SPACE TECHNOLOGY LABORATORIES

INTEROFFICE CORRESPONDENCE

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TO: Brig. Gen. O. J. Ritland   CC: See list   DATE: 10 July 1959

SUBJECT: Special STL Analysis of DISCOVERER Problems   FROM: [redacted]

This memorandum is written in response to your request that STL perform on a crash basis a special independent analysis outlined as follows:

a. Analysis of basic specifications and performance of DISCOVERER vehicle (particularly the configuration flown on last four flights) with particular reference to off-nominal performance and to "design margins."

b. Analysis of the specific telemetry and tracking data obtained on the last four flights.

c. Analysis of the flight planning for the next several DISCOVERER flights.

d. Provision to AFBMD of any conclusions or recommendations which appear pertinent at this time to the immediate or long range DISCOVERER program.

You further requested that this STL study be performed under the personal supervision o[redacted]nd myself; approximately 25 additional STL people worked on various specific parts of the study. (It should be recognized that since STL does not carry a line responsibility in the DISCOVERER program and hence does not have established project engineers assigned to each of the various subsystems and problem areas, two weeks is a very, very short time for the completion of the type of comprehensive analysis requested.) This memorandum can be considered as a preliminary summary report to AFBMD; a more detailed report will be written as soon as possible.

SPECIFICATION AND PERFORMANCE ANALYSIS

STL has conducted an analysis of the probability of orbiting the specified payload with the specified nominal injection altitude of 120 statute miles, with the specified nominal orbital eccentricity of 0.01, and with the specified nominal orbital characteristics for recovery purposes, using the Thor/DISCOVERER vehicle and trajectory as specified and as used for the last flights. This analysis took into account what we consider to be reasonable tolerances to be expected around the nominal values for such variables for both stages as specific impulse, thrust, propellant loading and boil-off, propellant utilization, dry weights, autopilot drifts and steering errors, horizontal attitude at injection, etc. We also considered that a sufficiently predictable orbit was desired (from a drag slow-down standpoint) to minimize the recovery problem.

> <u>CONCLUSION:</u> Our analysis indicates that the probability of achieving what we understand to be the specified orbital conditions with the vehicle configuration used is about 0.55 if all subsystems operate within reasonable tolerances from the specified nominal values, and not including reliability factors. The analysis further indicates that for the specified trajectory and orbital conditions, even large improvements in vehicle performance would bring the probability of achieving the specified orbital conditions to only about 0.7.

> <u>RECOMMENDATION:</u> Both vehicle performance improvements and changes in the specifications for trajectory and orbital parameters should be considered mandatory prior to next flight.

Therefore, in addition to investigating various ways of achieving vehicle performance improvements, we also extended the probability and performance analysis to other than the specific trajectories, injection altitudes, and recovery characteristics, and have also calculated the sensitivity of system performance to individual changes in the specifications for various subsystem parameters. Since the added performance required is not easy to obtain and may delay the launch date, one would like to select the trajectory, injection altitude, and eccentricity which minimizes the added performance required to get a high probability of achieving an orbit with characteristics acceptable to the payload and acceptable to the recovery system.

> <u>CONCLUSION:</u> If one wishes to approximately maintain the specified recovery characteristics and to hold the orbital eccentricity to the 0.01 originally specified, one should loft the trajectory and inject at a higher nominal

altitude (approximately 140 miles) in order to obtain greater than 0.9 probability of orbiting with minimum increased vehicle performance, not including reliability factors. The analysis indicates that this still requires that the vehicle generate an increased injection velocity (referenced to the originally specified 120 statute mile altitude) of about 500 fps. Since the tolerances used in the analysis are in themselves in some cases difficult to estimate (propellant utilization for example), and since the vehicle performance analysis indicates that the vehicle does not have excess nominal performance, good engineering practice dictates that the requirement for added vehicle velocity prior to the next flight should actually be established at a level higher than 500 fps, i.e., with a reasonable design margin. A design margin of 200 fps appears to be the minimum for this trajectory, and a design margin of 400 fps would be desirable, giving a requirement for added vehicle velocity of 700 fps minimum and 900 fps desirable for this trajectory.

