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AEROJET NUCLEAR SYSTEMS COMPANY
Sacramento, California

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The subject report is forwarded for your information.

R. V. Evleth, Manager
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MASTER

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MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

5301 Bolsa Avenue, Huntington Beach, CA 92647 (714) 896-3311

12 January 1972
A3-130-0107

Subject: CONTRACT NAS8-27951, SUBMITTAL OF SECOND
MONTHLY PROGRESS AND STATUS REPORT

To: National Aeronautics & Space Administration
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama 35812

Attention: Mr. W. F. Crawford, A&TS-PR-RS

1. Pursuant to Data Requirement Document Number 265 of subject contract, the Contractor is submitting herewith one (1) copy of the Second Monthly Progress and Status Report as required by DR Number MA-02. Additional distribution has been made to the below addressees.

2. In order that we may have a record of compliance with contractual requirements, we will appreciate your acknowledging receipt by signing and returning the attached copy of this letter.

William E. Schweickert
Contract Administrator
Advance Systems & Technology

WES/hm

Enclosure: Second Monthly Progress and Status Report (1 copy)

cc: NASA/MSFC
A&TS-PR-M (1 copy)
A&TS-MS-IL (1 copy)
J. W. Russell, PD-SA-P (10 copies)

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SECOND MONTHLY LETTER PROGRESS AND STATUS REPORT

REUSABLE NUCLEAR STAGE SYSTEM DEFINITION

STUDY -- PHASE IV

CONTRACT NAS8-27951

DPD NO. 265, DR NO. MA-02

REPORT PERIOD: DECEMBER 1 - DECEMBER 31, 1971

MCDONNELL DOUGLAS

CORPORATION

SUMMARY

This document represents the second progress letter under Contract NAS8-27951. Brief technical summaries of Parts A and B are given below. A more complete technical summary is given in the following sections according to tasks.

Part A -- Alternate RNS Concepts Definition

Part A Task 1, Concept Synthesis and Evaluation, was completed during the past month. The results were presented at the first performance review at MSFC on December 16. An RNS concept employing two 150 K-lb LH_2 capacity propellant modules was selected for the alternate second stage approach. Four 75 K modules were selected for the externally mounted shuttle launched concept. Tasks 2 and 3 were initiated with definition of first level trade studies.

Part B -- Interface Definition and Trade Studies

An interface review meeting was held at MSFC on December 16 including representatives of MSFC, SNSO-W, SNSO-C, ANSC, and MDAC. ANSC will review and comment on all the interface recommendations presented.

Four trade studies were active: Engine/Stage Astrionics System Optimization, Safety Criteria Analyses, Development Test Propulsion Module Feasibility and Program Support. Status reports were supplied to the COR on these trade studies.

Study Status

The study activities performed during this reporting period were in accordance with the program schedule shown on the following figure. No deviations were taken from the major milestones. The engineering hours expended on the contract are indicated on the second chart, with the total hours being within budget. The lower rate at the end of the month is due to full week holiday from December 27 through December 31.

The planned activities for the next two months of the study include initiation and continuation of trade studies and interface tasks in Part B, as well as initiation of trade studies in Tasks A2 and A3.

TASK PROGRESS REPORT

REUSABLE NUCLEAR STAGE SYSTEM DEFINITION STUDY, PHASE IV
PROJECTED AND ACTUAL EXPENDITURES

Part A
ALTERNATE RNS CONCEPTS DEFINITION

TASK 1 -- CONCEPT SYNTHESIS AND EVALUATION

This task was completed during December. A technical review was held at MSFC on December 2 concerning the activities up to that time. Also, an Interim Briefing was held at MSFC on December 16, which presented the results of this task. Therefore, only highlights of the results which were reported will be reviewed in this letter. The primary result of Task 1 was the recommendation of two modular RNS system concepts for in-depth evaluation during the balance of the study. The first system concept, compatible with launch by an alternate second stage on the space shuttle booster, utilized two 150 K-lb LH_2 modules with a 28 ft. diameter which are launched to orbit one module per launch with a new common LH_2 tank second stage concept. It was found essential to optimize the LH_2 resupply by utilizing a customized alternate second stage/tanker configuration. The second recommended system concept was compatible with launch of LH_2 modules external to the space shuttle orbiter. The RNS configuration consists of four 75 K-lb LH_2 modules with a 20 ft. diameter which are launched two at a time mounted parallel to the fuselage of the orbiter. LH_2 resupply for this system would be performed by an optimized orbiter/tanker configuration. A non-jettison mission mode was recommended for both concepts. Also, it was recommended that the RNS operate independent of external support (such as space tug retrieval in Earth orbit) during the mission. Principle results of the subtasks will be reviewed in the following discussion.

