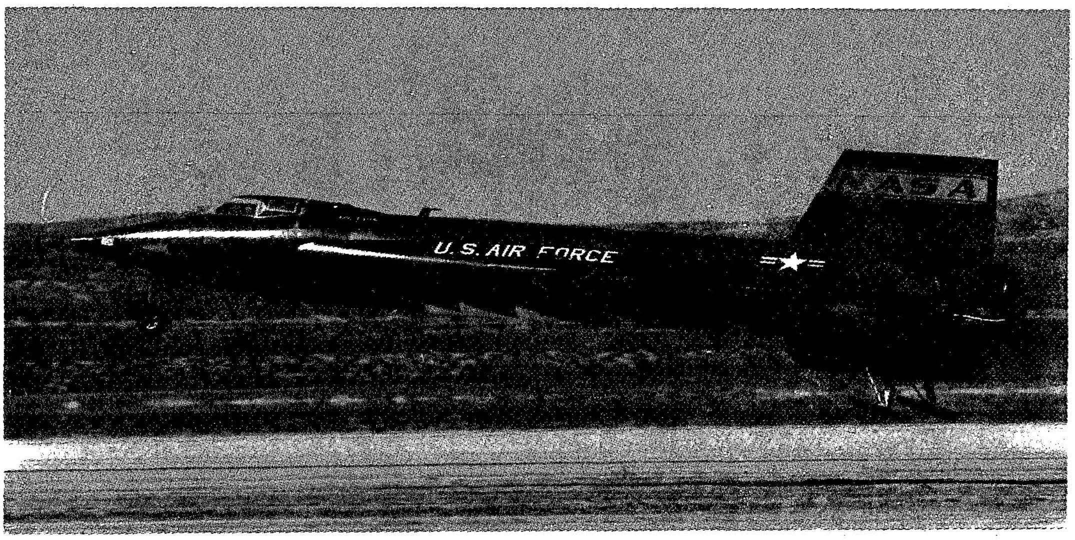


Figure 1

Figure 1 is a photograph of the X-15 airplane immediately prior to touchdown. The airplane had an overall length of 50 feet, a wing span of 22 feet 4 inches, a launch weight of 34,000 pounds, and a landing weight of 15,500 pounds.

Figure 2

The between-flight activity on the X-15 airplane can be divided into three primary periods or areas of activity: post-flight, modification and repair, and pre-flight. When no configuration changes or repairs were required, only post-flight and pre-flight activities were necessary. There was, of course, no sharp dividing line between these periods of activity; in fact, there was usually an overlap to provide better utilization of available time. Careful planning was required for an overlap of activity to prevent conflicting requirements or wasted effort.

The post-flight activity consisted initially of "safetying" the airplane and of draining and purging the propellant system, which normally took about 2 hours. The post-flight inspection was the second phase and took about 2 days. This consisted of a thorough visual inspection of the aircraft for such items as loose fasteners, cracks, and evidence of leakage (hydraulic or propellant), overheating, or any other discrepancies. The engine system was leak-checked with helium. Recorded data on the operational systems were scanned for any anomalies. At the end of this period, the project engineer met with representatives from the research and instrumentation groups, the aircraft crew, and the shops to discuss work requirements and schedule the next flight.

Immediately following the post-flight period was the modification and repair period. The first item was troubleshooting problems or discrepancies from the flight that were reported by the pilot, found during the post-flight inspection, or were observed in the data. Some items were straightforward (i.e., cracks, leaks) but some were vague and difficult to pin down (i.e., pilot reports that the engine sounded strange during start transient).

Modifications usually consisted of items required for research or research instrumentation purposes which would not be applicable to an operational vehicle but were very applicable to a development vehicle. Close control of these types of items will be necessary to conduct the development program for the space shuttle in a timely manner. However, this control should be left with the flight-test operational personnel conducting the flight-test program to maintain the flexibility required to expedite the program.

Modifications also consisted of items to update the aircraft. Flight-safety items were scheduled according to their urgency, and convenience items were accomplished with the least schedule delay possible. Periodic maintenance was also accomplished at this time.

