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PART II

of

A REPORT TO

THE COMMITTEE ON APPROPRIATIONS

U. S. HOUSE OF REPRESENTATIVES

on

RELIABILITY EFFORTS

IN

BALLISTIC MISSILE PROGRAMS

This Volume Devoted To Test Firing Results On Atlas, Jupiter, Thor Missiles

PART I -- UNCLASSIFIED DATA

DECLASSIFIED UNDER AUTHORITY OF THE INTERAGENCY
SECURITY CLASSIFICATION APPEALS PANEL.
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Surveys and Investigations Staff

December 1958

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December 22, 1958

MEMORANDUM FOR THE CHAIRMAN

By directive dated March 19, 1958, the Committee instructed that a study be made of reliability efforts in ballistic missile programs. The directive was signed by Congressmen George Mahon and Richard B. Wigglesworth, Chairman and Ranking Minority Member respectively, of the Subcommittee on Department of Defense Appropriations. It was approved by the Honorable Clarence Cannon, Chairman, and by the Honorable John Taber, Ranking Minority Member of the Committee on Appropriations.

Because of the classified nature of some of the information, it has been necessary to prepare the report in two volumes. Part II, presented herewith, is limited to the test firing data for the Atlas, Jupiter and Thor missiles and is classified Secret. Part I is unclassified and contains the information developed by the Staff regarding reliability programs for ballistic missiles.

Respectfully submitted,

Robert E. Rightmyer

Robert E. Rightmyer, Director
Surveys and Investigations
House Appropriations Committee

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PART II

SUMMARY OF BALLISTIC MISSILE TEST FIRINGS

A. Introduction

For the convenience of the reader, certain characteristics of the missiles mentioned most often in this report are summarized in Table 1, on the following page.

The ensuing discussion is restricted to the Jupiter, Thor, and Atlas missiles because of the insignificant quantity of firing data available on the other two missiles. As of November 1, 1958, Titan had not been flight-tested, and the two Polaris firings which had been attempted were not successful. Failure of the first Polaris flight was due to improper operation of the guidance system. Failure of the second flight occurred when the second stage ignited on the firing pad. The range safety officer was forced to destroy the missile in each instance.

Although no data on either Titan or Polaris are given here, all failures were analyzed, and several changes were introduced in successive versions of both missiles as a result of the analysis.

B. Interpretation of Success or Failure

For purposes of this report, the results of all firing tests are given in terms of the classifications used by the Army in connection with the Jupiter missile. According to the Army's system of rating this missile, a research and development firing is termed a "success" if all primary test objectives are achieved. A firing is a "partial success" if most of the test objectives are achieved. If less than

TABLE 1

PRINCIPAL CHARACTERISTICS OF FIVE MISSILES

Characteristic	Atlas	Titan	Polaris	Jupiter	Thor
Type	ICBM	ICBM	IRBM	IRBM	IRBM
Service	Air Force	Air Force	Navy	Army	Air Force
Prime Contractor	Convair	Martin	Lockheed	Chrysler	Douglas
Status	Development, Production	Research, Development	Early Research, Development	Development, Production	Development, Production
Range, Miles	5500-6200	5500	1500	1500-2000	1500-2200
Propellant	Lox, Kerosene	Lox, JP 6	Solid	Lox, Kerosene	Lox, Kerosene
Thrust, lbs.	400,000	300,000	80,000 100,000	150,000 165,000	165,000
Warhead	Nuclear	Nuclear	Nuclear	Nuclear	Nuclear

50 percent of the test objectives are achieved, the firing is classed as a "failure." An operational firing conducted by service personnel (as opposed to missile scientists) would be judged a success, a partial success, or a failure depending upon the level of target destruction it caused or might have caused. To date, all firings of the Jupiter missile have been of the research and development type.

Because of similarities in design among the Redstone, Jupiter C, and Jupiter missiles, certain data on Redstone and Jupiter C are included for comparison with the results of tests on Jupiter. The definitions of success, partial success, and failure are the same as those used in relation to Jupiter.

The Air Force data were initially presented in somewhat different form from that described above. For example, results of Thor test firings were shown in terms of the actual percentage of primary and secondary objectives achieved in each firing. However, the data were reclassified in accordance with the performance standards used by the Army, so that Thor and Atlas firings could be classed as successes, partial successes, and failures. The Air Force also supplied a description of the type and cause of failure in each unsuccessful firing.