Task 1.1 -- RNS Launch Assessment

This task is subdivided into evaluation of SSB/alternate second stage concepts, external launch concepts, and definition of initial deployment concepts.

Task 1.1.1 -- SSB/Alternate Second Stage Concepts

Parametric loading analyses initiated during the preceding period were extended utilizing the reference trajectories to assess the loading impact of alternative launch configurations. Two boosters were evaluated in depth for this purpose.

The parallel burn booster, which has a piggyback mounting of the orbiter, was evaluated with an SIVB/J-2/8 SRM second stage and the interface loads were determined for two candidate RNS launch configurations, a single 300 K-lb LH_2 module with a 33 ft. diameter and a single 150 K-lb LH_2 module with a 28 ft. diameter. It was found that the 300 K-lb LH_2 module slightly exceeds the orbiter flight envelope for the forward radial reaction, but the 150 K-lb LH_2 module is within the bounds of the orbiter flight envelope. The second booster considered was the LO_2/RP booster, which has a tandem-mounted orbiter belly tank ahead of the booster. Interface loads were evaluated for this booster and a common LH_2 tank second stage configuration over a range of module diameters from 18 to 36 ft. and for RNS module capacities of 100 K to 300 K-lb LH_2 . It was found that whereas the large single module imposes severe integration problems, a 150 K-lb LH_2 module which would be analogous to the orbiter belly tank is more favorable. More complete data for both booster concepts were reported in the interim briefing.

Task 1.1.2 -- External Launch Concepts

A recommended launch configuration was reported during the last period consisting of launch of the RNS modules, two at a time mounted parallel to the fuselage of the orbiter. Orbiter interface loads were investigated for a reference 20 ft. diameter tank as a basis for initiating impact studies. Results were reported in the interim briefing.

Task 1.1.3 -- Initial Deployment

Based on the considerations noted in the preceding subtasks, the recommended SSB/alternate second stage launch envelopes were determined as follows. The 300 K-lb LH_2 module can only be launched one module per launch, which amounts to launching the full RNS in a single launch. This represents the most difficult RNS configuration to integrate with the launch vehicle, and depending on the space shuttle configuration selected could conceivably be precluded on this basis. It appears quite adequate to launch the 150 K-module at a rate of 1 module per launch, and this should not pose a major integration problem,

particularly since a significant reduction of diameter can be achieved compared to the 300 K-lb LH_2 module without imposing a performance penalty on the RNS mission. For smaller RNS propellant module sizes it appears adequate to launch them at a rate of two modules per launch. Based on the loading analyses performed it is anticipated that there will be a requirement to investigate load relief for the launch of the RNS/second stage configuration for the selected space shuttle booster concept.

Task 1.2 -- Preliminary Design Optimization

This task is concerned with defining and optimizing design features to a sufficient level to establish significant differences and implications of the candidate RNS concepts--1, 2, 3, 4, and 8 propellant modules. The results of this optimization were reported in detail in the interim briefing and will only be highlighted here. The Phase III studies established the advantages of a modular RNS design concept incorporating a command and control module and a propulsion module. These have been retained as baseline features for Task 1, so candidate RNS configurations are distinguished primarily by the number of propellant modules, their size and arrangement. A tandem array of propellant modules was adopted, since the range of module diameters under consideration would not be expected to incur controllability or structural stability problems, and a tandem array simplifies the design and operational requirements. Phase III results for subsystems were utilized, configured to achieve a no-single-failure criterion. Propellant utilization and residuals were customized for each configuration, operating on the reference lunar shuttle mission profile, and providing for venting of depleted tanks after completion of each maneuver. The propellant module diameter was optimized for each configuration considering structure (the mission configuration after jettison of launch structure), meteoroid/thermal protection, and the NERVA external shield for both jettison and non-jettison mission modes. The shielding requirements were determined according to Phase III criteria and parametric results, constraining the RNS envelope to a 10° half-angle cone, which is consistent with a 160" diameter ~~run tank on the propulsion module~~ and a 140" cap radius on the aft propellant module aft bulkhead. Two modules at 150 K each were optimum for the alternate second stage concept and had a λ' of 0.781. Similarly, four modules at 75 K each were optimum for the external launch concept and had a λ' of 0.775.