Pre-flight activity was built around a complete functional test of all the aircraft systems within 15 calendar days of the flight. The functionals were in the form of written procedures to be followed by the aircraft crew and witnessed by quality assurance personnel. Problems found during the functionals were resolved during the pre-flight activities and the functional was performed again, which sometimes required careful planning as for modification/repair overlap. Often, pre-flight activities were repeated because the time limit was exceeded, and discrepancies were sometimes found and repaired during the repeated preflight activity. The last two pre-flight items presented no related problems and were normally accomplished the day before and the day of the flight, respectively.

BETWEEN-FLIGHT ACTIVITY

- **POST-FLIGHT**
  - 'SAFETYING' THE AIRPLANE
  - DRAIN AND PURGE OF PROPELLANTS
  - POST-FLIGHT INSPECTION
- **MODIFICATION AND REPAIR**
  - TROUBLESHOOTING PROBLEMS OR DISCREPANCIES
  - PERIODIC MAINTENANCE ITEMS
  - MODIFICATIONS
  - PRE-FLIGHT ENGINE OPERATION (WHEN REQUIRED)
- **PRE-FLIGHT**
  - FUNCTIONALS
  - MATING TO B-52
  - PROPELLANT SERVICING

Figure 3

At the start of the X-15 program, an engine run was required before each flight. By the end of the program, when confidence in the engine and engine checkout was established, a pre-flight engine run was required only when the engine was removed or changed, when any major maintenance was performed on the installed engine, or after three flights.

Figure 3 shows the aircraft being prepared for an engine run. The primary purposes of this operation were: (1) to provide a leak check of the engine/propellant system with propellants (at cyrogenic temperatures) and (2) to prove out the aircraft/engine combination. To accomplish item (1), four crew members in protective clothing visually inspected the propellant system components and engine in the pressurized/prime condition and with the engine turbopump operating, which pressurized most of the engine system. The airplane systems were operated by one of the project pilots from the cockpit. Many times small leaks were found and repaired as a result of this operation. Some examples of aircraft/engine combination problems were: (1) unstable turbopump operation caused by internal leaking of ullage helium past the swing spout O-rings into the turbopump H_2O_2 system; (2) internal leakage of the helium through the NH_3 safety valve into the NH_3 feed line, causing pump cavitation during the start transient; and (3) helium leakage through a faulty flapper valve in the NH_3 tank into the feed line when more than half the NH_3 was used, causing rough engine operation. These were feed system problems which would not be found in normal feed system checks (except possibly item (2)).

Thrust measurement during the engine run was of secondary importance and was measured indirectly by utilizing chamber pressure and the engine pressure budget (calibration) generated prior to installation during tests on the engine maintenance stand. Although the maintenance stand simulated the airplane in tankage configuration and utilized aircraft system components, the chamber pressure (thrust) was found to be consistently slightly higher in the aircraft. The installed thrust was important in flight planning and could have a significant effect on some profiles.

