REON

ROCKET ENGINE OPERATIONS — NUCLEAR

REPORT NO. RN-S-0067

TO

AEC-NASA SPACE NUCLEAR PROPULSION OFFICE

AEROJET RESPONSE TO CONTRACT SNP-1
CONTRACT YEAR 1963 PRELIMINARY REVIEW

NERVA PROGRAM   CONTRACT SNP-1

MARCH 6, 1964

AEROJET
GENERAL TIRE
GENERAL

DISCLAIMER

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AEROJET-GENERAL CORPORATION

A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

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FOREWORD

This submittal presents Aerojet-General Corporation comments on the Government Review of Aerojet-General Corporation Technical Performance on a Subtask Basis for Contract Year 1963, and the transmittal letter to W. C. House, Vice President - REON, from R. W. Schroeder, Chief, SNPO-C, 19 December 1963.

The review and transmittal letter represent the preliminary evaluation of Aerojet performance under AEC/NASA Contract SNP-1 for the period from 1 October 1962 through 30 September 1963. As outlined under the award-incentive provisions of the contract, the final evaluation by the NASA and AEC will follow oral and written presentations of Aerojet's comments on the preliminary evaluation. The written presentation, in three parts, is presented herein.

Part I contains a discussion of the applicability of the award-incentive type of contract to this program.

Part II comments specifically on Space Nuclear Propulsion Office (SNPO) evaluations of individual subtasks for which a reply appeared necessary.

Part III consists of comments from consultants who were asked to review the program and the evaluation.

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CONTENTS (cont.)

PART I APPLICABILITY OF THE AWARD INCENTIVE CONTRACT TO THE NERVA PROGRAM

The preliminary evaluation report and transmittal letter rated the Aerojet-General 1963 Contract Year's work on the NERVA program as "below normal" in its overall performance.

Our company was greatly shocked at this report. It was believed that the work on this complex project had been closely and responsively coordinated with SNPO. It concerned our management deeply that the company performance would not be considered adequate by the SNPO organization, even recognizing that the letter and report are not the final rating. Aerojet-General considers that the rating and the rating method it stems from are of questionable validity, and that a potential of damage to the NERVA program is generated by them.

In particular, the rating came as a surprise because the evaluation for the first three individual quarterly periods received throughout the year had given little indication that such a rating for the year might be forthcoming. (The fourth quarterly evaluation and the annual evaluation were received together.) The overall ratings in the categories of Technical, Schedule, and Administration, and General are shown by quarters in Figure 1. (The comments in the Administration category are largely concerned with costs rather than other aspects of management or administration.) These categories are of course related, in that a problem area of a technical sort will usually cause a delay and increased costs in catching up. Our first half year was normal, overall. The third quarter showed a slight downgrading. The fourth quarter evaluation shows a severe downgrading, and is accompanied by the annual report, which is even more severe than the fourth quarterly evaluation. Apparently no consideration was given to the preceding quarters; the attitude at the year's end dominates the rating for the entire year. It is difficult to determine the significance of this rating, or the validity of whatever rating system may have been used, in the light of these individual ratings. On this basis alone, Aerojet-General cannot accept the preliminary rating.

HISTORY OF INCENTIVE APPLICATION TO NERVA

In late 1961, over a year before the beginning of Contract Year 1963, Mr. Webb, Dr. Seaborg, and Mr. Zisch discussed some possible approaches to award incentives.

In a letter, Mr. Zisch proposed that a joint committee of government and contractor management be formed to evaluate the previous year's performance in several areas as a basis for establishing an appropriate fee for the ensuing year's efforts. Subsequently, however, we were informed that the government was planning to initiate a system wherein the previous year's performance was to be judged retroactively and the fee for the previous year to be determined accordingly.

In a letter to SNPO, Aerojet suggested the need for early establishment of the principal objectives of the government and further suggested that these be clearly defined and measurable with the methods of measurement initially agreed upon. This was considered very important because of the complex yet flexible nature of the NERVA development program. The items to be measured and evaluated must be only those that were actually under the control of the contractor. Aerojet recommended the elimination of "subjective" performance areas which lacked precise and agreed-upon measurement yardsticks and we agreed to work closely with government personnel in developing mutually acceptable measures of performance. In August 1962, Aerojet was informed that a unilateral award type incentive arrangement was being contemplated by the government and that no definitive performance criteria would be applied. The evaluation would reflect only the judgment of the government evaluators. This concerned us greatly. We knew from past experience that if the program were to get into trouble in one or two areas, the customer project group would naturally become very concerned. At such a time it would be easy for this group to become convinced that <u>all</u> of the contractor's performance was bad, because of their concern about the one or two areas. Objective measurement criteria, and review by someone not involved in the day to day pressures of the program are essential for fair evaluation under these circumstances.

Finally, in the spirit of Mr. Zisch's talks with Mr. Webb, Aerojet did agree to this experiment. We trusted that the many groups involved and the technical difficulties to be overcome would be given full weight in the evaluation. There was confidence that the management level of the final evaluators would afford the necessary objectivity in judging the validity of the application of the evaluation method.

It is believed that when the Review Board now considers all of the factors involved, it will agree that the award application trial was in fact <u>not</u> successful, and that it would be best to frankly agree that this is so. This type of contract is not to be used in the program this year because of the program redirections that have occurred. Consideration of the redirections that occurred in Contract Year 1963 will verify its inapplicability.

While Aerojet strongly believes in contract incentives, and wholeheartedly subscribes to their use in any program where sound evaluation criteria are agreed upon at the outset, it does not appear that the advanced nature of this program, and the changes in direction that have occurred, make them applicable to it.

<u>PROGRAM REDIRECTIONS IN CONTRACT YEAR 1963</u>

The fluid nature of the program is indicated by the number of major program redirections that have occurred during Contract Year 1963. These major program changes are shown in Figure 2, which is a summary of those significant directions received from SNPO during the year, together with an indication of the program planning efforts completed by the contractor. These are major directions; the detailed special technical guidelines and changes provided on a day-to-day basis are not shown. Aerojet is not suggesting that program redirections are not needed or are not logical, but the question does arise as to whether or not the government evaluators have given sufficient consideration to these in rating schedule and cost performance. Some schedules and milestones established at at the outset were not achieved as forecast because they have simply disappeared through redirections; others have been rescheduled for later achievement in accordance with reprogramming guidelines. Also, the detailed milestones indicated in the Contractor's Technical Administration Documents were internal

Page I-4 - Delete the first sentence of the last paragraph and replace with the following: "A major system decision initiated by SNPO before Contract Year 1963 revised the cycle from a heated bleed to a hot bleed system. Additionally, the coating on the nozzle was eliminated. These two revisions resulted in a 30% increase in pressure and a 50% increase in temperature for the turbine, clearly requiring a major redesign of the turbine". Errata Sheet - Mar '64 management guidelines only and were certainly never intended as, nor did they become, contractual commitments. They appear, however, to have been used in the ratings. The key NERVA goals and objectives and corresponding milestones are few; they are associated with the test date of the NERVA reactor and of the engine, and with deliveries to the vehicle contractor for ground test and flight. An evaluator must exercise caution in judging the effects, on the major program objectives, of any slippages in these internal working milestones. It is inherent in research and development work that minor milestones will slip or change as problems are encountered. They are indicators to the program management that effort must be applied to prevent any slippage in the major milestones.

The transmittal letter for the evaluation strongly emphasizes, in much more severe terms than the report proper, two of the areas of development. It states, "the prime contractor's most major in-house design and development responsibilities involve the design and development of a suitable NERVA turbopump assembly and a suitable exhaust nozzle." Although these tasks account for less than 20% of the dollar effort for 1963, they are given much attention in the letter. The turbopump development, which received particularly severe criticism, offers a good example of the redirections referred to above.

A major system decision initiated by SNPO before Contract Year 1963 revised the cycle from a heated bleed to a hot bleed system, requiring a 30% increase in pressure and 50% increase in temperature for the turbine, clearly requiring a major redesign of the turbine. Emphasis had been placed on the heated bleed cycle by Aerojet, which resulted in the Mark III design. A redesign of the Mark III, designated Mod 2, was made as an intermediate, to avoid schedule delay, and Mark IV Mod 0 was initiated to meet the total requirement. A chronology of these and subsequent events is shown in Figure 3. The SNPO direction required the inclusion of a balance piston, a wet pump design, and change in the head capacity slcpe of the pump. These requirements were reviewed by our engineering staff and Vice President-Engineering, and were considered a matter of "designer's choice." The final design was submitted only a week after it was scheduled, despite a specially called review meeting in Cleveland. The turbopump has not, in fact, paced the development program, nor caused any slippage in a major contract milestone.

It is our opinion that our performance was, in fact, exceptionally good on the turbopump.

These facts appear to substantiate that the program fluidity and changes that have been the reason for not applying an incentive to Contract Year 1964 existed to an equal or greater extent in 1963, and that the rating procedure leaves something to be desired.

THE EVALUATION PROCEDURE

We now come to a discussion which we consider to be most significant, namely the validity of the evaluation procedure, the technique for performing the evaluation, and the quality of the results. In both the quarterly and the annual evaluations, the contractor is rated relative to "normal." It is difficult to understand just what establishes normalcy and who is qualified to judge it and deviations therefrom. The evaluation reports define normal as "that which a contractor qualified in his field of endeavor would be expected to perform." This definition refers "normal" performance to a "qualified contractor" and someone's expectation. What is expected? Accomplishment of all technical objectives of a research and development program on schedule and precisely to the budget level predicted in the beginning of any contract period? The history of research and development contracts, we believe, would show that no contractor has ever achieved this, and indeed there would therefore be no qualified contractors.

Would a "qualified contractor" not be expected to encounter technical difficulties in a research and development program that advances the state-of-the-art? If not, there would be no need for a development program at all, and our defense and space system projects would be reduced to manufacturing and assembly. If a qualified contractor does encounter technical difficulties, does he suddenly become unqualified? Does he rate "below normal" if he spends more funds than initially budgeted in the areas where the difficulties occurred? Is he unqualified if he does not meet a schedule he prepared that did not allow for these particular technical problems? These questions underlie the apparently simple and clear definition of normalcy. Normally, a qualified contractor does run into technical holdups on advanced R & D work, and expends additional effort in resolving them. This is what is meant by exerting best effort on an advanced R & D scope.

The definition says, "... would be expected to perform" - expected by whom? Presumably, by the evaluator, since he is to apply the definition in the evaluation. What is a "qualified contractor?" Aerojet must have been qualified to have been selected in the first place. So the definition of normal means "what the evaluator expected Aerojet would do," a completely subjective reference point. It may well be asked at this point, what is a "qualified evaluator?"

Even if "normal" can be defined, the problem shifts to what the various terminologies for deviations from normal mean. What is the relative ranking and weighting of "slightly below," "somewhat below," "appreciably below," and "significantly below." What is the position of "just about normal," "well above normal," "far below normal," "exceptionally good," and other such terms recurring throughout the reports? These questions are not intended to play with words, but to seriously question the validity of the rating method, and its dependence on individual interpretation of people directly concerned with the immediate effects of their ratings.

For an incentive system to be fair and equitable, a sound evaluation system must be defined at the start and people must be qualified in the technique of rating. Whereas a proposed rating system may legitimately be secret, a performance rating system must be open to be equitable; an agency doing work has the right to know on what basis its work will be judged and rewarded. An inadequate incentive system will serve to discredit both the particular system and the principle of incentive awards. The evaluation system must have specific, well-defined, measurable criteria and must be objective and consistent. Aerojet has repeatedly stressed its belief that the customer has the responsibility of insuring that the contractor knows what is to be measured and how it will be measured.

An illustration of the problems in rating is the independent evaluation by both SNPO and Aerojet of the efforts of the principal subcontractor, the Westinghouse Astronuclear Laboratory, for the first three quarters of the Contract Year 1963. Figures 4 and 5 show typical comparisons for the second and third quarters. In all, 51 tasks were rated by both Aerojet and SNPO personnel. For example, in the third quarter, of the 51 individual ratings, Aerojet and SNPO agreed on 14. Of the 37 remaining tasks, there were 19 instances in which the Aerojet ratings were significantly higher than SNPO ratings, and 18 instances in which they were significantly lower. Both groups of raters were conscientiously trying to use their best judgment but in spite of this, a substantial disparity resulted. Obviously, "normal" really belongs anywhere in the middle one-third of the range, and there is no real significance to the differences in the final ratings by the two rating agencies.

A number of additional points further substantiate the questionable validity of the evaluation procedure. First, the rating, supposedly restricted to Contract Year 1963 efforts, appears to have been colored by events occurring in Contract Year 1962 and also by conjecture as to what may occur or has occurred in 1964. For example, the alleged turbopump deficiencies relating to foresight, analysis and planning would apply, if at all, primarily to Contract Year 1962. Expressions of anxiety that the ~~turbopump~~ nozzle would be pacing the NERVA reactor test program are certainly a matter of conjecture regarding events to occur in Contract Year 1964 or beyond.

Per Errata Sheet May 64

Secondly, we should point out that there is an inconsistency apparent in the criticism of Aerojet task ratings as compared to the rating of Westinghouse in the systems analysis work for the NERVA experimental reactor. By agreement with SNPO, this work was assigned exclusively to Westinghouse. It is perplexing to find that Westinghouse was rated "normal" in this area, while Aerojet was reviewed a "below normal" rating. Furthermore, much discussion in the evaluation

Page I-7 - Delete the last sentence of the third paragraph and replace with the following: "Expressions of anxiety that the nozzle would be pacing the NERVA reactor test program are certainly a matter of conjecture regarding events to occur in Contract Year 1964 or beyond." Per Errata Sheet May 64

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report is devoted to conjecture concerning the overrun potential in certain of Aerojet's tasks, as well as statements regarding possible delays that could be encountered in the NERVA reactor test program as a result of Aerojet's performance. These conjectured statements do not properly belong in a performance evaluation, since they are not about work that has been performed; however, the same type of comments would be expected about the Westinghouse fuel element production task. Instead, stated specifically in the evaluation report, the Government indicated that it did not intend to take cognizance of this fact.

Thus far we have seen the overall evaluations by quarters, and have looked at the apparent grading steps and at the reference point: "normal." Now let us look at the distribution of "above" and "below" ratings. Figure 6 shows all of the task items and the quarterly ratings coded for above, below, and normal. The annual ratings are shown as above, A; normal, N; and below, B. The distribution suggests the scatter of ratings we showed on the Westinghouse evaluation chart, and raises the question of how another independent evaluator might rate the subtask performance.

The number of subtask ratings by quarters in the above, normal, and below categories are shown in the vertical bars of Figure 7. The "aboves" about equal the "belows" throughout the rating year, and the preponderance of ratings were "normal." The sum of the quarterly ratings is shown on the right. To compare these with the annual rating, the annual ratings are plotted, multiplied by four. These do not appear to represent fairly the sum of the quarterly ratings, as we noted on the overall chart.

Figure 8 shows the quarterly rating weighted by the dollar amounts of each subtask, to balance up for the cost scope of each effort. Again, the "aboves" balance the "belows" and the "normals" predominate, although with some shifting in distribution. Cost weighting is not necessarily more valid, but may be closer to whatever measure is the "true" one, if such exists.