In a meeting several days ago, Lockheed proposed to AFBMD to relax the eccentricity specification to 0.05, holding the nominal injection altitude to 120 miles. A subsequent meeting was held between STL, AFBMD and Lockheed to interpret the analysis over the range of eccentricities from 0.01 to 0.05, and over the range of injection altitudes from 120 to 145 miles.

CONCLUSION: If one accepts an eccentricity of 0.05, then one may use a trajectory which injects at a nominal altitude of 120 miles, and still obtain greater than 0.9 probability of orbiting with minimum increased vehicle performance, not including reliability factors. In this case, the requirement for added vehicle velocity, including design margin, is about 900 fps minimum and 1100 fps desirable. The trajectory with 0.05 eccentricity may complicate the recovery problem. Lockheed is reported to be making a detailed analysis of the effect of 0.05 eccentricity on the recovery probability. Acceptance of the 0.05 eccentricity should be made contingent on AFBMD/Lockheed agreement that recovery can be successfully carried out under the conditions generated by the 0.05 eccentricity. STL has not made an analysis of effect of 0.05 eccentricity on recovery probability.

CONCLUSION: It appears that a choice part-way between the two extremes of 120/0.05 and 140/0.01 may be optimum from a combined performance/orbiting probability/recovery/payload standpoint. There has not been time to date to define such an optimum. Further analysis should be performed on this problem.

CONCLUSION: The results of the STL analysis indicate a preference for the 140/0.01 trajectory for the next flight from a combined orbiting and recovery standpoint. The apparent advantage of the 120/0.05 trajectory is that past preparation at Vandenberg with respect to range safety and missile trajectory calculations have been based on a nominal 120 mile injection altitude. Changing to the 140 mile injection altitude would presumably delay the launch date somewhat. STL has not made a specific investigation of the range safety and schedule problems at Vandenberg for the 140 mile injection altitude.

RECOMMENDATION: AFBMD should select either the 120/0.05 or the 140/0.01 trajectory depending on the final results of the Lockheed analysis of the recovery problem at the 0.05 eccentricity and depending on the results of a specific investigation of the range safety and schedule problem at Vandenberg for a 140 mile injection altitude.

SPECIFIC ANALYSIS OF TELEMETRY AND EXTERNAL TRACKING DATA FROM PAST FOUR FLIGHTS

STL has analyzed the raw telemetry and external tracking data from the past four flights.

CONCLUSION: Our analysis yields consistently lower estimates of the performance actually achieved on the past four flights than does Lockheed's analysis. (As several examples: we estimate the final velocity attained on the fourth flight as about 200 feet ps lower than Lockheed's estimate; we do not believe the first flight actually achieved orbital velocity.) The analysis of flight data is generally consistent with the performance and probability analysis discussed earlier.

CONCLUSION: The telemetry and tracking data combined are inadequate for conclusive diagnosis and evaluation of flight trajectory and performance. In view of this basic uncertainty, the next several flights should be considered as diagnostic in nature and very strong efforts should be made to obtain added flight data. The added data most critically needed is external tracking data from more favorable look angles, and can be obtained without adding anything to the vehicle, but by establishing a tracking station near the point of injection. Some specific improvements could be made in airborne instrumentation but these are less important.

RECOMMENDATION: A tracking station should be established near the point of injection prior to the next flight.

RECOMMENDATION: Consideration should be given to improving instrumentation characteristics of the accelerometer and to incorporating level switches in each of the propellant tanks of the second stage. It is not considered necessary to make these changes prior to the next flight. On a longer range basis, consideration should be given to carrying on FPS-16 beacon in the second stage.