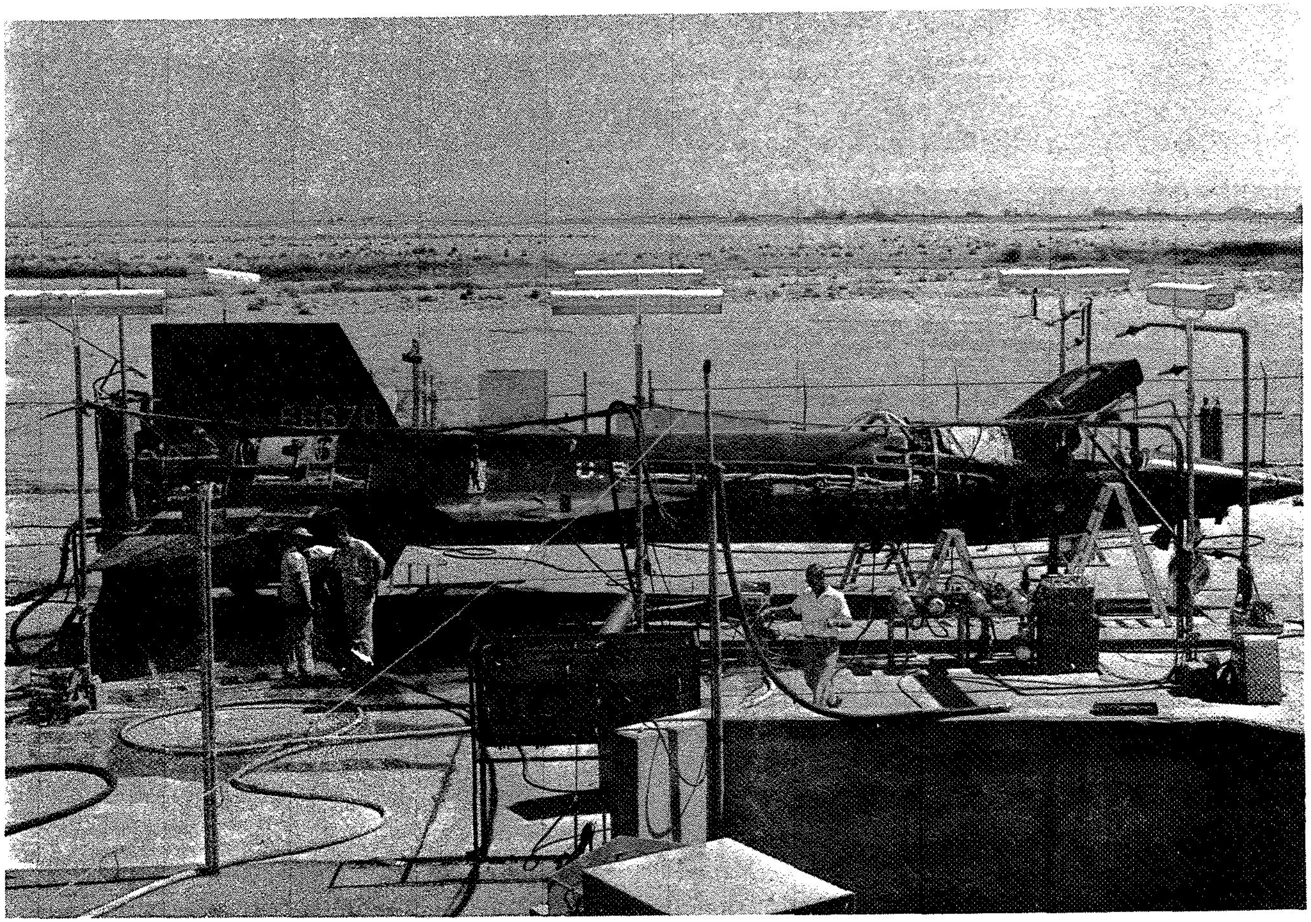


Figure 4

Periodic maintenance items may be divided into two categories: those which were calendar time dependent, and those which were flight time or flight cycle dependent. For the X-15 airplane, flight time and flight cycle were essentially the same. The flight time per flight varied only slightly. Figure 4 presents sample items of each category. The items were selected for their varied requirements. An explanation of each item follows.

The 30-day ejection seat inspection was primarily an exercising of the ejection seat hydraulic system. If the system were not exercised, the pistons and lock assemblies would bind because the O-rings would dry and not function properly.

The 360-day ejection seat inspection was primarily an overhaul and re-rigging of the ejection system.

The pyrotechnic life was established by the contractor and was related to the X-15 environment. The primary problem was the unique devices used and the long lead time for obtaining qualified replacement items, with 1 year not being unusual.

The hydrogen peroxide tank corrosion inspection was based on a reasonable time to check for a potential problem.

Shoulder harness is typical of an item which deteriorates with calendar time and must be periodically proof loaded.

The tension regulators had to be periodically checked for freedom of movement and no binding throughout their travel.

The landing gear was very highly stressed and operated with low margin because of the increase in basic aircraft weight with time. Measurement points were located on the landing gear struts to check for deflection. Landing gear deflection measurement and X-rays were taken after every 5 flights.

Because of its configuration and landing loads, the X-15 airplane could not be landed safely without flaps. The flap teleflex gear box was one of the weak points in the system and was, therefore, a periodic inspection item.

The complete alinement of the stability augmentation system and auxiliary stability augmentation system was accomplished on initial installation and checked thereafter on a periodic basis. The routine preflight activities did not check alinement.

100 percent lubrication was a routine maintenance periodic item.

Engine and APU inspection/overhaul periods were a function of their operating time, but did require consideration in maintenance scheduling because of the added workload of changing the units.