Another type of weighting is by the importance of the individual tasks to the overall program. According to the evaluation report, this approach was

Page I-9 - Delete the words "turbine and" from line 8.
(Errata sheet Rpt RN-S-0068 Mar '64)

used by the SNPO. The problem is that the importance of items varies throughout the program. At any time, and depending on where the breakthroughs are being pressed for, any of a number of items may be critical. Usually, those that have slipped become critical automatically. Another set may be critical later, when the latter have been resolved. It is true, for example, that the nozzle had to be completed before the first NRX test firing. But this test itself was but a part of the overall effort, although certainly a point on which much attention was focused. The turbopump and nozzle were not on the critical path of the PERT net, though, because the fuel elements were pacing. An attempt was made to assign a representative quantitative rating to these factors but it could not be accomplished on any basis we considered valid, because of the problem described. Some such consideration was stated to have been used in the evaluation.

* See Errata Mar. '64

Aerojet considers, from the quarterly and final individual subtask and overall ratings, from the nature of the rating procedure, and from what we think is normally expected from a contractor on this type of program, that a "normal" rating is just as valid as any other; that there is no real difference between "below normal," "normal," and "above normal" in view of the evaluation data.

We fully realize the problem SNPO had in attempting to assess performance on an equitable and objective basis without pre-established criteria when so deeply involved in design choices, problem areas, and the day-to-day turmoil of an R & D program. We recognize the pressure that outside factors and redirections put on the program. We think the preliminary evaluation in the light of all these factors is understandable, but from an overall, objective standpoint, gives an untrue picture.

SNPO OVERALL EVALUATION

AGC PERFORMANCE ON SNP-I

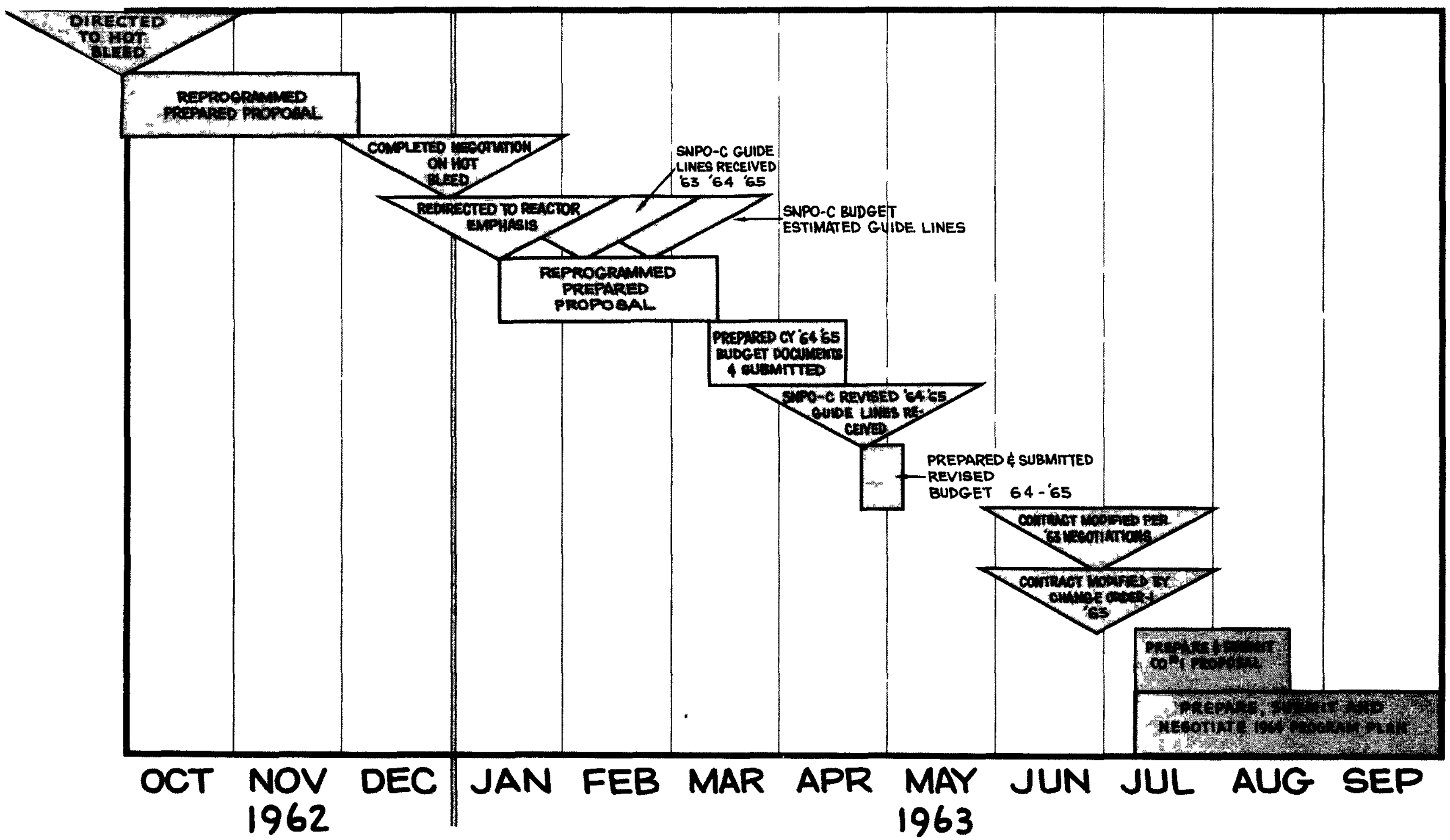
	TECHNICAL	SCHEDULE	ADMINISTRATION	OVERALL
FIRST QUARTER	NORMAL	NORMAL	NORMAL	NORMAL
SECOND QUARTER	NORMAL	NORMAL	NORMAL	NORMAL
THIRD QUARTER	SLIGHTLY BELOW	SLIGHTLY BELOW	NORMAL	SOMEWHAT BELOW
FOURTH QUARTER	SOMEWHAT BELOW	APPRECIABLY BELOW	SOMEWHAT BELOW	SOMEWHAT BELOW
ANNUAL	SOMEWHAT BELOW	BELOW	SOMEWHAT BELOW	BELOW NORMAL

AEROJET GENERAL

Figure 1

MAJOR PROGRAMMING ACTIONS

CONTRACT SNP-1
CY 1963

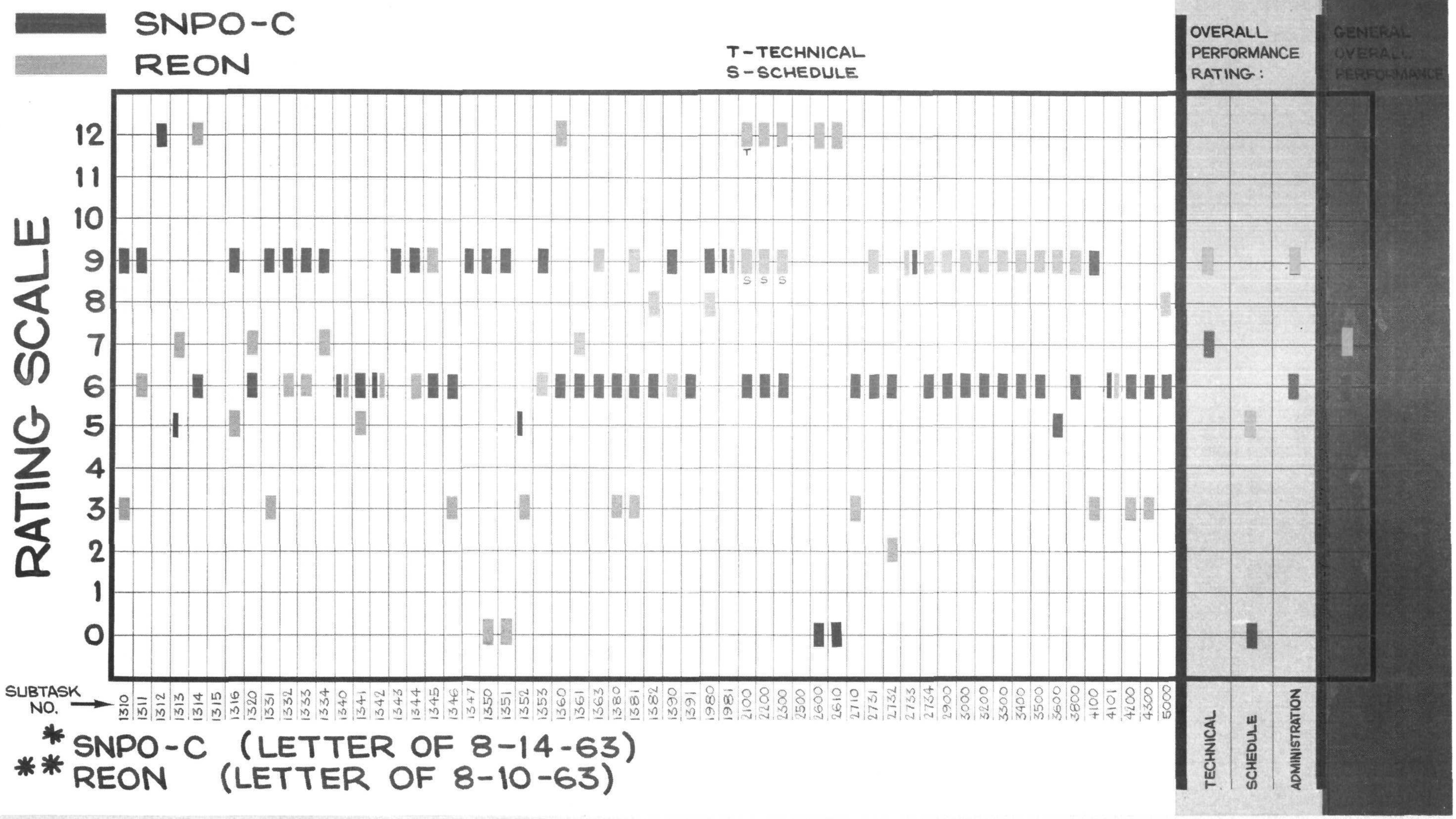


AEROJET GENERAL

Figure 2

SNPO-C* AND REON** RATING OF WANL

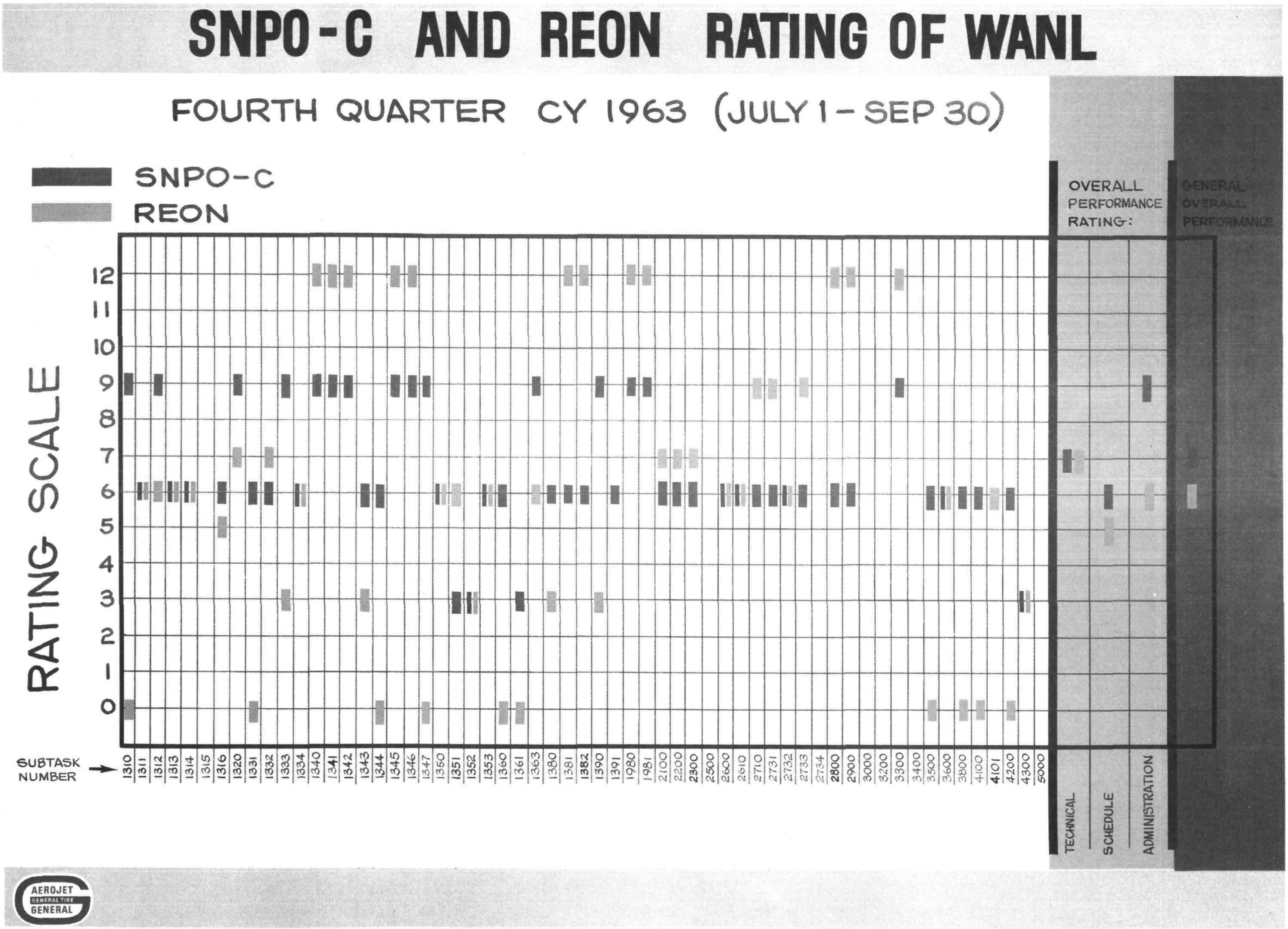
THIRD QUARTER CY 1963 (APRIL 1-JUNE 30)



* SNPO-C (LETTER OF 8-14-63)
** REON (LETTER OF 8-10-63)

AEROJET GENERAL TIRE GENERAL

Figure 3



SNPO-C AND REON RATING OF WANL
FOURTH QUARTER CY 1963 (JULY 1-SEP 30)
SNPO-C
REON
RATING SCALE
12
11
10
9
8
7
6
5
4
3
2
1
0
SUBTASK NUMBER
1310 1311 1312 1313 1314 1315 1316 1320 1331 1332 1333 1334 1340 1341 1342 1343 1344 1345 1346 1347 1350 1351 1352 1353 1360 1361 1363 1380 1381 1382 1390 1391 1980 1981 2100 2200 2300 2500 2600 2610 2710 2731 2732 2733 2734 2800 2900 3000 3200 3300 3400 3500 3600 3800 4100 4101 4200 4300 5000
OVERALL PERFORMANCE RATING:
TECHNICAL
SCHEDULE
ADMINISTRATION
GENERAL OVERALL PERFORMANCE
AEROJET GENERAL TIRE GENERAL