USE OF RJ-1 PROPELLANT IN THOR

Lockheed has proposed that RJ-1 fuel should be used in the Thor booster for the next DISCOVERER launch. Douglas has concurred in this recommendation. In general, STL feels that the fundamental characteristics of RJ-1 and the limited experience with RJ-1 are such that if certain additional engine and captive tests are successfully performed between now and the next launch date, one should have adequate confidence in the use of RJ-1 for the next launch. However, it is important to point out that since the Rocketdyne engine on the DISCOVERER missiles does not have a head-suppression valve, the RJ-1 fuel (being denser than RP-1) produces at the high accelerations encountered late in the Thor booster flight, fuel pump inlet pressures which in turn result in engine mixture ratios which fall outside the model specifications and outside the PRFT specifications for the Rocketdyne engine; this in turn also results in fuel flow and pressure conditions outside the range of the specifications for the Thor IOC missiles. In examining this problem, one should ideally include the possible benefits of reorificing and recalibrating the engines to the best mixture ratio for RJ-1. For the next two flights, it has been agreed that consideration should only be given to the use of the existing orifices and existing calibration data to avoid the requirement for removing the engine from the missile and returning it to Rocketdyne. For subsequent flights reorificing and recalibration could be accomplished if further analysis indicates such action to be desirable. It is currently estimated that with the orifices existing in the next DISCOVERER missile, the mixture ratio of the engine using RJ-1 will drop to approximately 1.85 at maximum acceleration. (A more careful analysis of this minimum mixture ratio will be conducted during the next few days and may alter somewhat the 1.85 figure.) The minimum mixture encountered in Thor flights with RP-1 is approximately 2.1. There is some sketchy test evidence that combustion instability may be encountered as the mixture-ratio goes below approximately 1.90; one test at a mixture-ratio below 1.7 resulted in violent combustion instability. It must be pointed out that most of the low mixture-ratio tests conducted to date are subject to rather wide instrumentation errors.

CONCLUSION: Engine tests at 158,000 (or thrust chamber assembly tests if Rocketdyne considers these adequate) should be conducted by Rocketdyne with RJ-1 over a range of mixture ratios extending somewhat beyond those nominally expected in flight, i.e., down to about 1.8. The number of tests at the lowest mixture ratio should be determined by Rocketdyne as that number which would permit Rocketdyne to certify the engine for flight use with RJ-1 at a mixture ratio of 1.85. Four to six tests at mixture ratios near 1.85 would appear reasonable. It appears reasonable to expect these tests to be completed in a week to ten days.

CONCLUSION: Battleship tests should be conducted by Douglas at Sacramento using RJ-1 at the 158,000 thrust level with standard orifices and with tank pressure to simulate the pump inlet pressures and mixture ratios expected throughout the flight. Of course, the low mixture ratio tests at Sacramento should only be run after Rocketdyne has determined that the engine can be safely operated at the low mixture ratios. Two or three full-durabtion battleship tests at Sacramento with tank pressures programmed over the range of conditions expected in flight appears to be reasonable. It should be possible to complete these tests during the next week to ten days.

RECOMMENDATION: Douglas and Rocketdyne should be directed to conduct a test program essentially as outlined above. The successful completion of these tests should be considered as a mandatory flight prerequisite for the use of RJ-1.

PERFORMANCE IMPROVEMENTS FOR NEXT FLIGHT

The following improvements in performance of the vehicle have been discussed with Lockheed, Douglas, or Rocketdyne as appropriate and appear possible prior to the next flight. (Each of the improvements can be characterized by its addition to final injection velocity, referenced to the originally specified 120 mile injection altitude, with a launch azimuth of 180 degrees.)

1. Change of launch azimuth to 170° ------------------ 200 fps

   (This change of course introduces range safety problems at PMR; new calculations of destruct lines for 170° launch azimuth are required; these calculations must in turn await final determination of trajectory and injection altitude.)

2. Weight reduction of 63 pounds in second stage ------ 270 fps

   (STL has not examined in detail these Lockheed weight reductions.)

3. Use of RJ-1 in Thor ------------------------------- 150 fps

4. Reduction of Thor weight -------------------------- 70 fps

   (These reductions are obtained by removing one helium bottle and removing guidance mounting bracketry which is not needed.)