SAMPLE PERIODIC ITEMS

● **TIME DEPENDENT**	
EJECTION SEAT	30-DAY INSPECTION
EJECTION SEAT	360-DAY INSPECTION
PYROTECHNIC LIFE	5-YEAR SHELF
	3-YEAR INSTALLED
H_2O_2 TANK CORROSION INSPECTION	12 MONTHS
SHOULDER HARNESS	180 DAYS
TENSION REGULATOR CHECK	180 DAYS
● **FLIGHT DEPENDENT**	
LANDING GEAR DEFLECTION MEASUREMENT AND X-RAY	5 FLIGHTS
FLAP TELEFLEX GEAR BOX WEAR	5 FLIGHTS
SAS, ASAS ALINEMENT	5 FLIGHTS OR 5 MONTHS
100 PERCENT LUBRICATION	3 FLIGHTS
ENGINE MAJOR INSPECTION	30 MINUTES OPERATION
APU MAJOR INSPECTION	15 HOURS OPERATION

Figure 5

Two periods were selected to analyze the X-15 maintenance history. The periods were selected on the basis of a series of similar flight plans with almost the same aircraft and instrumentation configuration. The first period, July 8, 1964, to April 23, 1965, covers preparations for flights 31 to 41 for the X-15-3 airplane. This was a series of heat transfer flights with similar flight plans and some minor research instrumentation changes. The ballistic control system was not required or used for these flights. The second period was April 4, 1968, to December 20, 1968, and covers the last 7 flights of the X-15-1 airplane. These flights were all altitude flights which required an operating ballistic control system. In figure 5 a 5-flight sample of the two periods was analyzed by aircraft systems to show the problem areas.

The data were taken from two sources: (1) the engineering log maintained by the flight operations project engineer which contained items he was concerned with and (2) the inter flight work sheets (IFWS) which were included in the airplane work book maintained by the airplane crew. Problems related to weather or research configuration changes were not included; only problems of an operational type were counted. There were some deviations between engineering log and flight work sheet data for the following reasons:

(1) Engineering log data contain items which had a definite effect on flight schedule or flight preparation activity but not routine repair items handled by the aircraft crew chief which did not affect the schedule.

(2) Components removed for access or inspection, found faulty, and repaired or replaced away from the aircraft were not always noted on the flight work sheets. If the schedule was affected, a note was made in the engineering log.

(3) Inertial and research instrumentation system items were noted in a separate set of flight work sheets which are no longer available. When the schedule was affected, a note was made in the engineering log.

The figure shows many more items from the inter flight work sheets than from the engineering log, which corresponds with the sheets containing the routine items taken care of by the aircraft crew. Where the engineering log number approaches the IFWS number, as under propellant/pneumatic system leaks, it means that the problems usually affected the flight schedule or increased the effort required to retain the schedule.

Propellant/pneumatic system leaks were the most troublesome problems, probably because they usually occurred or were found during pre-flight functional activity or flight servicing. Many of the leaks were due to O-ring or gasket failures, both in the system plumbing and in the components. Although the number of structural repair items was high, most were minor and were found during post-flight inspection, which permitted them to be considered in the flight schedule. The electrical wiring in the X-15-3 airplane was becoming a serious problem during the period considered and the aircraft was subsequently rewired to eliminate the problem.