Figure 4

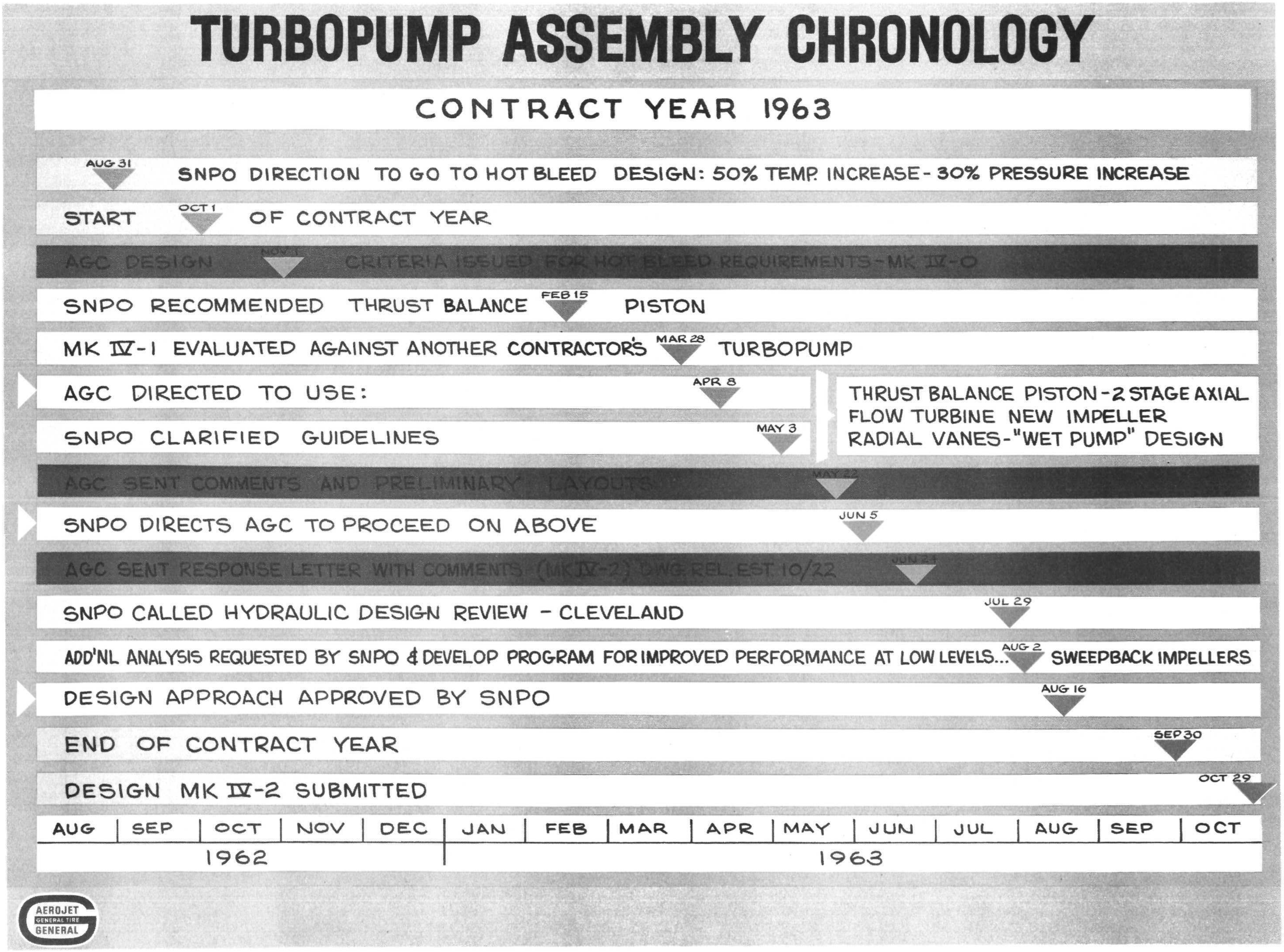

TURBOPUMP ASSEMBLY CHRONOLOGY
CONTRACT YEAR 1963
AUG 31
SNPO DIRECTION TO GO TO HOT BLEED DESIGN: 50% TEMP. INCREASE - 30% PRESSURE INCREASE
START
OCT 1
OF CONTRACT YEAR
AGC DESIGN
NOV 1
CRITERIA ISSUED FOR HOT BLEED REQUIREMENTS - MK IV-0
SNPO RECOMMENDED THRUST BALANCE
FEB 15
PISTON
MK IV-1 EVALUATED AGAINST ANOTHER CONTRACTOR'S
MAR 28
TURBOPUMP
AGC DIRECTED TO USE:
APR 8
SNPO CLARIFIED GUIDELINES
MAY 3
THRUST BALANCE PISTON - 2 STAGE AXIAL FLOW TURBINE NEW IMPELLER RADIAL VANES - "WET PUMP" DESIGN
AGC SENT COMMENTS AND PRELIMINARY LAYOUTS
MAY 22
SNPO DIRECTS AGC TO PROCEED ON ABOVE
JUN 5
AGC SENT RESPONSE LETTER WITH COMMENTS (MK IV-2) DWG REL. EST. 10/22
JUN 24
SNPO CALLED HYDRAULIC DESIGN REVIEW - CLEVELAND
JUL 29
ADD'NL ANALYSIS REQUESTED BY SNPO & DEVELOP PROGRAM FOR IMPROVED PERFORMANCE AT LOW LEVELS...
AUG 2
SWEEPBACK IMPELLERS
DESIGN APPROACH APPROVED BY SNPO
AUG 16
END OF CONTRACT YEAR
SEP 30
DESIGN MK IV-2 SUBMITTED
OCT 29
AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP OCT
1962
1963
AEROJET
GENERAL TIRE
GENERAL

Figure 5

DETAIL SNPO EVALUATION OF REON EFFORT

ABOVE NORMAL — NORMAL — BELOW NORMAL

CONTRACT SNP-1 CY 1963

A - ABOVE NORMAL   N - NORMAL
B - BELOW NORMAL

TASK NO.	TASK DESCRIPTION	MILLIONS OF DOLLARS	1ST Q	2ND Q	3RD Q	4TH Q	ANNUAL
1.1	ENGINE SYSTEMS	2.9					B
1.2	PROPELLANT FEED SYSTEM	3.7					B
1.3	REACTOR SUBASSEMBLY	.4					N
1.4	THRUST CHAMBER ASSEMBLY	5.3					B
1.5	ENGINE CONTROLS	2.0				T/S	B
1.6	ENGINE DESTRUCT SYSTEM	1.7					B
1.7	PNEUMATIC SUPPLY SYSTEM	.23					A
1.8	NRDS OPERATION	.86					A
1.9	RADIATION EFFECTS PROGRAM	3.4					B
2.1	REMOTE HANDLING EQUIP.	4.3					A
2.2	CHECKOUT & TEST SYSTEM	.57					B
2.3	LOGISTICS, TRANSPORT & MAINTENANCE	1.2					B
2.4	INSTRUMENTATION	1.5					B
2.5	FIELD SUPPORT	.01					N
2.6	RELIABILITY & Q. C.	3.0					N
2.7	SAFETY	1.1					B
2.8	TRAINING	.14					B
2.9	LASL SUPPORT	.69					N
3.0	GENERAL SUPPORT FACILITIES	.72					A
3.1	NERVA EXHAUST SYSTEM	.95					A
3.2	TEST STAND ETS-1	.36					N
3.3	ETS-1 INSTRUMENTATION & CONTROL	.31					N
3.4	TEST STAND ETS-2	.20					B
3.5	E-MAD FACILITIES	.30					B
3.6	REACTOR DEV. FACILITY	.24					B
3.7	RADIATION EFFECTS FACILITY	.06					A
3.8	NRDS RADIOACTIVE MATERIAL HANDLING	.20					A
3.9	RIFT STAGE DEV. FACILITIES	.02					N
4.1	PROGRAM PLANNING & CONTROL	.79					A
4.2	FISCAL CONTROL	.91					B
4.3	ADDITIONAL DOCUMENTATION	.60					A
4.4	NERVA CENTRAL DATA SYSTEM	.10					A
4.5	SUBCONTRACTS ADMINISTRATION	.31					B
4.6	SPECIAL PROGRAM SERVICES	.05					N
5&6	SPECIAL TEST EQUIPMENT & GOVERNMENT PROPERTY	6.5					B

AEROJET GENERAL TIRE GENERAL

Figure 6

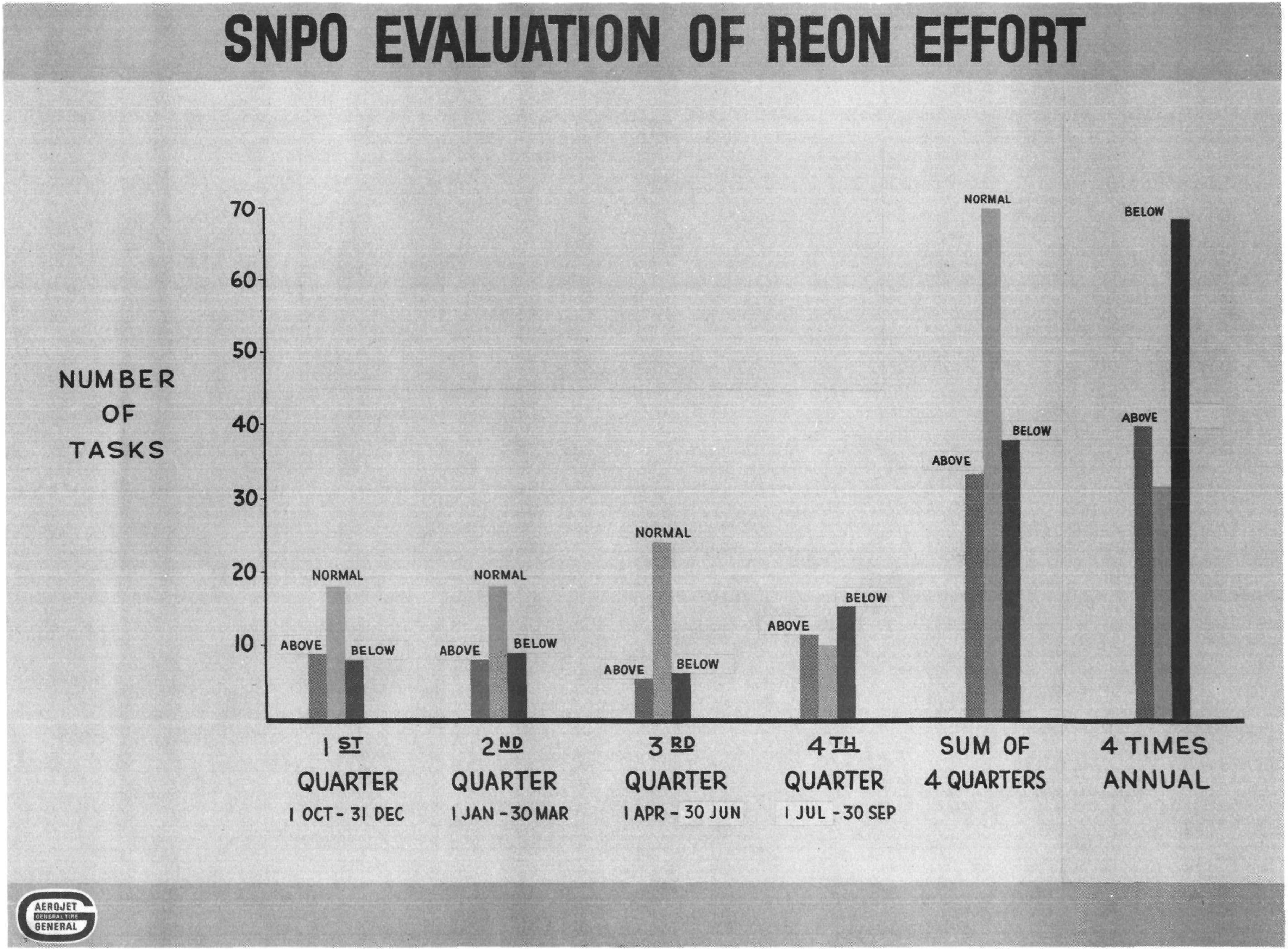

SNPO EVALUATION OF REON EFFORT
NUMBER OF TASKS
70
60
50
40
30
20
10
ABOVE
NORMAL
BELOW
1 ST QUARTER
1 OCT - 31 DEC
2 ND QUARTER
1 JAN - 30 MAR
3 RD QUARTER
1 APR - 30 JUN
4 TH QUARTER
1 JUL - 30 SEP
SUM OF 4 QUARTERS
4 TIMES ANNUAL

Figure 7

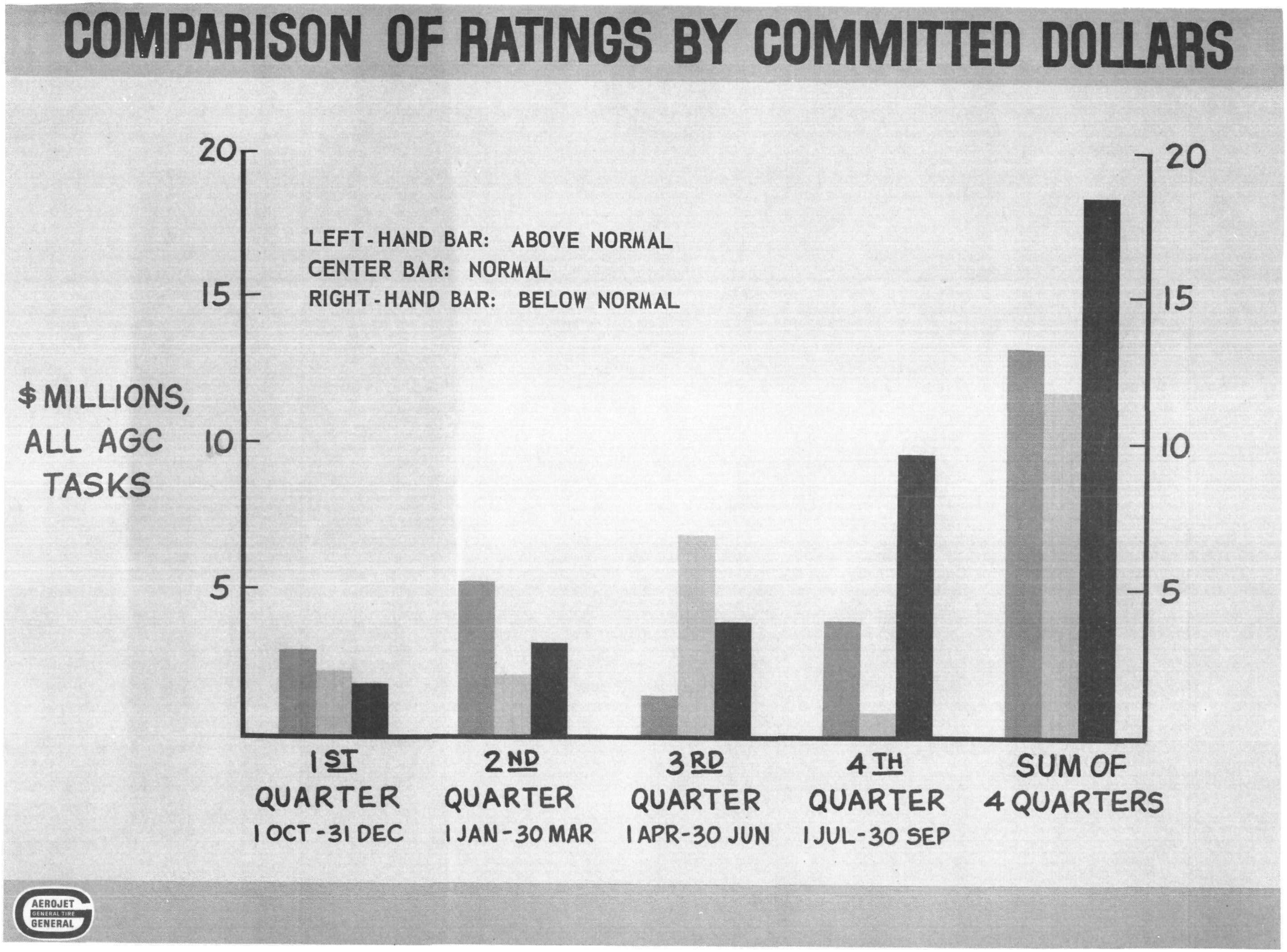

COMPARISON OF RATINGS BY COMMITTED DOLLARS
LEFT-HAND BAR: ABOVE NORMAL
CENTER BAR: NORMAL
RIGHT-HAND BAR: BELOW NORMAL
$ MILLIONS, ALL AGC TASKS
20
15
10
5
1 ST QUARTER 1 OCT - 31 DEC
2 ND QUARTER 1 JAN - 30 MAR
3 RD QUARTER 1 APR - 30 JUN
4 TH QUARTER 1 JUL - 30 SEP
SUM OF 4 QUARTERS
AEROJET GENERAL TIRE GENERAL

Figure 8

PART II TECHNICAL RESPONSE

A. INTRODUCTION

The technical discussion that follows is in response to SNPO's appraisal of Aerojet's performance in work under Contract SNP-1 for Contract Year 1963. The evaluation and comments received in SNPO's letter of 19 December 1963 have been carefully reviewed by Aerojet management. While it is recognized that the establishment of quantitative criteria for use in such an evaluation is extremely difficult, Aerojet considers the SNPO evaluation unduly subjective in some subtasks. To properly convey Aerojet's position and opinions to the Government with regard to this evaluation, an oral presentation by Aerojet management is planned for the first week of March 1964. The data contained herein present Aerojet's response to the specific comments by subtask and supplement the oral presentation.