Task 1.3 -- Logistics and Support

This task is concerned with evaluating logistics and support systems compatible with the launch concepts selected in Task 1.1. Since data was presented in the interim briefing, only highlights of the topics investigated will be summarized here. RNS deployment configurations range from single modules to completely assembled multi-module RNS configurations. When using a SSB/current hardware derived second stage (S-IVB/J-2/8 SRM) the space shuttle logistics system was utilized. However, when a new stage concept employing partial reuse is considered the relatively low transportation cost characteristics make it an attractive candidate for logistics support as well as for initial deployment. In the case of external launch on the orbiter a compatible orbiter logistics system was considered. Sensitivity to program models ranging from two to eight RNS flights per year over a ten year period was investigated. Also, the cost of module replacement for a jettison mission mode was compared to a non-jettison mission mode.

Task 1.4 -- Mission Analysis

Alternative RNS mission modes were identified and evaluated, including independent modes (non-jettison, jettison, and aero-braking) operating apart from any external assistance during the entire mission, and the assisted mission modes which depend on external systems for mission completion. The latter include tug retrieval in earth orbit, tug assist for refueling upon arrival in earth orbit, or refueling in lunar orbit. The results which were reported in the interim briefing indicated that the independent mission mode compared favorably with the assisted mission modes when identifying equal payload requirements. While the tug assisted modes were shown to be slightly more cost effective, the associated operational complexities and Van Allen radiation hazard do not justify their selection. In cases of unusual high payload delivery requirements, jettisoning of propellant modules or addition of an extra module to the RNS configuration would be favorable.

Task 1.5 -- Concept Evaluation and Selection

This task was concerned with selection of the RNS system concepts to be evaluated during the balance of the study, using the mission performance and cost data generated for the optimum launch concepts designs and operations defined in the

preceding tasks. The screening process was completed by answering a series of questions as follows: (1) determine the most favorable RNS concept for each launch and logistics concept, (2) determine the most favorable systems from these, (3) identify and compare alternative system concepts, (4) recommend RNS systems responsive to anticipated program levels, and (5) review sensitivity of the system selections to space shuttle concepts. Parametric data concerning these questions was presented in the First Interim Briefing.

In the case of a launch system utilizing an alternate second stage and space shuttle logistics the S-IVB/J-2/8 SRM represents the most attractive launch vehicle for a limited program, and an RNS configuration consisting of two 150 K-lb LH_2 modules launched one at a time is most favorable, considering system operating costs and launch vehicle integration. When a new second stage is used for launch it should also be used for LH_2 logistics. An RNS configuration consisting of two 150 K-lb LH_2 modules launched one at a time is also most favorable with this launch/logistics system when using a non-jettison mission mode. Some improvement of payload delivery and transportation cost could be achieved by using a configuration consisting of three 100 K-lb LH_2 modules, jettisoning two of those modules in a lunar orbit. However, the mission analyses showed that increasing the RNS propellant capacity would result in equal or more favorable operating cost with an optimized, non-jettison configuration, which has the advantage of simpler operations and higher likelihood of mission success. Accordingly, the two 150 K-lb LH_2 modules RNS configuration was recommended for all of the alternate second stage launch/logistics system alternatives.

It was found that the S-IVB launch system with space shuttle logistics is adequate for a very limited program model. However, for traffic rates exceeding three missions per year over ten years it appears that development of a new second stage launch system, including additional development of a customized LH_2 tanker, would be warranted.

Similar analyses indicated that in the case of external launch a configuration consisting of four 75 K-lb LH_2 modules operating in a non-jettison mission mode would be most favorable. No alternative hybrid or space shuttle derivative RNS concepts were identified which promised improvement of the baseline system characteristics.

It was found that the logistics cost for the two selected systems have been reduced to about 40% of that obtained in the Phase III concepts. The key factor has been identification of optimum new modes of propellant resupply.

Considerable attention was given to the sensitivity of the RNS systems which have been evaluated to the continuing changes of the space shuttle concepts. It appears that the current space shuttle performance parameters are compatible with RNS launch and logistics, although a severe degrading of shuttle performance could be undesirable. The recommended launch configurations are controllable for the range of space shuttles which have been investigated. Whereas, the system costs will change for the range of space shuttle concepts, it is apparent that the principles which produce the relative cost effectiveness of the different launch and logistics concepts apply for the concepts considered. Also the relative loading impact of the RNS module capacity and diameter appears to be consistent for the alternative booster concepts with either piggyback or tandem mounting. The design optimization of the RNS diameter is on a conservative basis which is consistent for the range of configurations investigated. Therefore, the general conclusions concerning the desirability of freeing the RNS from the constraints of the space shuttle cargo bay and utilizing new multiple module configurations and improved LH_2 delivery systems are expected to remain valid.