MAINTENANCE ITEM SUMMARY FOR 5 TYPICAL FLIGHT PREPARATIONS

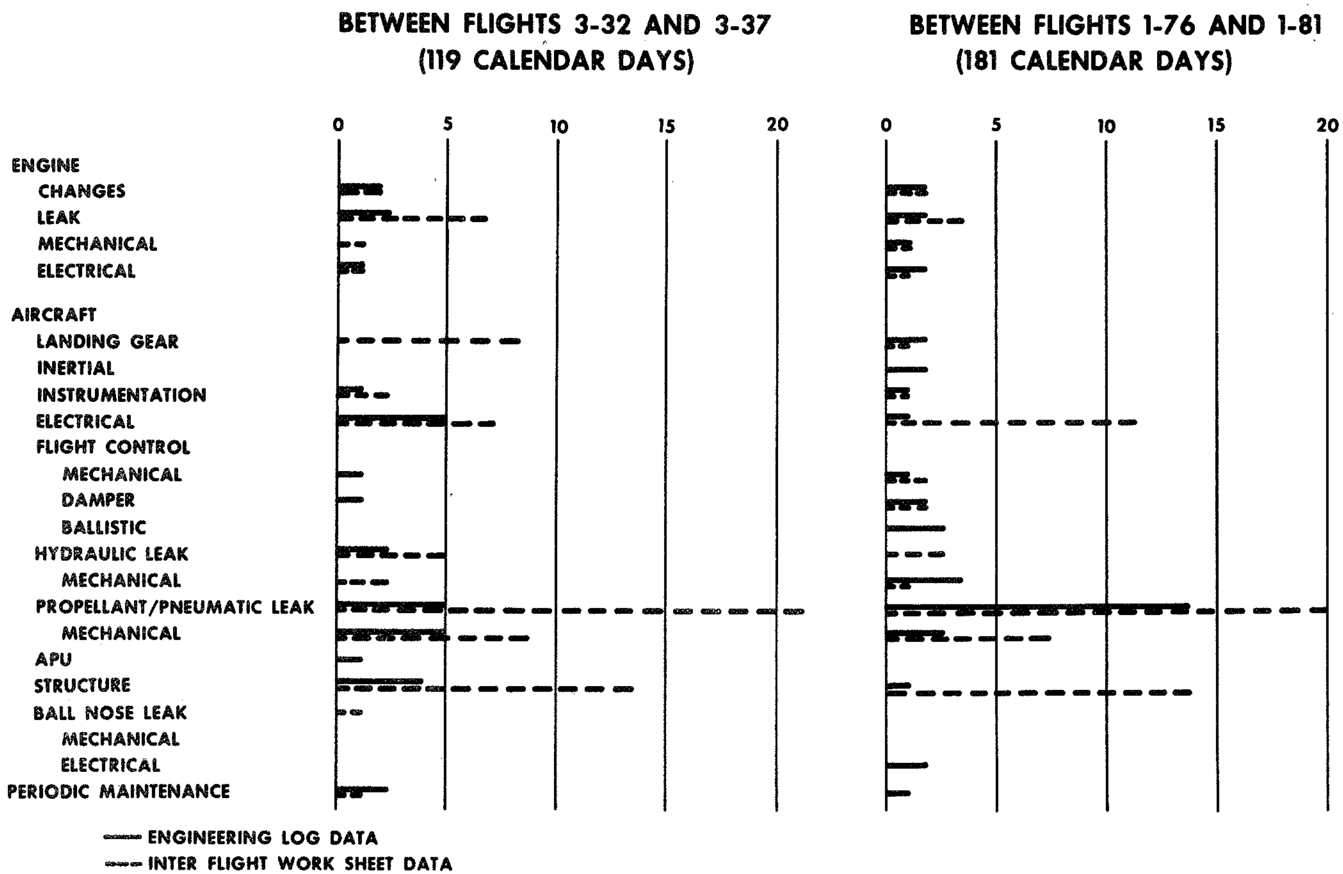


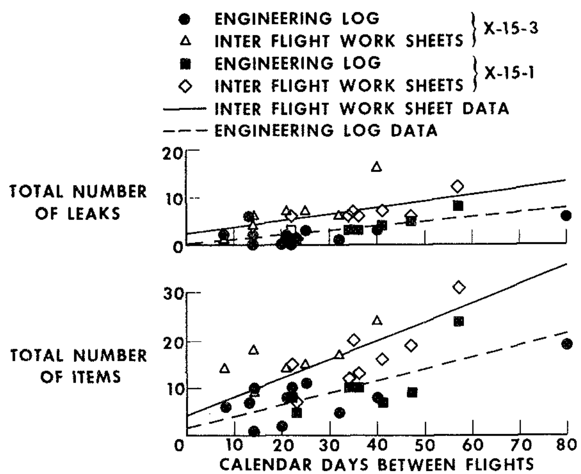
Figure 6

The number of leaks in all systems and the total number of items required versus the calendar days between flights for the time periods considered in the discussion related to figure 5 are presented in figure 6. Complete inter flight work sheet data were not available. It is well known by those who work around aircraft that an airplane that does not fly in a reasonable time develops problems, usually leaks due to drying out of seals and O-rings. For example, the B-52 airplane has a series of inspection requirements of increasing severity, depending on the number of calendar days since the last flight. The X-15 functionals were designed to exercise and test all the systems and were sometimes performed to exercise the system during long periods of lay up. The 30-day seat inspection (fig. 4) is an example.