B. SUBTASK 1.1 - ENGINE SYSTEMS

1. Analyses

a. Aerojet does not agree that the performance on this subtask should be rated below normal. With regard to the comments on the NRX analysis, the primary responsibility for this work was assigned to WANL. This work was accomplished under the WANL Systems Analysis Coordinator. By mutual agreement with the customer, the AGC effort was to have no direct contact with the WANL effort except through the WANL coordinator. The evaluation comment states that a noticeable lack of effort on NRX-A "performance" analyses existed (but means pre-test analyses) with respect to Test Cell A. The basic pre-test analysis for NRX A-1 was issued as TME-400, using the model described in TME-483, and assumed a perfect feed system since the digital computer code in use at WANL computes the steady-state flow conditions. This analysis was supplemented by WANL using the WANL analog computer to consider transient effects. Several WANL reports were issued concerning both the control system and feed system for Test Cell A - NRX-A system (i.e., TME-504, -525, and -533). The evaluation letter for WANL states that the WANL test planning effort was improved during the fourth quarter of CY 1963. This improvement was a direct result of Aerojet direction. In addition, a review of the Government's rating of WANL work in this area reveals that WANL was rated average. In view of the above comments, Aerojet considers that this task should be rated normal.

b. The CFDTS pre-test analyses made during CY 1963 were reported in TM738:63-204 and considered flow conditions on the CFDTS system after the TPA was primed. The analysis of chilldown of the TPA inlet line during this period centered on development of a mathematical model, which was completed on a schedule which did not permit early publishing of analytical results. These analytical results were later published in the CFDTS Test Plan (Aerojet Report 2710) and were reviewed by SNPO-C personnel, who commented that a good job was done.

c. In the customer evaluation, there is general criticism of, but no specific adverse comments on, the systems analysis activities relating to the NERVA engine. Therefore, some discussion of the steady-state (digital) and transient (analog) E-engine programs is in order. The Nuclear Engine Analysis Program, a steady-state program used to define the engine operating-constraint map, was generated during CY 1962. The program was written up as TM734:63-001 (dated 16 May 1963) and was used to redefine the engine operating map as of 5 June 1963. Other activities were studies of the diluent extraction point, laminar flow stability, etc. A partial list of memoranda or reports on these and other analytical efforts is presented in Section II,P, below. During CY 1963, the analog computer at Azusa was used to study transient problems as related to the engine as well as control components and systems. The areas of investigation were cooldown and restarting, power-range simulation of the NERVA hot-bleed engine, FX engine startup transients for various initial conditions, malfunction studies, etc.

2. Fabrication

a. The evaluation states that "fabrication of the master gages was unsatisfactory because of adaptation and rework which had to be performed." Aerojet does not agree that the fabrication of gages was unsatisfactory. Nine (9) gages and match plates were fabricated. Of these, seven (7) were accepted without deviations and two (2) had minor discrepancies.

During fabrication of these gages it became apparent that certain design changes were desirable. Some of these changes were made. Although others were desirable, they were not made, because a more economical procedure to achieve the intended purpose made use of fixture adapters rather than gage design changes. This accounts for some of the "adaptation" mentioned in the criticism. The following gages and match plates were fabricated:

No.	Item	User	Manufacturer
T-603316	Cylinder Master Gage	WANL	Marquardt Company, Ogden, Utah
T-063317	Closure Master Gage	WANL	Marquardt
T-063318	Nozzle Master Gage	WANL	Marquardt
T-603093	Shield to Reflector Match Plate	WANL	Marquardt
T-603094	Cylinder to Closure Match Plate	WANL	Marquardt
T-603329	Shield Master Gage	AGC	Standard Tool Company, Los Angeles
T-603330	Reflector Master Gage	AGC	Oakland Machine
T-603006	Cylinder Aft Match Plate	AGC	Mechanical Specialties, Los Angeles
T-603007	Nozzle Match Plate	AGC	Mechanical Specialties

Of these gages and match plates, only the cylinder and closure master gages were found to be discrepant. In addition, although not discrepant, the nozzle gage was subjected to rework to compensate for the discrepancy on the mating diameter of the cylinder master gage.

During the fabrication of the cylinder master gage at Marquardt, an AGC representative spent the week of 13-20 August 1963 at Ogden in preparation for final inspection and shipping of the part, which was due to be completed by 31 August 1963. Subsequent machining problems and added shop load caused by competing shop requirements delayed the scheduled completion.

On 17 September 1963 Marquardt notified AGC that the cylinder was in final inspection with numerous discrepancies, and that the closure master gage would be available for final inspection by 20 September. AGC sent a representative to Marquardt to spend full time there until the gages could be shipped. The LRP representative determined that the cylinder discrepancies were caused by unauthorized repair work, consisting of welding and attempted cold working of the cylinder master gage after final stress relief. AGC had not been consulted on this work. AGC recommended that the gage be metallized, be stress-relieved again, and be remachined to tolerance. However, this would entail an additional delay of 4 to 6 weeks. Consequently, on 10 October 1963, a meeting was held at AGC with WANL to review the cylinder discrepancies. Because many of the discrepancies were minor and would not affect the use of the gage, it was decided that WANL would use the gage "as built" as an inspection fixture for the NRX A-1 assembly. The gage would subsequently be reworked to the correct dimensions and would then be classified as a master gage for future use.

The closure master gage was also fabricated by Marquardt during the same period as the cylinder gage. Several contour discrepancies were noted in the final inspection at Marquardt. These were evaluated in the 10 October 1963 meeting mentioned above, and AGC and WANL agreed that the contour discrepancies would be acceptable provided that the discrepant areas were identified by markings. The gage was shipped to WANL, was inspected, and was accepted.

The closure gage interface surface was of chrome-nickel and other surfaces were of black oxide. Subsequent cleaning by WANL in trichloroethylene exposed bare casting surfaces which had inclusions of sand. Although the casting furnished by Marquardt did indeed leave something to be desired, it was determined that the usefulness and function of the gages would not be impaired if the surfaces received a protective coating. Accordingly, a plastic-impregnated coating was applied by Godfrey and Wing, Inc., Cleveland, at a cost of approximately $450. This part was then accepted.

The nozzle master gage was completed by Marquardt to print and shipped to WANL on 4 September 1963. In the 10 October 1963 meeting between LRP, REON, and WANL, it was mutually agreed that this gage, having been delivered to WANL and accepted, would be used for NRX-A1. Subsequently, the diameters which mated with the cylinder master gage would be reworked by WANL to compensate for the discrepancies in the cylinder gage.

b. From the above accounts of gage-fabrication events, it can be seen that the major difficulty encountered with regard to the cylinder gage resulted from an unauthorized repair by a subcontractor. Sound engineering judgment was then exercised to determine the most economical and effective way of obtaining usable hardware while maintaining the program schedule. The closure gage from the same subcontractor appeared to be acceptable and was accepted. Although the casting proved to be below standard, an acceptable gage did result with a very modest additional expenditure of money.

The problems encountered with regard to two of the nine items involved are considered normal in R&D programs and first-item fabrication, and Aerojet believes that this should not be reason for downrating this task. Considering the performance on both analyses and gage fabrication, Aerojet believes that this task should be rated normal.

C. SUBTASK 1.2 - PROPELLANT FEED SYSTEM

1. General Discussion

Aerojet does not agree that the performance on this subtask was below normal. By way of review, it is noted that late in the previous contract year Aerojet was proceeding with the Mark III, Mod 1 and 2 TPA designs for a heated-bleed engine cycle, on a schedule which would have accomplished all the planned goals and objectives for Contract Year 1963. The Mod 2 design was the planned follow-on design incorporating the remote removal and disassembly features.

With the change to the hot-bleed engine cycle and the elimination of nozzle coating, which significantly increased the nozzle pressure drop, the pump performance and turbine-temperature requirements increased beyond the capabilities of the Mark III, Mod 1 and 2 designs. To accommodate this situation, Aerojet proposed two designs to be pursued concurrently. The first - a rework of the Mark III, Mod 2 designated as the Mark III, Mod 3 - was a short-lead-time interim design with which to achieve the desired performance and early test data. This design incorporated a two-stage turbine which would provide the required performance. Concurrently, and secondly, a prototype design was proposed (Mark IV, Mod 0) utilizing a higher drive-gas temperature to provide the required performance and improved efficiency. The impeller for this design also provided improved cavitation characteristics as compared with the Mark III design. Either of these designs would have adequately fulfilled the requirements of the NERVA engine. Had effort been concentrated on these designs, significant accomplishments would have been achieved during the contract year, with minimum delay or effect on the overall program goals.

The Mark III, Mod 3 TPA has demonstrated its capability of supplying full FX flow and pressures with liquid hydrogen (LH_2) in Test Runs 1.2-08-NNP-004 through-009 and 1.2-09-NNP-014. Runs 1.2-08-NNP-004 through -006 were completed in September 1963 and Runs 1.2-08-NNP-007 through-009 and Run 1.2-09-NNP-014 were completed in October 1963. The pressure levels achieved were in excess of 1000 psi, whereas the FX pressure requirement was 915 psi from pump discharge. In CY 1963, the TPA bearings were successfully operated at full loads and speed with LH_2 cooling in a non-radiation environment for 75 minutes of accumulated endurance on one set. In October 1963 this endurance demonstration was increased to 91 minutes on one set of bearings. The 75 minutes of operation was completed during Test Runs 640-016 through 640-019. The test runs for the 91 minutes of endurance were Nos. 640-020 through 640-023. In October 1963 the turbopump bearings satisfactorily completed tests at loads and speed with LH_2 cooling in an equivalent radiation environment for endurance times of 5 and 10 minutes. The tests were run at the G/D Fort Worth ASTR facility. The 5-minute run was made in MIT No. 902 and the 10-minute run in MIT No. 903.

Throughout the year, however, many additional changes amounting to design refinements to the TPA were directed by SNPO-C, including: (a) impeller revision to further extend the negative slope characteristics because of SNPO concern that there might be a stability problem; (b) incorporation of a balance piston to reduce bearing loads because of SNPO concern that the bearings might not be capable of withstanding the thrust loads; and (c) provision of a capability to accommodate a "wet" pump installation with its attendant configuration changes and revised sealing requirements in the event that the hot pump startup would be eliminated at a later date. While these further changes may be considered designer's option, they were not mandatory in order to meet the requirements, and there was not unanimity on the desirability of making the changes at that time. As a consequence, Aerojet proposed the associated design and development effort as an addendum item (low priority) and was later directed to proceed. The implementation of these directions resulted in Mods 1 and 2 to the originally conceived Mark IV design, causing some delay in the schedule and cost increase.

2. Detail Discussion

a. The evaluation states that "because of insufficient foresight, insufficient system analysis, and insufficient long range planning, it now becomes necessary to abandon the Mark III TPA design in favor of the Mark IV." -- TPA development has been influenced by extensive consideration of and customer direction to incorporate the latter, designer-option, changes rather than for the reasons stated above. Furthermore, it is not evident that the Mark III, Mod 3 or the Mark IV, Mod 0 designs should have been abandoned because much could have been gained by early testing, and it is not yet apparent that they could not be utilized. It is not considered that Aerojet's responsiveness to incorporation of these changes is cause for downrating the TPA effort.

b. The evaluation also states: "It may be expected therefore that tests of the Mark IV will lead to discovery of problems that were not revealed by Mark III testing." -- Further testing of the Mark IV, Mod 2 turbopump may very well lead to discovery of problems not isolated during the Mark III testing, but such discoveries are to be expected as part of a normal development cycle, and the likelihood of major problems would have been minimized by proceeding with tests on earlier designs.

c. The evaluation further asserts: "Similarly the status of the turbopump development threatens to delay the NERVA schedule." -- The status of the turbopump development program need not delay the NERVA schedule. The Mark III, Mod 3 TPA is currently capable of providing the E-1 engine pressure requirements, and with minor modifications to the turbine, it could be operated at the planned higher turbine-drive-gas temperatures. Furthermore, current scheduling of the ETS-1 test stand indicates that even the Mark IV, Mod 2 TPA could be available in time for engine firings.

d. The evaluation also asserts: "A very large fraction of the total overrun is attributed to the turbopump." -- As can readily be seen from the data presented herein, considerable effort was a direct result of customer-directed changes.

e. The evaluation states: "A retrospective review of the 1963 performance a year hence may well establish that the 1963 development work applied to the Mark III turbopump contributed little to the development of the final NERVA engine prototype component." -- Early isolation of problem areas by extensive development testing of hardware and the step-by-step incorporation of design improvements as the problems are isolated have historically contributed to the successful performance of engine components. Aerojet firmly believes that the development work on the Mark III TPA will make a significant contribution to the final design. A case in point is the excellent performance of bearings tested to date; these bearings can now be applied to future designs. It is considered that conclusions based on conjecture and prophecy do not form a valid basis for rating the performance during the past year.

f. The evaluation also states: "The design and development program was not adequate to insure that the turbopump would meet the negative slope criteria." -- The impellers utilized in the Mark III, Mod 3 and the proposed Mark IV, Mod 0 designs are believed to provide suitable stability characteristics. Evidence does not exist that a negative slope characteristic is a necessary requirement at 4 NPSP and above. In mid-year, however, SNPO-C directed Aerojet to provide such a characteristic. Aerojet was responsive to this requirement in the Mark IV, Mod 2 design and believes that the program does adequately provide for this criterion, although still not in concurrence with its necessity.

g. The evaluation asserts: "Aerojet did not perform sufficient analysis and make use of existing data in calculating and minimizing the balance piston thrust loads." -- Sufficient and adequate analyses were made for the balance piston. A well-balanced design considering turbine and impeller efficiency and piston load take-out capability has been achieved. It is assumed that the evaluation comment refers to the fact that (1) the bearings were changed at the time the balance piston was incorporated, and (2) these new bearings are not capable of accommodating the full thrust load in the event that the balance piston fails. Even though the previously tested bearings were capable of accommodating the full thrust load, they could <u>not</u> be used in conjunction with the balance piston because the balance piston requires axial movement to function properly. Consequently, the bearings had to be redesigned to permit this axial movement. However, these bearings had been made largely to accommodate the full thrust load and there would be no need for the added complexity of the balance piston.

h. Finally, the evaluation asserts: "In the area of turbopump testing unnecessary hardware failures and testing delays resulting from improper setup and procedures were encountered. Analyses in reporting the test results in the turbopump area are considered below normal. The major schedule turbopump test objectives and test reports were not met during the contract year, in part because of facility problems and also because of improper setup and test procedures." This comment is unduly harsh. Only two significant hardware failures occurred during the 38 tests conducted during the contract year. Neither was due to improper setup or procedure, but both were the product of normal development testing which has the object of determining deficiencies for design-improvement purposes. Some test objectives which were not completed during CY 1963 are attributable to the late activation of facilities; other delays in testing are attributable to an insufficient supply of Government-furnished propellant. In either event, it does not appear reasonable to reduce the rating given to the TPA program for these causes.