There are a number of basic problems involved in any effort to assess the reliability of a particular missile on the basis of data from research and development test firings. One problem is the frequent use of incomplete missiles for testing purposes. Initial firings are sometimes made with missiles containing only a propulsion system and an airframe structure. Later, test missiles may also include a guidance system -- first as a passenger with telemetered responses, and then as a functional component with closed loop guidance. It is usual to find that each missile test-fired in the research and development stage is different from its predecessor. These differences result not only from the addition of components, but also from engineering changes which correct weaknesses discovered in previous tests. If such differences are disregarded in computing attained reliability -- as they usually are -- it is argued that the reliability estimates have meaning by virtue of showing how much progress has been made. That is, as missiles become more and more complete and have more comprehensive performance requirements, an increasing number of parts and components become potential sources of failure. Therefore, if estimated reliability does actually increase as more test firings are made, it is logical to assume that reliability is in fact improving. A corollary to this argument is that one can have greater confidence in an estimate involving recent and more complete missiles than an estimate based on early versions which may contain engineering flaws.

It may be noted further that, when reliability estimates are based on research tests involving completed missiles, the results are assumed to constitute reasonable approximations to estimates which would be obtained from data collected in Service evaluation tests. This assumption is supported by experience with troop firings of complete Redstone missiles. Two highly successful firings by troops not only yielded accurate precision measurements, but also demonstrated the ability of troops to handle the Redstone missile. Army engineers judge the firing of Jupiter to be even simpler than that of Redstone.

Notwithstanding the belief that research firings of complete missiles should indicate the results of troop firings, it is proper -- if reliability estimates are made -- to use rules of computation which keep such estimates conservative. Under the rules used by the Army, a success is scored as 1, a failure is scored as 0, and a partial success is scored as 1/2. The latter practice -- adopted after a period during which partial successes were scored as 0 -- results in partial successes being scored half of the time as failures and half of the time as successes. Only two firings of the Thor missile were clearly in the partial-success range, but they were good enough to warrant scoring them as successes for purposes of the comparison presented in Table 4.[1/]

There is still a question as to the accuracy of any reliability estimates which may be made on the basis of available firing data. A rigorous computation of the confidence interval would be desirable, but the changing missile configuration complicates the statistical problem. However, certain known methods of statistical analysis are applicable. For example, it is feasible to use an approximation based on the binomial distribution. The procedure is analogous to sampling plans used in quality-control programs, and can be refined to some extent by the application of methods of sequential analysis. It is not necessary to go into detail here, but it is important to note that a great deal more can be done even with the small statistical samples encountered in missile programs. Reference to quality-control sampling plans shows very quickly that significant information can be obtained from samples consisting of as few as five or ten items.

1. Flight-Test Data on Jupiter

The results of 11 research and development firings of Jupiter are summarized in Table 2. This summary gives firing date, primary mission of each firing, result of firing, and cause of failure. The table also indicates which test missiles were equipped with closed loop guidance.

Engineering analysis of the failure of the last shot -- missile number 9 -- is not yet complete, but valuable information leading to design changes was obtained on the other failures. The trouble observed in missile 1A -- overheating in the tail section -- was corrected by the use of a jet-blast shield. Sloshing in propellant

1/See page 11.

TABLE 2

RESUME OF JUPITER MISSILE TEST FIRINGS

Date Fired	Missile Number	Missions*	Closed Loop Guidance	Success or Failure	Cause of Failures**
1 Mar 57	1A	1-3-6-10-11		Partial Success	A
26 Apr 57	1B	1-3-6-10-11		Partial Success	B
31 May 57	1	1-4-9-10-11		Success	
28 Aug 57	2	1-4-6-9-10-11-19		Success	
22 Oct 57	3	1-4-7-10-11-18-22-23		Success	
26 Nov 57	3A	1-4-7-10-11-18-20		Partial Success	C
18 Dec 57	4	1-5-7-11-18-20-22-23-24-25		Partial Success	C
18 May 58	5	1-5-8-11-12-15-17-18-19-20-24		Success	
17 Jul 58	6	1-5-8-11-12-13-15-17-18-19-20-26	X	Success	
27 Aug 58	7	1-5-8-11-12-13-16-18-19-20-22-23-24-26	X	Success	
15 Oct 58	9	2-5-8-11-12-14-16-18-19-20-21-22-23-24-26	X	Failure	A