5. Raising thrust to 158,000 ------------------------ 185 fps

   (This change requires that Lockheed perform an aerodynamic heating analysis on the second stage; it is not anticipated that heating difficulties will be encountered.) Rocketdyne concurs in raising thrust level to 158 K on next four engines.

6. Total -- 875 fps

It also appears feasible to fill the lox tank of the Thor with an additional 15 cubic feet of lox by moving the float switch in the lox tank upward in the tank to the position used in certain special flights from AFMTC. (Correspondingly more fuel can then also be loaded into the fuel tank.) Douglas will determine if this can be done for the next flight. A velocity gain of about 80 fps could be obtained in this manner.

CONCLUSION: It appears possible to provide for the next flight sufficient added vehicle velocity to at least cover minimum design margins needed to achieve high confidence in orbiting, excluding reliability factors, for either the 120/0.05 or 140/0.01 trajectory.

RECOMMENDATION: The first five performance improvements indicated above should be included in the next flight, and if possible also the sixth. (Assuming, of course, that the RJ-1 tests specified earlier are successful, that the range safety problem at PMR is solved, and that provision to increase propellant loading in the Thor can be accomplished in time.)

PERFORMANCE IMPROVEMENTS FOR SUBSEQUENT FLIGHTS

A number of additional performance improvements have been in development or under consideration for some months. Not all of these will be reviewed here. It does appear, however, that the following significant additional performance gains could be achieved in less than two months.

1. Adding uncooled skirt to thrust chamber of 2nd stage engine ------------------------ 400 fps
2. Use new higher performance injector being tested at Bell ------------------------------ 250 fps
3. Additional Thor weight reductions --------------- 150 fps
4. Raise Thor thrust to 165,000 ------------------ 165 fps
5. Total -- 965 fps

<u>RECOMMENDATIONS:</u> These performance requirements should be explored in detail. Items (1) and (2) particularly should be pushed vigorously in engine and ground tests.

<u>GENERAL COMMENTS</u>

The conduct of this special study has required during the past two weeks many conversations and conferences with AFBMD, Lockheed, Douglas, and Rocketdyne personnel active on this program. These contacts have led to several general reactions which may be helpful to you:

1. The program has frequently been termed a "high risk" program, and I believe it inevitably <u>is</u> a "high risk" program. The basic reliability problem on so complex a total system and the recovery operation inherently make each flight a "high risk" venture. For this reason particularly, I would expect that in the absence of malfunctions or failures, the probability of orbiting should not be allowed to supply any risk at all--i.e., the design margins should be established to achieve very high probability of orbiting properly in the absence of malfunctions or reliability failures.

2. During the past two weeks, "target launching dates" first of 15 July and now of 23 July have been set by AFBMD. Establishment of definite early launching dates is a reasonable and satisfactory way of focusing all the necessary launch preparations when no major development problems are being encountered. However, our ballistic missile experience indicates that when serious problems are encountered, the early establishment of optimistic flight dates can be detrimental to achieving an orderly solution to the developmental problems. In these cases, we have found it most valuable to initially concentrate attention on the tests or decisions or analyses which are mandatory prerequisites to flight, and let the firm flight date subsequently follow automatically. Thus flight dates could be initially predicted as "eight days after firm decision on trajectory and injection altitude," or "four days after successful completion of all RJ-1 tests," etc. This approach tends to minimize a natural tendency to short-cut the detailed prerequisites for a high-confidence launch as the launch date approaches, and eliminates much of the last minute rescheduling. In the present

instance, for example, I feel that the selection of a July 23 launch date in advance of clearly defining exactly who must do what prior to launch, i.e., in advance of clearly defining in detail the prerequisites to flight may create problems or result in last-minute schedule delay.

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Memorandum from [redacted] to Brig. Gen. O. J. Ritland, dated 10 July 1959; Subject: Special STL Analysis of DISCOVERER Problems.

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