3. Conclusion

In light of the above comments and the achievements in propellant-feed-system components other than the TPA in this subtask and the recognized commendable performance in the area of bearing development, Aerojet considers that the performance rating for this subtask should be above normal.

D. SUBTASK 1.4 - THRUST CHAMBER ASSEMBLY

1. Aerojet does not derive much satisfaction from the nozzle effort during CY 1963 since the effort did not yield success in that period. The significance of the nozzle and its successful early development to support both the reactor program and an engine program in the future is clearly recognized. An analysis shows that we could have, and probably should have, started earlier in attacking some of the problems encountered. The year was started with a development program which involved primary effort on an aluminum jacket-type nozzle, with only secondary backup effort on an alternate all-steel design. Perhaps our mutual error was in not recognizing the severity of the problems to be faced with regard to the aluminum jacket nozzle and in not providing additional funding for and emphasis on the backup nozzle sooner. It should be recognized that all

aspects of the nozzle development program were fully disclosed to the customer representatives during CY 1963, and Aerojet believes that it was properly influenced by the customer in the approaches taken. Aerojet does agree that a top-notch performance was not achieved; however, the severity of the rating is questioned in view of the complexity of the task.

2. Some of the rating comments included in the CY 1963 evaluation letter are extracted as follows:

a. "The developmental status of the other major assembly, the exhaust nozzle, causes even greater anxiety. The design originally chosen by the contractor for development includes stainless steel tubes within an aluminum casting. This has led to most serious problems involving aluminum ductility, aluminum porosity, and mechanical and heat transfer contact between the tubes and the aluminum. There appears to be a strong possibility that this design ultimately will be superseded by an all-steel design of either brazed or welded construction. The latter are in the first phases of fabrication development and are expected to require very considerable amounts of fabrication development before the nozzles can be evaluated by means of hot firing tests."

b. "When viewing the overall schedule performance from a broader perspective, it becomes evident that tests of the NRX-A1 cold flow test reactor are being delayed by the nozzle status, and it becomes indicated that the nozzle status may well jeopardize the reactor development schedule for some time."

c. "A retrospective review of the 1963 performance a year hence may well establish that the 1963 development work applied to the cast aluminum nozzle contributed little to the development of the final NERVA engine prototype components. Should this be the case the effectiveness of the money spent in 1963 will be diminished considerably."

d. "The most severe criticism is a result of the excessive time lag between the recognition of critical problem areas and appropriate corrective action. For example, nozzle jacket casting problems were recognized early in the contract period and yet it was not until late June 1963 that a special nozzle task force was formed. The special nozzle task force has been a major factor in approaching a solution to the nozzle fabrication problems."

3. The criticism of this area of effort hinges on the fact that problems were encountered and took significant effort to overcome. It is agreed that serious fabrication problems were encountered with the cast-aluminum jacket design. To establish a proper basis of understanding it is necessary to present some chronology. On 4 and 19 January 1963, a Kiwi nozzle and a Hybrid nozzle respectively failed to pass hydrotests. In April 1963 a Kiwi nozzle failed in a hot firing test. Failure analyses for the first two nozzles were completed in February 1963 and indicated that lack of ductility was a major problem. A task force consisting of specialists in all applicable disciplines was formed in March 1963. The third nozzle satisfactorily passed hydrotesting but failed in the April hot firing. As a result of actions taken by the task force, acceptable ductility was achieved in the nozzle cast in July 1963 at the Aerojet Sacramento facility. This was the first nozzle which incorporated the input of the task force. One other nozzle was cast at the facility of the vendor who had cast the nozzles which had previously failed. This nozzle did not achieve the desired ductility, due to foundry limitations that did not permit implementation of the task-force recommendations. Notwithstanding, useful heat transfer data from a hot firing were obtained by wrapping this nozzle with fiber glass.

Aluminum porosity was likewise a problem. Again, task-force decisions (covering foundry mold designs, pour procedures, gating, sprueing, etc.) were first checked by nozzle casting in July. Although some gas porosity was still observed, it was considered acceptable for the intended use of the nozzle. Subsequent nozzles have been cast with controlled changes in casting technique, and all of those cast at the Aerojet foundry have been acceptable for their intended use from a gas-porosity viewpoint.

There has been, from the beginning, a further problem with respect to mechanical and heat-transfer contact between the tubes that carry liquid hydrogen for coolant and the aluminum jacket, which provides hoop and longitudinal strength and stiffness. Detailed analysis based on experimental model data has shown that there is no appreciable problem in the cooling of the aluminum casting for the NRX application. Problems have existed with regard to leakage of liquid hydrogen between the aluminum jacket and the tube bundle. Design modifications were developed to overcome the problem, and it is expected that the solution will be demonstrated on actual nozzles by mid-March.

The evaluation report indicated that the nozzle has delayed the NRX-A1 reactor test. Aerojet wishes to state that at no time was the schedule of NRX-A1 in real jeopardy due to nozzle unavailability. In June 1963, SNPO-C directed Aerojet to include viewing ports in the nozzle for NRX-A1, which added complexity to the nozzle development program. However, since this requirement was imposed by the customer, Aerojet had no alternative but to comply and did so on a best-efforts basis. In accepting this direction, Aerojet recognized some alternative courses of action:

a. As protection against possible failure of the one nozzle intended for NRX-A1, a second nozzle incorporating view ports was started for backup purposes. This backup nozzle has been delivered to NRDS for NRX-A1 cold-flow testing.

b. Other nozzles intended for development testing, without view ports, could have been delivered if such a compromise were considered acceptable, as was the case prior to June 1963. These alternatives were suggested to SNPO-C, but a decision to accept such a deviation on the first nozzle was not made.

With reference to the assertion that "a long developmental path must still be followed," it is recognized that nozzle development problems still remain in the following categories: fabrication development, simulation testing using LO_2/LH_2, NRX-A1 cold-flow testing, and NRX-A2 and subsequent firings. Fabrication development for the cast aluminum jacket nozzles will undoubtedly require improvement but, as evidenced by the facts to date, the primary fabrication problems have been solved and nozzles are being fabricated to support both simulation testing and the NRX program. Simulation testing using LO_2/LH_2 has been successful in short-duration tests. Hardware is available. The ability of the tube bundle to withstand the simulation testing can only be determined by tests. There may be some further difficulties; however, there is also a solid analytical basis for expecting the nozzle to perform satisfactorily in the required tests. The NRX-A1 nozzle has been delivered. Prior to its delivery it was subjected to all of the cold-flow conditions expected, so that difficulty is not expected in the NRX-A1 cold-flow testing due to the nozzle. The delivery of the NRX-A2 nozzle should be as required if the LO_2/LH_2 simulation-test firings are accomplished without difficulty. Meanwhile, the first all-steel backup nozzle has successfully passed hydrotesting and gives added confidence.

4. In summary, the overall evaluation of Aerojet's performance on this task depends on whether or not Aerojet recognized the problems, such as low ductility, and took timely effective corrective action, and whether the NRX schedule was unduly jeopardized. It is Aerojet's opinion that such corrective action was taken and that at the end of the contract year the NRX schedule was not in jeopardy. These difficulties were recognized and special action was taken in February 1963, to bolster the nozzle-fabrication effort which bore fruit in July. At the customer's request, additional experienced manpower was placed on the program in June 1963, which has undoubtedly helped; because of lead time, however, these added personnel could not have effected the improved results achieved in July had not Aerojet taken the previous action. Accordingly, Aerojet requests Government reassessment of the severe rating given to this task.

E. SUBTASK 1.6 - ENGINE DESTRUCT SYSTEM

1. The evaluation comments regarding the destruct system subtask are so limited that it is difficult to formulate a response. There does appear to have been a basic problem with regard to mutual understanding of the work to have been accomplished.

2. The evaluation states: "... the interpretation of the studies based on detail analyses were not in sufficient depth." -- The analyses of data resulting from the tests conducted depended greatly on correlation between crude simulant materials and Government-furnished core material. Receipt of this material later than scheduled had a marked effect on the extent to which Aerojet could conduct detailed analyses.

3. The evaluation also states: "The technical report summarizing the post-operational destruct work was not considered satisfactory and was returned for further review and rewrite." -- In this instance, the criteria for evaluation of the test data, and therefore the report, changed after the draft copy had been submitted to SNPO-C.

4. In this subtask, we performed the job as we understood the year's contract work statement. SNPO-C personnel newly assigned in mid-year apparently placed a different connotation on the contractual requirements than did Aerojet. In addition, it is believed that the effort on Subtask 1.6 was aimed at determining

practical specification requirements as much as at achieving them. Aerojet feels the revised approach should not penalize the performance rating and considers that a "normal" rating should be given in this subtask.

F. SUBTASK 1.9 - RADIATION EFFECTS PROGRAM

Aerojet agrees with the evaluation's below-normal rating on this subtask. The Government's quarterly and annual comments in this area have constituted a useful tool in stimulating positive corrective action to eliminate delays in this subtask. Indeed, it was recognized just prior to the fourth quarter that the subnormal performance was primarily due to lack of adequate program management (emphasis) and lack of personnel. Accordingly, two primary actions were taken to resolve these deficiencies. Additional senior personnel were assigned to this task, and organizational changes were effected to provide adequate program emphasis. The effect of these changes has been rapid and significant improvement in schedule performance has been achieved. Successful tests of pallets EIT 501, MIT 902, and MIT 903 were completed in September and October 1963. Tests of pallets EIT 502 and MIT 904 will be completed in March 1964. Aerojet believes that this demonstrated improvement in control and management is evidence that all goals and objectives for the CY 1964 effort will be accomplished in a timely manner.

G. SUBTASKS 2.2 and 2.3 - GROUND SUPPORT EQUIPMENT

1. Aerojet does not agree with the below-normal evaluation for this subtask. The evaluation states: "Improvement is needed with respect to coordination among REON, LRP, and WANL. Difficulties with coordination among REON, LRP, and WANL resulted in late inputs from design groups and subsequently in late submittals of operational support plans and attendant support equipment lists." -- Coordination of operational support plans and attendant equipment lists constitutes only a portion of AGC subtask activity. Management and technical review and integration of actual hardware and design make up a large portion of these tasks. The performance in this area as well as the technical adequacy of the Operational Support Plan (OSP) are considered above normal. This conclusion is based on the status and performance of the hardware, and the customer reaction and response throughout the contract year. It is considered that recognition should be given to this portion of the work in rating this subtask.

2. In response to the evaluation comment, it is emphasized that there was no time during CY 1963 when an item of support equipment or planning was the pacing activity in the NERVA program. Furthermore, an accurate, timely method was developed and used to report support equipment status; the coordination techniques are considered to be excellent.

The lack of timely performance in most cases is directly attributable to many late responses from WANL to AGC technical direction. It is Aerojet's opinion that all practical effort was exerted to accelerate this input. In addition, while the OSP did not meet the predetermined scheduled milestones, the submittal of the NRX-A1 plan would properly coincide with the NRX-A1 test plan. This is because the OSP is dependent upon the test plan for basic information.

It is further noted that the evaluation of WANL performance on this subtask noted the late inputs but gave recognition to the fact that the equipment and plans were not the pacing items and, consequently, WANL received an average rating. For this and other reasons noted above, it is Aerojet's opinion that AGC performance on these tasks was at least normal.

H. SUBTASK 2.4 - INSTRUMENTATION

1. AGC concurs in part with statements made in the customer's evaluation but questions the rating of "below normal." Several pertinent comments below are intended to clarify the development approach for this subtask and thereby indicate the different interpretation that AGC places on the evaluation comments.

2. The control instrumentation work in the high-temperature measurement region had been based on expectation that the LASL-design thermocouple would perform satisfactorily. During the year it was demonstrated that this design would be inadequate; hence, new designs were prepared and analyses were conducted to ensure that the necessary performance could be attained. These new designs are now being procured and tested, and the NRX schedule will not be delayed.

3. Pressure-control instrumentation has been viewed as an offshoot of the work on diagnostic pressure instrumentation. The work on diagnostic pressure transducers has served as the basis for the pressure-control instrumentation program evolved during the last half of the contract year and is progressing on a schedule compatible with the requirements for initial use on the NRX-A3.

4. Based on the above remarks, Aerojet questions that part of the evaluation statement implying schedule delays, but at the same time recognizes that more detailed planning and analysis could have been performed with regard to the high-temperature measurement regime and that work on alternate approaches might have been started on the basis of analyses rather than test results.

5. The implication of detrimental effects because "some duplicate efforts and duplicate tests and development programs have been carried out" must be challenged. Under the scope assigned, WANL and LRP are individually responsible for developing instrumentation associated with their end items. Indeed, the same type of instrumentation was evaluated for different applications, but it is Aerojet's belief that this resulted primarily from the use of information on a type of transducer, gained by one organization for its particular application, to indicate the suitability of that type for the different application of the other organization. For example, WANL may have found that a particular pressure transducer had good radiation-resistance properties. LRP, requiring a different pressure level, different mounting, and different temperature environment, would then evaluate this type (same manufacturer) under the specific non-radiation environment.

I. SUBTASK 2.7 - SAFETY

It appears that undue emphasis is given to one detail of the flight safety program, which represented in CY 1963 a small segment of the overall safety program. The evaluation comment concerns a single, highly ambitious, analytical study effort written into the work statement late in program formulation that was in fact not completed during the year.