* Numbers refer to items of Annex A - "Missions"

** Letters refer to items of Annex B - "Cause of Failure"

ANNEX A OF TABLE 2

MISSIONS

1	Flight test of R&D airframe.
2	Flight test of tactical airframe (lightweight).
3	Flight test of S-3D liquid-propelled rocket engine with 135,000 pounds of sea level thrust.
4	Flight test of S-3D liquid-propelled rocket engine with 139,000 pounds of sea level thrust.
5	Flight test of S-3D liquid-propelled rocket engine with 150,000 pounds of sea level thrust.
6	Flight test of inertial guidance system (passenger only).
7	Flight test of inertial guidance system (interim system).
8	Flight test of complete inertial guidance system (closed loop).
9	Flight test of radio-inertial guidance system (passenger only).
10	Flight test of boom angle-of-attack meter for attitude control.
11	Flight test of local angle-of-attack meters for attitude control.
12	Flight test of air jet system for spatial attitude control.
13	Flight test of 500-pound Vernier engine for fine velocity control.
14	Flight test of solid propellant Vernier engine for fine velocity control.
15	Flight test of air jet system for spin control.
16	Flight test of spin control rockets.
17	Flight test for nose cone recovery.
18	Flight test of nose cone with re-entry protection.
19	Flight test for first separation (body unit from thrust unit).
20	Flight test for second separation (nose cone from aft unit).
21	Flight test of swiveled turbine exhaust nozzle for roll control
22	Flight test of radar fuse.
23	Flight test of inertial fuse.
24	Flight test of impact fuse.
25	Flight test of XW-35 warhead.
26	Flight test of XW-49 warhead.

ANNEX B OF TABLE 2

CAUSE OF FAILURE

A	Severe overheating in the tail section.
B	Sloshing in propellant tanks causing missile to go out of control.
C	Failure of engine turbopump-turbine drive causing propulsion failure.

tanks in missile 1B was eliminated by the use of baffles. The turbopump-turbine problem in missile 3A required modification of the pressure system, but this could not be done until additional data on a similar problem in missile 4 were available.

It is important to note that the failures described above appear to have been due primarily to deficiencies in missile design rather than to operator error or to weak parts.

It is of interest here to note that Jupiter components were carried on 25 of 36 flights of the Redstone missile. Although these firings contributed directly to the Jupiter test program, they cannot properly be included in a summary of firing data on Jupiter, and hence are given in a separate table. In view of the rather general comparison for which the Redstone data were needed, the Army was asked to submit results grouped by recentness of firing, in the manner shown in Table 3.

Two operational firings by troops are included among the ten most recent test shots. The practice of having troops fire research missiles is a conservative one, for the probability of success is not enhanced when troops are substituted for the Army firing team composed of scientific and engineering personnel. Explorer shots are also included, for the reason that the Jupiter C vehicle used in the Explorer Satellite shots was a modified Redstone missile. Since the Redstone portion of Jupiter C operated properly even in those cases in which an orbit was not achieved, it is fair to use these data in the evaluation of the Redstone.

It should be noted that additional successful Redstone trials have occurred since the data shown in Table 3 were collected. Complete failure of a Redstone missile has not occurred for many months.

TABLE 3 RESUME OF REDSTONE AND EXPLORER MISSILE TEST FIRINGS				
Missile Group	Successes	Partial Successes	Failures	Total
20 prior to January 1957	2	16	2	20
Next 6	4	2	0	6
Last 10, up to June 30, 1958	7	3	0	10
Last 10 plus 6 Explorer	13	3	0	16

2. <u>Flight-Test Data on Thor</u>

The 23 firings of the Thor missile are divided into three groups by degree of completion of the missile and type of objective established for the test.

Phase I missiles (eight in all) consisted of the airframe and the propulsion and auto-pilot systems. The last three missiles were more complete than the first five, and were flown to demonstrate capability of flight control, loop stability, and maximum range.

The three missiles in Phase II consisted of the airframe, the propulsion and auto-pilot systems, and the closed-loop inertial-guidance system.