Task A-2

CONCEPTUAL DESIGN DEFINITION

This task was initiated toward the end of the last month following selection of the two RNS concepts in Task 1. Preliminary design criteria were established and first level design trade studies were defined and reviewed with the COR. These trade studies listed below will be initiated during January:

- RNS geometry
- Thermal protection system
- Intermodule structure
- Reliability design approach
- Maintenance level
- Valve and valve drivers
- Primary electric power supply
- Data management
- Data bus configuration
- Emergency detection approach

TASK A3
SYSTEM REQUIREMENTS

The Operations subtask will be active during January, with the Mission and Performance Analysis subtask being initiated as required to support the operations activities. Mission Operations will be the principal effort, with prelaunch operations being analyzed on a preliminary basis to choose baseline transportation, storage, and test methods for use in other tasks as required. A number of specific trade studies have been identified and defined to a first level within this task, and they are listed below. Those which will be initiated during January are grouped directly below, while trade studies scheduled for start in February or later are grouped separately.

Trade studies scheduled for January initiation

- LH₂ Resupply Operation Definition
- Expedited Module Disposal Operations

Trade studies scheduled for February or later initiation

- Module Transportation Alternatives
- Module Storage Alternatives
- Post-manufacturing Acceptance Testing Alternatives
- Earth Launch Operations Definition
- Space Shuttle/RNS Module Interface Definition
- Space Tug/RNS Interface Definition
- Integrated PIL/SIL/NRDS Test Program Definition

Task B-1

REFERENCE INTERFACE DEFINITION

The NERVA interface recommendations summarized in the last monthly report were reviewed at MSFC on December 2. Following this an interface review meeting was held at MSFC including representatives from SNSO-Washington, SNSO-Cleveland, and ANSC. There was concurrence with many of the recommendations and Aerojet will review and comment on all items.

The two major differences are the location of the structural interface plane and the engine configuration resulting from provision for orbital maintenance at the component level. The MDAC recommendation was to locate the engine stage structural interface at the gimbal bearing in order to eliminate the additional flange connection and simplify the thrust structure for equipment mounting and thermal protection. The ANSC position favored retaining the upper thrust structure as an engine component because it contains the attach lugs for the gimbal actuators. This item is being reviewed at both ANSC and MDAC. The MDAC recommendation for orbital maintenance with the propulsion module concept was to accomplish maintenance by replacement of the full module and to configure the engine accordingly. ANSC pointed out at the review meeting that they needed the current engine configuration in order to efficiently accomplish maintenance during the engine ground test program. Accordingly, no reconfiguration of the engine will be made and the orbital maintenance level will be examined further.

Aerojet's review of the interface recommendations is expected this month. Upon receipt all items which are resolved will be incorporated into the reference interface definition and will be included on the interface control drawing.

TASK B2
RNS TRADE STUDIES

Five trade studies were active during the second reporting period, namely, TS-I-001 - NERVA/Stage Structural Dynamics During Space Shuttle Launch, I-002 - Engine/Stage Astrionics System Optimization, S-001 - Safety Criteria Analyses, P-002 - Development Test Propulsion Module Feasibility, and P-005 - Program Support. Summary status statements for each of these activities are presented in the following paragraphs.

TS-I-001 - NERVA/Stage Structural Dynamics During Space Shuttle Launch

This trade study has been slow in starting due to lack of definition of the space shuttle vehicle. However, preliminary activities were initiated in December. These activities consisted of (1) generating stiffening data on the MDAC Propulsion Module structure for use by ANSC in their dynamic analyses and (2) meeting with ANSC to establish the data package that they will provide to us for the engine/stage trade study. The meeting was held on December 9 between Bob van't Riet of MDAC and Ira Hall and Dennis Vronay of ANSC. Agreement was reached on the dynamic model of the NERVA to be provided to MDAC. This model will consist of a free-free model without the mass of the biological shadow shield. Modal data will be provided on all the low frequency engine modes, with computer cards being used for data transmission. These data were received on December 23. Trade study activities during January will include loading portions of the ANSC data into the existing MDAC two-dimensional program and checking out the operation, as well as modifying the program to a three-dimensional tool which will accommodate the ANSC data in its entirety.

TS-I-002 - Engine/Stage Astrionics System Optimization

The engine/stage processor integration portion of this trade study has gathered generic reliability data to provide a basis for sparing portions of the computer system architecture. This will allow for definition of the

candidates within the standby module sparing class and the level of redundancy in the other candidate classes during the next reporting period.

Preliminary conversations with ANSC have indicated that they are planning to change their baseline electrical harness approach to use flat cable consistent with the recommendations of the "Cabling and Connector Study," performed under Contract NAS8-25620. This will contribute to a consistent definition of the physical interface between the engine and stage harnesses. However, the current 400 E engine is not configured to be compatible with a run tank, so a finalization of its interface will be contingent upon a firm definition of the NERVA configuration.