Aerojet does agree, however, that the overall safety program for CY 1963 left something to be desired: With respect to the development of an overall safety program adequately related to the specific contractual requirements and the even more important implications of responsibility in the contractual chain, it would be less than objective to fail to recognize that until late in the contract year neither Aerojet nor SNPO clearly recognized the fundamental nature of the action necessary to put the safety program on a sound basis.

As noted, late in the year both parties began action, which still continues, to clear up misconceptions and establish sound policies and procedures in the safety area. As late as 29 January 1964, a communication designed to confirm understanding in the safety area was issued by SNPO.

J. SUBTASK 2.8 - TRAINING

Aerojet concurs with the comments made by the customer in this evaluation. It is to be noted that as a result of customer evaluation during the first quarter of CY 1963, AGC placed the cognizance for this task with the Nevada Test Organization, for whose benefit the training task exists. The improvement noted in the customer's evaluation during the last half of the contract year was a direct result of this action.

K. SUBTASK 3.4 - TEST STAND ETS-2

1. Aerojet performance is criticized here on the premise that early in the contract year facility-criteria documents were not entirely responsive to customer technical direction, resulting in discussions and revisions.

2. In the prior contract year Aerojet produced Test Stand Criteria recommending three test stands, based on requirements as known at that time, and provided basic criteria and design concepts for ETS-2 as required and known at the time. Early in CY 1963 SNPO-C redirected us to two test stands, resulting in substantial additional integration, coordination, and meetings. Throughout the year additional ground-rule and technical-direction changes further influenced the firmness of criteria.

3. Typical of the ground-rule changes and general redirection received from SNPO-C during this criteria preparation period were the following:

a. The original direction required maximum-utilization studies for ETS-1/ETS-2 including test planning data, turnaround times, test rates, consideration of logistics, and capability evaluations beyond normal facilities critical requirements.

b. The 300-sec-duration testing requirement was increased to full duration.

c. The design criteria for the ETS-2 run tank vacillated "to be like ETS-1," "with shielding," and "without shield but with future capability," and with equal consideration to "close coupling Engine/Vehicle tank consideration" to adjustable engine component height variations.

d. The single control room for ETS-1/ETS-2 was redesigned to separate control rooms.

e. The requirement to test a 40:1 nozzle was changed to a 25:1 nozzle.

f. The NES duct installation technique was revised from remote to manual procedures and vacillated from like "ETS-1 duct" to "provide capability for a full pumping duct system," which was undefined.

g. The ETS-2 run tank and companion shielding were left unresolved when the CY ended.

h. Obvious constraints were imposed by minimum facility construction fund expenditure considerations.

4. Due to these changes and the intention of Aerojet to facilitate continual interchange of information and ideas with SNPO-C as they evolved, many preliminary drafts and partial drafts of criteria were transmitted. These were not documents submitted for approval, and revisions should have been expected. Aerojet believes a rating of normal on this subtask is appropriate in view of the obvious uncertainties in programming.

L. SUBTASK 3.5 - E-MAD FACILITIES

1. Aerojet does not agree with the evaluation rating on this subtask. The evaluation stated: "The contractor's performance has fluctuated below and above normal throughout the contract period. Although a general improvement was noted at the end of the contract year, it is felt that a yearly rating less than normal is warranted. The contractor has been responsive to SNPO-C requirements and has provided basic criteria and design reviews commensurate with the established objectives of the task. However the qualifications associated with these inputs have often made it difficult to finalize design of a particular facility feature or function. In addition technical coordination of subcontractor inputs was considered inadequate during the majority of the period."

2. In reviewing these statements it appears that Aerojet is being downrated for performing what we understand to be our job - namely, that of providing constant and complete technical advice and design-feature considerations to SNPO-C. In the design review and acceptance effort, qualified approvals were noted to apprise SNPO-C of the impropriety of granting the A&E blanket approval for marginal designs when many of the system designs accommodated by the building were essentially undeterminable at the time. Such qualifications as submitted by Aerojet during this period were intended to reduce the possibility of facility restrictions and constraints to actual operation. In this task there has been a consistent lack of recognition by the customer of the overall engine-development responsibility. Aerojet is determined to exercise what is believed to be its basic responsibility to look at long-term aspects of the development program. Shortcuts for either lack of experience or cost savings in facility design can and usually will increase program costs, due to delays in either operational problems or later modifications. This continued "penny wise, pound foolish" attitude must be curtailed for the program's sake rather than any contract performance-rating criteria. Aerojet has had a tremendous amount of experience in this area and firmly believes that facilities properly designed in the beginning will save in the end.

3. Regarding the assertion of inadequate coordination with subcontractors, it is assumed that this comment refers to the occasional omission of WANL comments during review of the post-mortem cell's final design. In this case, when WANL comments were not received by the predesignated and negotiated date, the review comments were not delayed and were transmitted to SNPO-C in accordance with the directed 2-week time limit established by SNPO-C. Upon later receipt of WANL comments, Aerojet reviewed and determined their validity and merit; if valid, they were forwarded to SNPO-C separately. It is believed that Aerojet undertook all practical steps to ensure the timely submittal of WANL data, and Aerojet believes that the evaluation of performance on this task should be "normal."

M. SUBTASK 4.2 - FISCAL CONTROL

1. Aerojet takes exception to a below-normal rating in technical performance. While it is true that errors were found in the May <u>budgetary</u>-type

submittals, it should also be remembered that these were required in a new format and the close timing forced the entire budget to be handled manually. The complete rerun, in the same month as the first submittal, imposed an almost impossible scheduling burden but it was accomplished as scheduled.

2. Subsequently, machine programs have been created which eliminate manual computation and the corresponding possibility of human error. No errors have been called out in the last three major program-plan submittals, which would reflect major improvement worth recognition. Also, complete reprogramming of monthly cost reports for a new format requirement was accomplished on a timely basis, which should be worthy of recognition. Under the circumstances, it is not clear as to what other steps could have been taken to improve performance. Consequently, Aerojet considers that this subtask deserves a normal rating.

N. SUBTASK 4.3 - ADDITIONAL DOCUMENTATION

It is believed that the below-normal rating of Subtask 4.3 for administration was not justified in view of the above-normal rating for technical and schedule performance and, at minimum, a rating of normal should be given. It appears that the rater merely looked at the figure for actual expended dollars in relation to budget dollars without considering the increased efforts imposed by the customer as outlined below.

When the budget estimates were made for RN-63002, Program Plan - Contract Year 1963, the requirements for "Special Technical Reports" were averaging about five per month based on the months of December, January, and February. At that time the estimate allowed for some increase in report requirements but not nearly twice the effort. The average output per month from April through September was 10 reports, with 14 reports being published in September. In addition, the size of technical reports grew - e.g., the Instrumentation Data Book (Aerojet-General Report 2320) grew from two volumes and 600 pages in April to five volumes and 1300 pages in September.

The budget estimates for RN-63002 were based on producing a "Program Planning Document for Contract Years 1964-65" of about 800 pages covering approximately 47 subtasks, these figures being based on past experience. Actually, four additional Program Plans were submitted for a total page count of 3464, an increase of about 350% over that estimated. Additional unanticipated effort was expended in producing the budget estimates for 1965 because of customer requirements for a completely new format and method of presentation, requiring fiscal-year budgets and contract-year budgets, and separation between AEC and NASA funds. In addition, these Program Plans were produced on very tight schedules requiring considerable overtime in the processing and reproduction departments.

O. SUBTASK 4.5 - SUBCONTRACTOR ADMINISTRATION

1. Comment relating to performance on this subtask during Contract Year 1963 appears to be subjective and the result of a broad generalization from relatively few specifics. Furthermore, the comment "faulty and inadequate inspection" is not applicable to the normal functions of Subcontract Administration or to the work statement covering Subtask 4.5 in Contract SNP-1. In addition, it should be noted that the customer has taken the position that the prime contractor (AGC) cannot be held responsible for surveillance of Westinghouse subcontractors.

2. With respect to the processing of 476 procurements for a total of $11.3 million, a detailed survey can only reveal that sound procurement practices are known and followed by those responsible. Many factors are involved in the rare instances when a procurement action falls short of the high standard sought by procurement management and operating personnel. The factor of technical dominance in an R&D program, particularly where state-of-the-art breakthroughs are frequent requirements, can be a compelling influence on the judgment of a buyer in evaluating sole- or single-source procurements sponsored by technical personnel. Further schedule factors, accompanied by attendant pressures from both technical and management activities, frequently occasion and sometimes justify shortcuts in procedure and documentation. It does not necessarily follow that sound procurement judgment has been abrogated.

3. There is ample evidence in review files that actions have been accomplished using the most expeditious means - telegraphic communication, air mail and air express, and diligent liaison and monitoring. The efficient use of schedule time spans remaining for completing procurement actions continues to be of paramount concern to those responsible. Aerojet strongly believes that performance in this area was above normal.

P. MEMORANDA AND REPORTS ON ANALYTICAL WORK

Tabulated below are the subjects and dates of some of the memoranda and reports on analytical work.

No.	Subject	Date
M0048	Steady-State Operating Map for NERVA Heated Bleed	4-26-62
M0050	Schematic Diagram, Flow Station Designation Revision	4-26-62
M0052	NERVA Reflector Pressure Drop	5-15-62
M0053	Shield Temperature Rise vs Time	5-15-62
M0061	Engine Thermodynamic Cycle Selection Report	5-28-62
M0063	Pressure Drop Through Coolant Passages	5-29-62
M0079	Growth Potential of the NERVA System	7-27-62
L0082	Control Error on Chamber Temperature	7-31-62
M0086	Pressure Drop Through Nozzle Coolant Passages	8-7-62
M0087	Schematic Diagram, Heated-Bleed Engine	8-14-62
M0092	Start Transient of E-Engine	8-24-62
M0098	Hot-Bleed Engine Parameter Schedule	9-6-62
M0108	Predicted Performance for the Hot-Bleed Nozzle	10-5-62
M0114	Engine Countdown Schedule	10-19-62
L0117	Binary Decks of Parahydrogen Properties Subroutines	10-26-62
M0124 (CRD)	Hot-Bleed Engine Parameter Schedule	11-2-62
M0130	Cooldown Analyses	11-9-62
M0132 (CRD)	Interpretation of Kiwi B-1B Hot-Flow Test Data and Determination of Hot-Bleed Engine Bootstrap Start Capabilities	11-14-62
L0133	Hydrogen Properties Component Program	11-15-62
M0156	Engine Parameter Schedule	12-11-62
M0158	Velocity of Sound in Two-Phase Parahydrogen	12-13-62
M0159	Effect of NES Capability on NERVA Start Simulation	12-17-62
M0167	Hot-Flow Development Test System	1-8-63
M0170 (CRD)	Block I E-Engine Parameter Schedule	1-10-63
M0171	Digital Computer Program for Parahydrogen Properties	1-11-63
M0178	Test Plan, Water Flow Test of Preliminary Pump Suction Line	1-16-63

No.	Subject	Date
M0189	Reactor Tie Rod Thermal Analysis	2-5-63
L0193	Transmittal Letter, NRX-A Parameter Schedule	2-12-63
M0197	Hot-Bleed Cycle, Schematic Diagram for Mod II Operational Engine	-
M0199	Comments Regarding Hot-Flow Development Test System Related to PFS	2-2-63
M0201	Analysis of Data for Gen. II Mod 1 Simulator Runs	2-26-63
L0203	Transmittal Letter, WANL Report on Tank Heating Calculations for NERVA	3-4-63
M0204	Hot-Bleed Cycle Selection Diagram for Model II Operational Engine	-
M0205	Steady-State Nuclear Engine Digital Computer Program	3-8-63
M0207	Effect of Diluent Orifice Area on Turbine Inlet Temperature	3-11-63
M0208	Theoretical Calculations of Pressure Drop, Orifice Sizes, and Temperature Variations Through Core Channels at Design Steady-State Points	3-11-63
M0226	Diluent Extraction Point for NERVA Engine	3-28-63
M0228	TPA Turbine Performance Data for Hot-Bleed Port Design	3-29-63
M0230	Digital Computer Deck for Thermodynamic Properties of Hydrogen	4-3-63
M0231 (CRD)	Theoretical Calculations of Pressure Drop and Temperature Variation Through Core at Off-Design Steady-State Points	4-4-63
M0232	Composite Heat Transfer Coefficients	4-4-63
M0234 (CRD)	Ideal Mixing Pressure Drop at Hot-Bleed Port	4-9-63
M0239	Hot-Bleed Cycle, Schematic Diagram for Mod II Operational Engine	4-12-63
M0247 (CRD)	Tie Rod Channel Exit Gas Temperature at Off-Design	-
M0252	NERVA Engine Nozzle and Hot-Bleed Port Design Limitations	4-23-63
M0255	NERVA Engine Reflector, Shield, and Core Design Limitations	4-22-63
M0260	NERVA Engine Cooling and Coolant Control System Requirements	4-30-63
M0267	Transient Startup Analysis	5-3-63

No.	Subject	Date
M0268	Diluent Extraction Point for NERVA Engine	5-3-63
M0277	Engine Analysis Program	5-16-63
M0286	Proposed Sonic Venturi for Turbine	5-28-63
M0290	Propellant Supply Line for CFDTS and ETS-1	5-31-63
M0296	FX Engine Parameter Schedule	6-5-63
M0306	Turbine Inlet Line Orifice	-
M0307	NERVA Steady-State Operating Map with Component Restraints	-
M0312	E-1 Design and Test Conditions, Parameter Schedules	6-26-63
M0330	Temperature of Cast Aluminum Nozzle Jacket During LOX-H_2 Simulation Test	7-11-63
L0340	Transmittal Letter LRP Report RMR0094, Critical Speed Analysis, NERVA TPA, Mark IV, Rotating System	7-31-63
M0342	NRX-A2 Steady-State Operating Conditions for Test Profile	8-5-63
M0343	Temperature of Cast Aluminum Nozzle Jacket During LOX-H_2 Simulation Test	8-7-63
M0344	Temperature of Cast Aluminum Nozzle Jacket During LOX-H_2 Simulation Test	8-7-63
M0347 (CRD)	Thermal Analysis of Kiwi B2 Insulation Tile and Slat	8-9-63
M0348	Modified Computer Program for Thermal Analysis	8-12-63
M0355	Effect on FX Engine Parameter Schedule of Changed Nozzle Coolant Heat Transfer Coefficient	8-21-63
M0356	Information on B2 Core When Utilized in NERVA Engine and Kiwi Test Facility	8-23-63
M0364	Equation Coefficients for Fit of Thermal Conductivity vs Temperature Curve	9-6-63
M0369	Minutes of Systems Analysis Meeting Held 9-10-63	9-11-63
M0370	Orificing of the Turbine Flow Line	9-16-63
L0371	Trans., Preliminary Specification, E-Engine	9-16-63
M0385	B-4 Support Block Eccentricity	10-5-63
TM734:63-001 (CRD)	Nuclear Engine Analysis Program	5-16-63
TM734:63-002 (CRD)	Diluent Extraction Point Investigation	5-1-63
TM734:63-003 (CRD)	Laminar Flow Stability	5-27-63