Phase III missiles were like those in Phase II, except that nose cones of various designs were added to demonstrate separation and re-entry characteristics. Of the 12 missiles in this group, 3 were of the Thor-Able type, and 1 was used for the first lunar shot. In the case of these last four missiles, the analysis presented here refers only to the portion of the test shot involving Thor.

Table 4 presents a summary of Thor firings by missile number, phase, order of firing, and main cause of failure. Evaluation of the success or failure of a flight was based on the standards used in connection with the Jupiter and Redstone missiles. It is estimated that this evaluation is fairly uniform in spite of the differences in test objectives and degree of completeness of the missiles.

Except for the turbopump failure -- which occurred twice -- all types of failure occurred only once. This fact indicates that test results were effectively fed back and corrective action was taken to prevent recurrence of trouble. Even in the case of the failure of the turbopump, the first failure was followed by four major design changes and the introduction of nine engineering procedures intended to correct the cause of malfunction as it appeared at the time. The exact cause of the second failure is not yet fully understood, but this failure was not a simple repetition of the first one.

3. Flight-Test Data on Atlas

The 13 firings of the Atlas missile are divided into two series with respect to degree of completeness of the missile and objectives sought in the test.

Series A missiles, which were involved in eight test firings, consisted basically of the booster engine and the airframe. The first two missiles in this series contained these two parts plus a programmer which controlled the auto-pilot. The third missile was like the first two, except that it also carried the completed guidance package, although only as a passenger. The other Series A missiles contained Vernier engines in addition to the parts mentioned above.

Series B missiles were more complete, in that they contained sustainer engines in addition to all Series A parts. A separating reentry vehicle was used for the first two flights, and a completely

TABLE 4

RESUME OF THOR MISSILE TEST FIRINGS

Missile Number	Phase Number	Result	Cause of Failure
101	I	Failure	LOX contamination
102	I	Success	
103	I	Failure	Tank regulator failure
104	I	Success	
105	I	Success	
107	I	Failure	LOX valve failure
108	I	Success	
109	I	Success	
112	II	Success	
113	II	Success	
114	II	Failure	Extreme yaw at 151 seconds
120	III	Success	
121	III	Failure	Fuel feed system failure
116	III	Failure	Turbopump failure
115	III	Success	
122	III	Success	
118	III	Success	
123	III	Failure	Main engine did not shut off
119	III	Success	
126	III	Failure	Pneumatic control failure
117	III	Success	
127	III	Failure	Turbopump failure
130	III	Success	

active guidance system was added to the other three missiles in this series.

The Atlas test firings were evaluated according to the same standards as those used for Thor and Jupiter. Table 5 lists the firings in order of their occurrence, and indicates the principal cause of failure in tests which were not successful.

C. Comments

As indicated previously, most of the data presented above were obtained during test-firings of missiles which were in the stage of research and development. These missiles were subjected to tests and adjustments at the firing site for indeterminate periods until pronounced ready for firing. That success was achieved in many of these firings -- even those involving complete missiles -- does not necessarily indicate the reliability to be expected under combat conditions, where the readiness requirements would probably be much more severe. Nonetheless, the observed scores on the later missiles which were essentially complete represent real and gratifying achievements, and justify the expectation that operational missiles may soon have adequately demonstrated reliability.

It is also important to note that most of the failures which were found to be "explainable" were due primarily to undetected deficiencies in design. Each such failure may indicate an inadequacy of test as well as a deficiency of components and point the way to correction of both.

TABLE 5 RESUME OF ATLAS MISSILE TEST FIRINGS			
Series	Firing Number	Results	Cause of Failure
A	1	Partial Success	Auto-pilot coupling
A	2	Partial Success	Overheating of rear end
A	3	Success	
A	4	Success	
A	5	Partial Success	Vernier overheating
A	6	Partial Success	Turbopump failure
A	7	Partial Success	
A	8	Success	
B	9	Partial Success	Loss of control
B	10	Success	
B	11	Success	
B	12*	Failure	Turbopump failure
B	13	Success	

* Firing number 12 was a special test with minimum instrumentation and was not part of the planned R&D firing schedule.

ADDENDUM

On November 28, 1958, Atlas missile No. 128 (firing No. 14) was launched at Cape Canaveral. The recorded data have not been completely analyzed, but according to available information all primary and secondary test objectives were achieved essentially 100 percent. The performance represents a significant milestone in the development, as it was the first time the missile had flown to full intercontinental range.