TS-S-001 Safety Criteria Analysis

The safety trade study activities during December included investigation of the benefits versus the costs of several safety design criteria. Specific items treated were the cost for a mission failure, the cost of a maintenance operation and the cost per pound of added module weight. These data were applied to the weight, reliability and maintenance data developed previously to obtain overall costs for each candidate criteria. The detailed results of these analyses have been documented for use in formulating reliability and maintenance criteria recommendations. The study will be concluded with a sensitivity data generating activity, where various parameters will be varied to determine the effect on the basic trade study conclusions.

TS-P-002 - Development Test Propulsion Module Feasibility

The activity on the Propulsion Module Trade Study included discussions with ANSC on definition of major test program activities at NRDS, initiation of preliminary test plan formulation for each of the candidate program/propulsion module development options, and initiation of program plan definition for each of the candidates.

Cliff Boehmer made a trip to Aerojet on December 6th to discuss a test program for the propulsion module. He talked with Mr. Bruce Nauslar on that subject, and also discussed the subject of reliability and safety with Mr.

J. A. Ramsthaler. The test discussion revealed that the NERVA Verification Plan, Document No. T-102-CP090290-F2, dated September 1970, represents the latest ANSC effort in this area. Consequently, it has been used as the primary source of engine test program data in the propulsion module test program definition.

Preliminary propulsion module development test schedules have been defined in conjunction with the test programs for the five candidate program/propulsion module development options, and will be refined during the following months as the test programs are refined. Major test program activities that have been identified and will be treated in more detail include component and system development and qualification. Requirements for Propulsion Integration Laboratory (PIL) and System Integration Laboratory (SIL) testing to support NRDS activities are also being defined. Additional support test program requirements identification and test hardware configuration definition efforts will be active during the next reporting period.

TS-P-004-Program Support

The activities in the area of Program Support during the second reporting period consisted of four technical meetings. Two were at Aerojet, one was at MSFC, and another was at MDAC. They are identified and briefly described below. Details of the meetings have been documented in trip reports, and have also been treated in part in appropriate Part B tasks and/or trade studies.

Propulsion Module Test Program Discussion -- A trip was made to ANSC by Cliff Boehmer on December 6th to determine the most recent results of test planning activities for the NERVA Program. It appears that the NERVA verification plan, dated September 1970, represents the latest AGC effort in this area. A secondary objective of the trip was accomplished through discussion of reliability and safety with Mr. J. A. Ramsthaler. This particular discussion included the AGC methods of designing for specific reliability goals and the method of reliability verification.

NERVA Dynamic Model Data -- Bob van't Riet went to ANSC on December 9th to obtain dynamic model data for use in the Engine/Stage Dynamic Trade Study, and to obtain information on the NERVA gimbal actuator to use in future controls and dynamics study efforts. A general agreement was reached on the dynamic model of the NERVA to be provided to MDAC, and the data package was received at Huntington Beach on December 23rd. Aerojet also agreed to provide MDAC with a drawing of their present NERVA cradle design, including the structural spring rate data for the cradle structural elements. ANSC requested some further definition of the MDAC forward interstage structure of the propulsion module. This definition was provided during a subsequent telephone conversation. The gimbal actuator discussion with ANSC was held to establish what studies had been performed by Aerojet in establishing the gimbal actuator dynamic response transfer function that was provided to MDAC in 1970-71. An additional discussion centered around work being done by ANSC in the guidance/NERVA aftercooling interaction area. Subsequent meetings will be held with ANSC on this subject during 1972.

Dual Mode NERVA Applications Meeting -- A coordination meeting was arranged between ANSC, MDAC, and TRW on December 9 at MDAC. The emphasis of the meeting was to review the objectives of the Phase IV RNS Study being conducted by MDAC, with TRW being interested in the study from the standpoint of data applicability to the dual mode NERVA applications study they are performing for MSFC.

NERVA Interface Meeting -- A joint meeting of MSFC, SNSO-C, SNSO-W, MDAC, and ANSC personnel was held in Huntsville on December 16th to discuss a number of interface topics. These included the choice of launch vehicle for NERVA launch, engine length and weight goals, maintenance levels, the engine/stage structural interface, NERVA electronics location, electrical connectors, and propellant management considerations. ANSC is in the process of responding to MDAC data and engine/stage interface recommendations made at the meeting. ANSC intends to make specific recommendations with MDAC participation, for resolution of the interface details and forward these to SNSO-C by mid-January 1972 for government action and resolution.