No.	Subject	Date
TM734:63-004 (CRD)	Some Aspects of Pulse Cooling of Nuclear Core	5-28-63
TM737:63-003 (CRD)	Need for and Objectives of the Hot-Flow Development Test System	3-63
729R:0004	Systems Analysis Program for CY 1963	4-23-63
729R:0005	Revised Systems Analysis Program for CY 1963	7-10-63
738:M2001	ETS-Nitrogen Coolant System Requirements	6-11-63
738:M2003	FX Engine Analog, Startup Transients	6-19-63
738:M2007	Preliminary Pre-test Analysis of CFDTS	7-23-63
738:M2010	Analog Simulation of Turbopump	8-29-63
738:M2011	Orificing of Turbine Flow Line	9-10-63
738:M2012	Turbopump Dynamics	9-26-63
738:M2013	TPCV Sudden Closure Malfunction Study	10-1-63
TM732:62-001	Representation of Reactor Dynamic Characteristics by 1003 Section Lumped-Parameter Model	6-6-62
TM732:62-002	Analog Computer Representation of Reactor Characteristics for Gen. II Mod I Engine Simulator	6-12-62
TM732:62-003	Simulation of Cooldown and Restart	6-12-62
TM732:62-004	Conditions Governing Use of Lumped-Parameter Model	6-14-62
TM732:62-005	Simulation of Cooldown and Restart, Version II	9-26-62
TM732:62-006	Salient Design Considerations for Exit Gas Temperature and Pressure Feedback Transducers, NERVA Power and Thrust Control Loops	10-16-62
TM732:63-010	Engine System Simulator	-
TM738:63-201	Preliminary Study of Engine Cooldown and Restart	8-30-63
TM738:63-202	Transient Cooldown Analog Equations for Analog Simulation of the AJ30-5 Engine Power Range	5-29-63
TM738:63-204	Preliminary Pre-test Analyses of the CFDTS	7-18-63
TM738:63-205	FX Engine Startup Transients	9-5-63
TM738:63-206	Steady-State Analysis of the ETS-1 Nitrogen Cooldown System	9-17-63
TM738:63-207	Dynamic Requirements for Block I Engine Control System	9-25-63
LRP 9443:312	Steady-State Operating Temperature Profile for Mod II Engine PV	5-31-63
LRP 8207:381M	NRX-A1 (In-House) Exhaust System	8-28-63

No.	Subject	Date
LRP 8207:382M	NRX-A2 Thrust Structure "Chilldown"	8-28-63
LRP 8207:398M	Steady-State Thermal Analysis of NRX-A2 Boom Adapter	9-17-63
LRP 8207:401M	Nuclear Heating of NRX-A2 Thrust Structure	9-20-63
LRP 8207:407M	Transient Temperature Profile in Vicinity of View Port of NRX-A1 S/N 10 Nozzle	9-30-63
LRP 8207:410M	Transient Temperature Profile in Vicinity of View Port of NRX-A1 S/N 10 Nozzle	10-3-63

Q. SUMMARY OF SIGNIFICANT ACCOMPLISHMENTS

A summary of significant accomplishments for Contract Year 1963 is presented on succeeding pages.

SIGNIFICANT ACCOMPLISHMENTS FOR CONTRACT YEAR 1963

- COMPLETE GEN II SIMULATOR TEST PROGRAM.
- ESTABLISHED STEADY STATE DIGITAL MODEL OF ENGINE.
- DELIVERED NRX-A INTERFACE MASTER GAGES .
- DEMONSTRATED MK III TPA OPERATION LH_2 COOLED BEARING.
- COMPLETED MK IV TPA DESIGN .
- DEMONSTRATE POWER TRANSMISSION BEARINGS IN RADIATION ENVIRONMENT.
- COMPLETED PRESSURE VESSEL STRUCTURAL TESTS .
- CONDUCTED FEASIBILITY DEMONSTRATION OF ANTICRITICALITY DESTRUCT SYSTEM .
- COMPLETED PNEUMATIC SYSTEM DESIGN AND ISSUED COMPONENT CRITERIA .
- COMPLETED DEVELOPMENT OF PRECISION CRYOGENIC TEMP MEASUREMENT SYSTEM.
- COMPLETED DEVELOPMENT OF ROCKIDE STRAIN GAGE PROCESS .
- ESTABLISHED TRANSIENT EQUATIONS FOR ANALOG SIMULATION OF THE AJ30-5 NERVA ENGINE IN THE POWER RANGE.
- COMPLETED PRELIMINARY ANALYSIS OF FX ENGINE STARTUP TRANSIENTS.
- COMPLETED THE DESIGN, FABRICATION AND TESTING OF TEMPERATURE AND RADIATION RESISTANT TPCV ACTUATORS.
- COMPLETED ETS-1 NES DESIGN CRITERIA BY SCALE MODEL TESTING.
- COMPLETED THE PRELIMINARY DESIGN OF THE ETS-1 NES DUCT .
- INITIATED PROCUREMENT OF STREAM GENERATORS FOR ETS-1 NES .
- COMPLETE BASIC DESIGN OF EIV, MCC AND OPS AND INITIATED FABRICATION.

- COMPLETED MODIFICATION SPECIFICATION FOR LOCOMOTIVE. INITIATED SUBCONTRACT ACTION.
- COMPLETED DESIGNS AND INITIATED FABRICATION OF NRX-A1 SUPPORT EQUIPMENT.
- SUBMITTED CONCEPTUAL DESIGN FOR RADIATION EFFECTS FACILITY AT NARF.
- COMPLETED OVERALL PRELIMINARY DESIGN PACKAGE (OPDP) FOR ETS-1 I & C.
- COMPLETED REVIEW OF OPERATIONAL FUNCTIONAL AND SAFETY REQUIREMENTS OF A & E PROPOSED CHANGES AND ADDITIONS TO ETS-1.
- COMPLETE "NERVA-POST OPERATIVE REQUIREMENTS AND SUPPORT SYSTEM UTILIZATION."
- COMPLETED REVIEW OF ETS-1 I & C DESIGN PACKAGE.
- SUBMITTED AGC REPORT 2603 WHICH MODIFIED DESIGN CRITERIA CONCEPTUAL DESIGN AND COST ESTIMATES FOR THE ENGINE TRANSPORT SYSTEM AND MAINTENANCE BLDG. AT NRDS.
- "NRX IN E-MAD" FEASIBILITY STUDY PER LTR 741-0264.
- COMPLETED CYRO-LAB TESTING FACILITY AT LRP.

PART III PROFESSIONAL OPINION

Part III of this presentation consists of comments from consultants to Aerojet who were asked to review the program and the evaluation because it was desired to obtain comments from qualified persons outside the program.

Security and time considerations restricted the choice for technical comments to persons already associated with Aerojet. In this area, letters were submitted by Dr. W. D. Rannie, Robert H. Goddard Professor of Jet Propulsion, California Institute of Technology; Dr. M. J. Zucrow, Atkins Distinguished Professor of Engineering and Director of the Jet Propulsion Center of Purdue University; and Dr. A. J. Acosta, Associate Professor of Mechanical Engineering, California Institute of Technology.

Comments on the technique of evaluation were provided in report form by Dr. L. Glen Strasburg, Assistant Professor of Business Administration, University of California at Los Angeles, and Dr. John V. Zuckerman, Director of the Air Force Research and Development Management Program at the Graduate School of Business Administration, University of Southern California.

Comments of Dr. W. D. Rannie, Robert H. Goddard Professor of Jet Propulsion, California Institute of Technology, in response to request from Aerojet-General Corp. to create an independent objective review of the technical performance of Aerojet-General Corp. on Contract SNP-1 for Contract Year 1963.

The writer was asked to review in as objective a manner as possible the technical performance of Aerojet-General Corporation on Contract SNP-1 during the Contract Year 1963, and to compare his evaluation of the performance with that of SNPO. The review was confined to subtasks 1.1, 1.2, 1.4, 1.6 and 1.9, with the larger part of the time directed to subtasks 1.2 and 1.4. The writer spent about 8 hours in total on February 3 and 6 at the Von Karman Center, Azusa, questioning managers of the subtasks. An additional 8 or 10 hours was spent in the study of the REON summary report, the SNPO evaluation reports, and written comments of managers and others on the evaluation reports. These activities, supplemented by information and impressions acquired previously at NAG meetings and other contacts with Aerojet-General, formed the basis of the comments below.

The writer found very quickly that it was almost impossible to specify meaningful norms as a basis for comparison. The program differs from the majority of development programs in two important characteristics:

(a) The program is the first one of its kind. The requirements are very different from any chemical rocket and, in many instances, are tentative. Much of the development is of an exploratory nature with major difficulties in meeting schedules. The criterion for normal performance under such circumstances is a very arbitrary one.

(b) The customer has a large and active technical monitoring staff in continuous contact with the program. The customer introduces frequent changes in design and direction. Not infrequently the customer and the contractor have different solutions to a problem. After weeks or more of explaining to each other their respective points of view and marshalling supporting information, the decision may be made by directive to follow the customer's choice. The contractor has spent time and effort on his solution, not necessarily directly applicable to the new program. If the customer is infallible, the contractor can be justifiably criticized for lack of foresight and wasted effort. The customer does not claim infallibility, but unless he displays some understanding of the contractor's problem, the effect on the contractor is not different than if he made such a claim.

Comments on each of the subtasks chosen for review are listed below:

Task 1.1, Engine Systems

The systems analysis effort and fabrication of certain gages were criticized as being below normal in the fourth quarterly review and in the review for the year. Both of these reviews were received on the same date and were consistent. The two previous quarterly reviews did not specifically mention this subtask; hence, it must be assumed that the rating for these periods was "normal". The rating for the first quarter was below normal.

Specifically, the systems analysis effort on NRX-A tests was criticized as being inadequate. However, WANL was given primary responsibility for NRX-A analysis with Aerojet-General assisting as required through a WANL Systems Analysis coordinator. Since the AGC subtask manager was given no indication privately or officially that the systems analysis was inadequate until the evaluation for the year arrived, and since WANL performance on this activity apparently was rated normal, there does not seem to be any basis for an abrupt downgrading of the effort.

The other specific criticism on this subtask concerned gages which, although not perfect as far as material properties are concerned, were acceptable and functionally satisfactory. No delay to the program resulted from the difficulties in fabricating the gages. The writer cannot see that any major criticism is valid when satisfactory gages are delivered.

Task 1.2 - Propellant Feed Systems

The evaluation report criticizes AGC for the initial design of the Mark IV turbopump because the predicted characteristic performance curve did not have a negative slope at a sufficiently low flow rate. The requirement on the slope of the characteristic curve is to a large extent arbitrary until exact operating conditions are known. Positive slope alone is not sufficient to cause instability if, as is almost invariably true, the load curve meets the characteristic curve at a steeper positive angle. Instability can arise only if the characteristic curve is double-valued so that a hysteresis loop occurs, and then only if the natural frequency of the system attached to the pump is sufficiently low. For an application such as the nuclear rocket, where it is scarcely possible to predict what may eventually be required of the pump in starting transients, the safest design would involve an impeller with blades bent well back and, hence, necessitate a two-stage pump. This is an extreme solution; if one gambles on a single stage, opinions can differ as to how far one should compromise overall performance by shifting the peak of the characteristic curve to lower flow rates.

The evaluation report is critical of the extent of the original analysis of the balance piston thrust loads. The requirement for a balance piston and the requirement for the position of the peak of the characteristic curve for the pump were both introduced during the contract year. Neither was thought necessary for AGC. The criticism, apparently directed to the rapidity of response to directive on two items that are "designer's choices", cannot be taken as very serious, particularly in view of the sentence, "Except for the above, the contractor performed a commendable job on the design of the Mark IV turbopump."

The letter accompanying the evaluation report contains a very severe criticism of the turbopump program. This criticism, not contained in or implied by the report proper, states that because of insufficient foresight, etc. (presumably by AGC!), it now becomes necessary to abandon the Mark III design in favor of the Mark IV. This is an example of the situation described under (b) of the Introduction. Abandonment of the thermal-resistant coating required higher pump head output and, in addition, after lengthy discussions between AGC supporting the heated bleed cycle and SNPO supporting the hot bleed, the argument was resolved in favor of the hot bleed by directive. The Mark IV turbopump was designed to meet the new requirements. The letter also mentions that new problems can be expected because of a different bearing arrangement on Mark IV. The change of bearing arrangement was required because of the introduction of the balance piston requested by SNPO.

The writer cannot agree with the evaluation report rating for the year of below normal or the letter rating of significantly below normal on any reasonable basis. The Mark III turbopump has been developed and the Mark IV design is proceeding well. The former can be used in cold flow and ground tests. Significant progress has been made in the development of hydrogen-cooled bearings. The turbopump has not delayed the program.

Some of these points have been singled out for commendation in the year evaluation report; in addition, the evaluation report for the second quarter given an above normal rating and for the third quarter by implication a normal rating. These accomplishments, in the face of introduction of several major design changes requested by the customer, would appear to balance, if not outweigh, delays in the development of this component.

Task 1.4 - Thrust Chamber Assembly

The nozzle has been plagued with fabrication difficulties during the major part of the year. Evidently, these are now under reasonable control, although AGC is criticized strongly for delays in recognizing the problems and in taking corrective measures. It is difficult to specify a "normal" performance for development of a component that departs as much from conventional design. In hindsight, it is clear that the early stages of fabrication should have been pursued more rapidly so the problems could be isolated and faced earlier. It seems to the writer that an equally important matter for evaluation is the imagination and zeal demonstrated in solving the problems once they have been recognized. These qualities appear to have been demonstrated to a sufficient extent that they, at least, partially counter the initial delay. The nozzle difficulties did not cause any delay in Contract Year 1963; since then, the nozzle has caused a delay of nearly three weeks. The statement in the letter accompanying the evaluation report that the nozzle may well jeopardize the reactor program is scarcely fair, since it has not yet occurred.

Task 1.6 - Engine Destruct System

This subtask is more of a research program than a development program. The specifications for anticriticality on destruction and for size of the pieces of the reactor are tentative because precise requirements are not known. The program under this subtask seems to be directed as much toward finding out what specifications can be met as to meeting certain specifications. Delays in testing were caused by circumstances that were not under control of AGC. Operators of test reactors were unwilling to allow irradiation experiments on explosives. The test site finally assigned for the destruct tests was very inconvenient with inadequate facilities. The delay in the experiments led to a delay in submitting the report. This report was sent back by SNPO for rewrite to include additional interpretation of the data on Task 2.7 (Safety). The subtask manager disagreed with SNPO as to the validity of the limited experiments for engine design studies, but did revise the report extensively in line with the SNPO request.

The writer has no basis for judging normal performance under circumstances such as these. The major criticism applied to the report which was resubmitted after the evaluation was written.

Task 1.9 - Radiation Effects Program

The criticism of this subtask in the evaluation report appears to be quite justified. The program was poorly staffed and off the premises of the REON management. Corrective steps should have been taken earlier, as it was obvious that they were needed. Such steps have been taken and the program appears to be making rapid progress.

* *

Admittedly, the writer's opinion is not a result of detail study, but it seems unlikely that deeper investigation would change the opinion. In fact, the writer was surprised at how little his very first impressions changed as he questioned managers of the subtasks in following up points that seemed to require clarification. The managers had been asked to be objective in their written and verbal comments; without exception, they were remarkably consistent and, delving into complex detail, in no case reversed the original impression.

In conclusion, the writer is of the opinion that Aerojet-General deserves an overall normal performance evaluation for the year's effort.