The figure shows the trend of increasing number of items versus calendar days and the higher number of inter flight work sheet items. The question naturally arises, "Did the number of items between flights determine the calendar days, or did the calendar days determine the number of items?" The X-15 experience was usually the latter, particularly during the last year of flying (X-15-1 data) when coordination for one of the experiments determined the flight schedule date and time, which was somewhat inflexible.

The fact that the lines do not go through the origin points out that there were normally items to be repaired when the aircraft returned from flight.

MAINTENANCE ITEMS RELATED TO TIME BETWEEN FLIGHT



CONCLUDING REMARKS

The maintenance history of the X-15 airplane shows that propellant pneumatic system leaks and structural repair were the biggest problem areas. Although the space shuttle will utilize newer equipment, materials, and techniques, the systems will be more complex and the operating environment far more severe than for the X-15 systems. To minimize the turnaround time, the number of maintenance items must be kept to an absolute minimum by careful application of the lessons learned in maintaining the X-15 airplane.

COMMENTS

The following was reconstructed from memory, from questions and comments after the oral presentation.

1. Question. Did you have any problems with ghosts?

   Answer. Rather than ghosts, there were very real problems for which a cause could not be found. After flight, the symptoms would completely disappear and no problem could be found. As an example, an APU shut down at launch on flight 3-50, was restarted later in flight, operated properly for the remainder of the flight, and operated properly through every ground test we could think of.

2. Question. How many problems did you find during an engine run which would have not been found otherwise?

   Answer. During the time period considered, 16 engine runs were accomplished, four of which uncovered engine or engine/aircraft compatibility problems. The engine was required to pass the same functionals for an engine run as for flight and would therefore have been considered ready for flight if the ground run had not been required. The table summarizes the run activity.

3. Question. What percentage of leaks were in the LOX system?

   Answer. Of the 41 leaks listed in figure 5, 15 were H_2O_2 system, 1 LOX, 3 NH_3, 16 He, 2 LN_2 cooling, 4 GN_2 (cooling and inflatable seals), and 1 pilot's breathing O_2 (not counted in the 41). Engine leaks were counted separately under engine system.

4. Question. What were some internal structure problems?

   Answer. In the cockpit area failure of a clip occurred in two aircraft due to differential expansion between the hot outer skin and cool internal skin of the pressurized cockpit area, resulting in loss of cabin pressurization. The third aircraft had a camera window installed in this area, relieving the stresses. Three small cracks were found by X-ray in the titanium inner wing structure of X-15-1 during the last year of flight. They were checked by X-ray between flights and did not increase.

5. Question. What was minimum turnaround time?

Answer. With no configuration changes, engine run required, or other problems, the aircraft could be turned around in one week (6 working days). The maximum number of flights per month for one aircraft was three; the overall average was about one flight per month per aircraft.

Date of run	Reason for run*	Good or bad	Comment
5 Aug 64	P	G	Engine had flown twice since previous ground run
15 Sep 64	P	G	First time engine had flown 3 times between runs
7 Nov 64	R	G	Engine had been changed for fire warning initiation in flight
19 Dec 64	R	G	Engine had been changed for lube seal leakage
8 Jan 65	R	G	Engine had been removed for access
5 Mar 65	R	G	Engine had been changed for chamber coating damage
10 Mar 65	M	G	Engine control box had been replaced
23 Mar 65	M	B	Engine control box had been changed; governor was found sticky during engine run
25 Mar 65	R	B	Engine had been changed; aircraft NH_3 valve had internal He leak cavitating the pump during start
27 Mar 65	R	B	Previous run attempt was unsatisfactory; metering valve was found stuck on engine
29 Mar 65	R	G	Engine had been changed
22 Apr 68	R	G	Engine had been changed
25 Jun 68	R	G	Engine had been changed
5 Sep 68	R	G	Engine had been changed
18 Nov 68	R	B	Engine was removed to repair engine mount; injector was found cracked after run
22 Nov 68	R	G	Engine had been changed

*P Periodic requirement
R Engine was removed or replaced
M Major maintenance was performed on installed engine