W. D. Rannie

W. D. Rannie
Robert H. Goddard Professor of Jet Propulsion
California Institute of Technology

20 February 1964

Comments of Dr. Maurice J. Zucrow, Atkins Distinguished Professor of Engineering and Director of the Jet Propulsion Center of Purdue University, in response to a request from Aerojet-General Corporation to create an independent objective review of the technical performance of Aerojet-General Corporation on Contract SNP-1 for Contract Year 1963.

MAURICE J. ZUCROW
Consulting Engineer
1428 Northwestern Avenue
West Lafayette, Indiana

27 February 1964

To: W. C. House, Vice President
REON, Aerojet-General Corporation, Azusa, California

From: M. J. Zucrow

Subject: Review of NERVA Program for Period 1 October 1962 through 30 September 1963.

1. Introduction

In response to your request, I have made an independent objective investigation of the CY 1963 NERVA Program, as conducted by the Aerojet-General Corporation. I have also reviewed the performance ratings received from SNPO. My investigation and review, which has taken several days, has been concerned primarily with Subtasks 1.1, 1.2, 1.4, 1.6 and 1.9.

In conducting my investigation, a large number of documents were studied, interviews were held with the AGC technical prople who worked on the above tasks, and the answers to many questions which I posed to pertinent AGC personnel were analyzed to the best of my ability.

Before presenting my specific comments with regard to the aforementioned subtasks, I find it desirable that I present certain general comments that should convey, at least in a general sense, my personal philosophical attitude and outlook with regard to research and development activities. In my opinion such general comments are essential to understanding how and why I arrived at my specific comments, the latter are presented later.

2. General Comments

First, let us examine what are the fundamental objectives of an engine research and development program. Such a research and development program is generally initiated so that a prototype new engine can be designed, built, and tested successfully. The inherent difficulties in achieving the objectives of the R and D program are related to the state of our technical knowledge at the time the R and D program is initiated; that is, to what degree the state-of-the-art is to be extended. If a large extension of the state-of-the-art is required, then the time and effort that must be devoted to the research phase not only will be extensive but also expensive, and vice versa. One caution that must be borne in mind is that even when only a small extension of the state-of-the-art is required, it is rarely, if ever, possible to predict with accuracy all of the problems which will be encountered in developing a new engine. The unanticipated problems may occur in different phases of the research and development program; for example, in the theoretical analysis, instrumentation, manufacturing, data procurement, and maintenance of a prescribed testing schedule, and so forth. Despite the importance and value of mathematical analyses and the great helpfulness of analog and digital computers, it is rarely possible by analyses and computations alone to predict all of the different problems that will arise, either with individual components or in their interactions when combined into a propulsion system. It is for these reasons that relatively small extensions of the state-of-the-art, in developing a turbojet engine, for example, have proven to be time-consuming and costly. One should not, therefore, expect that nature will be kinder in the case of developing an engine as radically new as NERVA, where there is no real state-of-the-art, than experience has shown nature to be in the case of developing turbojet and ramjet engines, where the extensions of the state-of-the-art has been considerably smaller and the background of technical knowledge has been considerably larger.

For the above reasons, when an engine component, is to be developed, such as the exhaust nozzle for NERVA, since that nozzle requires a substantial extension of the state-of-the-art, conservatism would dictate that a counterpart requiring less extension of the state-of-the-art should also be under development, if feasible, as a "backup" or insurance against unanticipated problems of unusual difficulty that may be encountered in developing the more advanced component. Since the unexpected difficult problems must be overcome during the R and D phase of the engine development, if the latter is to be successful, one might well ask "where does the real R and D portion of the engine development program begin and end?" The real R and D portion is basically that activity which involves cycles of "from drawing board, to the test, back to the drawing board," the cycle being repeated until the required performance is obtained from each component and the system.

In any R and D engine program the effort is ordinarily channeled so that one principal date is of extreme importance; that is, the date for the delivery and test of the prototype of the desired engine. To achieve that objective, the following dates become the firm schedule dates of the R and D program.

1. The dates for "freezing" the designs of all of the components comprising the engine;
2. The date for completing the assembly of the components for final checkout;
3. The date for the first test of the complete engine.

The period from the initiation of the development of the engine up to the "freeze" dates listed above should be utilized as effectively as possible for the continuous improvement of the pertinent components and subcomponents. Any dates set up for guiding the contractor during the true R and D phase of the development are "mileposts" and not true schedule dates. They are neither measures of accomplishment if met nor measures of lack of accomplishment if not met. Their real function is that of assisting in maintaining a reasonable time balance in the development of the components required for the prototype engine; they are not "sacred cows" and should not be regarded as absolute commitments. Until the first versions of the different pertinent components of the engine have been tested, and in the usual case they are "found wanting", the specific problem to be solved cannot be uncovered and understood. Consequently, slippages of such "mileposts" during the true R and D period, while they should not be encouraged, are not truly serious unless the contractor has not put forth his best efforts. Slippage will undoubtedly occur because either the anticipated problems are more difficult to solve than was originally expected or new unforeseen problems will be uncovered. The additional effort expended in uncovering new problems and initiating their solutions are part and parcel of the R and D phase. Moreoever, it should be recognized that the "mileposts" set up for managing the R and D period up until the design "freeze" dates are at best estimates made by fallible human beings at a time when they do not have the full knowledge required of the difficulty of the development problems that undoubtedly will be encountered.

Despite my experience of more than 40 years in R and D engineering, I must admit that I am unable to define in a precise, unequivocal manner what is implied by the word "normal", employed in the following defining sentence.

> "The definition of 'normal' is defined as that which a contractor, qualified in his field of endeavor, would be expected to perform."

I am quite familiar with both NASA and AGC and, to me, both are qualified organizations in their fields of endeavor. Perhaps, the difficulty is wrapped-up in the interpretation of the phrase, "would be expected to perform". The phrase is vague and does not define with any degree of definiteness what is actually expected from the contractor in the way of performance. What is the yardstick of normal performance? If a contractor merely has to practice the state-of-the-art normal performance would certainly be of a vastly different character from that which would be normal for an activity requiring a large extension of the state-of-the-art, as in the development of the NERVA engine. I maintain from personal knowledge covering twenty years of association that the Aerojet-General Corporation is qualified in its field of endeavor. But it is neither clear or even definite to me as to what is the yardstick by which the normal performance of such a contractor should be judged when performing on an R and D program involving an extension of the state-of-the-art. Due to the lack of an adequate definition of what was required, unrestrained opinion may enter and be regarded as judgment, it becomes then a personal matter, and when that occurs, there can be no single correct answer. Perhaps the best guide for judging performance under those circumstances is whether or not the contractor has made an adequate effort in conducting the R and D engine development program.

One should realize that qualified R and D effort which does not produce positive results is not necessarily a wasted effort. In many cases, the negative result may prove to be of greater value than positive results, since they may point out pitfalls which could not have been anticipated without conducting the R and D effort. The real worth of an R and D effort, in the long run, is its contribution in the form of new engineering and scientific knowledge. Such knowledge is essential to advancing our technical knowledge; that is, to make it possible to extend the present state-of-the-art.

I close my general comments with a few words pertaining to the problem of design. There is no single answer to designing a device for accomplishing a given objective; that is why there are so many different makes of flowmeters, for example. What guides a designer to his final design, is his own experience, the failures and successes he has achieved with different approaches, and his temperment. Consequently, the ultimate judgment of a specific design is whether or not it satisfies all of the specifications it was designed to meet.

3. Specific Comments

The specific comments presented below are limited to Subtasks 1.1, 1.2, 1.4, 1.6 and 1.9, since they were the only ones which could be investigated with a satisfactory degree of thoroughness in the available time.

In conducting my investigation, in addition to reviewing considerable documentation and holding discussions with pertinent REON personnel, I presented REON with a set of written questions for answer; the questions were based on my review of the government's evaluation letter, and are included in this report as Attachment A.

(3a) Subtask 1.1 (Engine Systems)

The AGC effort with regard to Engine Systems was conducted as a part of other subtasks during the 1st and 2nd quarters of CY 1963. It was not until the beginning of the third quarter that the responsibility for Engine Systems was placed in a special group having its own department manager.

Attachment B summarizes the accomplishments under related Subtask 1.1 during CY 1963. It is quite evident that the effort on Engine Systems increased during the 3rd and 4th quarters and many results of great value were achieved during those two quarters.

Nevertheless, the SNPO-C evaluations for Subtask 1.1 were as follows:

(1)	(2)	(3)	(4)	(Final)
Below Normal	Normal	Normal	Below Normal	Below Normal

The facts presented in Attachment B do not support the below normal rating for the 4th quarter, and consequently, for the final evaluation.

A major criticism presented in the customer's final evaluation of Subtask 1.1 relates to who was to be held responsible for the analytical work pertaining to the NRX-A. From discussions with the AGC personnel concerned with the Subtask 1.1, and also from substantiating AGC documentation, I am obliged to conclude as follows:

(1) The responsibility for the NRX-A analysis was assigned to WANL by SNPO-C, from performance analysis through data analysis.

(2) That the 4th quarter and final evaluations of "below normal" are difficult to justify based on my investigation of Subtask 1.1.

(3b) <u>Subtask 1.2</u> (Propellant Feed System)

The SNPO-C evaluations for Subtask 1.2 are presented below:

Quarter				
(1)	(2)	(3)	(4)	(Final)
Below Normal	Above Normal	Normal	Below Normal	Below Normal

Attachment C presents the accomplishments under Subtask 1.2, during CY 1963. In the attachment the Subtask 1.2 is divided into the major components involved, and the expenditures and manpower pertinent to the subdivisions. It also compares the "Development Goals" with "the accomplishments."

Attachment C, does not however, present the numerous redirections by the customer of the development program for the turbopump. As is to be expected, those redirections had a large impact upon the progress of the development program and its costs; it appears that the major portion of the overrun cost was due to the engineering manpower costs incurred so that the design and release rate of the drawings for the Mark IV TPA would occur in CY 1963. I am informed that the latter effort was made to satisfy SNPO-C. The "new proposal, new design" cycles that were required as a result of direction by the customer are most certainly the type of "mitigating circumstances" that lead to large overruns, and they did.

It appears necessary to clarify the conditions for which the different TPA developments were intended:

(a) The Mark III was intended for the heated bleed engine.

(b) The Mark IV was intended for the hot bleed engine.

(c) The Mark III Mod 3 was an interim assembly for development purposes only, it was not intended for the hot bleed engine.

SNPO-C in the final evaluation report states that

".....because of insufficient foresight,.....it now becomes necessary to abandon the Mark III TPA design in favor of the Mark IV.

The above comment may have some validity, but not for CY 1963. If there was a lack of foresight, it is my opinion that it occurred in CY 1962 and was due to not developing a TPA for the hot bleed cycle in addition to one for the heated bleed cycle, because SNPO-C and AGC had not reached an agreement regarding the cycle which was to be ultimately selected. Like Sir Roger de Coverly, it is a case of "there is much to be said on both sides" (SNPO-C and AGC). In any case, it is most unfair to penalize AGC performance in CY 1963 for a possible (?) lack of foresight in CY 1962.

Another remark made in the final evaluation report of SNPO-C which is worthy of examination is the statement -

"....It may be expected, therefore, that tests of the Mark IV will lead to the discovery of problems that were not revealed by Mark III testing."

As pointed out in my General Comments, it is normal to expect any change of any kind, no matter how insignificant it may appear at the time of initiating, it will under test reveal some unanticipated problems. It should be expected. The statement is an "iffy" one and should not be included or given credence in an objective evaluation.

Another conjectural statement that most certainly has no place in an objective evaluation, any more than a prejudicial leading question has in a court of law, is the following:

> "....Similarly, the status of the turbopump development threatens to delay the NERVA schedule."

According to my investigation, the Mark III TPA development made at least the following valuable contributions to the state-of-the-art of pumping liquid hydrogen

(1) Evaluated materials at cryogenic and high temperatures.

(2) Established the required material combinations and fits for different component parts.

(3) Established suitable bearing materials and bearing coolant requirements.

(4) Evaluated LH_2 pumping performance at high and low NPSP, and established the problem areas associated with high speed pumping of LH_2.

(5) Evaluated and established the thrust conditions for the TPA.

(6) Established the speed measuring techniques for high speed rotating machinery operating in a cryogenic environment.

(7) Verified the design and analyses techniques by testing the different components and correcting the techniques by applying the results obtained by test.

(8) Evaluated the turbine performance and obtained information that will be applicable to improved designs and giving improved performance.

(9) Determined some of the problems associated with operating a turbopump over the wide range of flows and pressures which are required for satisfying the NERVA engine requirements.

(10) Evaluated the problems associated with "bootstrap" starting of a turbopump with LH_2.

The above contributions to LH_2 are in disagreement with the following statement taken from the SNPO-C final evaluation.

"....A retrospective review of the 1963 performance a year hence ..... make no contribution to ..... final NERVA engine prototype component .....

The above statement is not only inaccurate in view of the preceding, but is an unusually prejudicial statement based on conjecture. Such statements should not be allowed in what is supposed to be an objective evaluation.

In the final evaluation for CY 1963, the following two statements occur. I quote

(1) "...the design and development program was not adequate to insure that the negative slope critiera..."

(2) "...did not perform sufficient analyses and make use of existing data in calculating and minimizing the balance piston thrust loads..."

Both statements are opinions, and should not be regarded as evaluations. What may be adequate for an experienced designer may not be for one who is inexperienced.

In designing a TPA the designer has choices with regard to the method for taking up the axial thrust loads; a balance piston, a thrust bearing or dividing the load between the two. Two experienced designers can disagree and neither be incorrect. It is important, however, that the method selected be adequate for the axial thrust loads. On the other hand, if the TPA is designed so that the thrust load is taken up by a thrust bearing, then a direction by the customer to incorporate a balance piston, cannot be regarded as a minor modification to the existing design.

My detailed review of Subtask 1.2 indicates that a great deal was accomplished that will be of value in designing future LH_2 feed systems. In my opinion, good progress was made despite the many redirections of the program by the customer. Furthermore, it appears that during the thirty-eight tests conducted with a TPA during the contract year, there were only two significant hardware failures. All in all, it appears that the contractor performed somewhat better than could be expected under the circumstances. In my opinion, his rating on Subtask 1.2 for CY 1963 should be, at least, "normal."

(3c) Item 1.4 (Thrust Chamber Assembly)

The SNPO-C evaluation for Subtask 1.4 is presented below:

		Quarter		
(1)	(2)	(3)	(4)	(Final)
Above Normal	Below Normal	Below Normal	Below Normal	Below Normal

To really appreciate and understand the AGC effort expended on Subtask 1.4, the chronological history of the development of the exhaust nozzle is important; it is submitted here as Attachment D.

The accomplishments during CY 1963 on Subtask 1.4 are presented as Attachment D.

The nozzle development is an illustration of the principle that a major objective of the R and D phase of an engine development is the uncovering of unusual problems that cannot be predicted by analysis alone.

The Customer's evaluation of Subtask 1.4 during the 1st quarter (1 October 1962 to 1 January 1963) was as follows:

> "In this area the contractor has applied sound programming, planning and organization, coupled with a good scientific and engineering approach in design concepts. The NRX nozzle design has proceeded satisfactorily and the model program has been good. In general, development programs have been carefully planned and modern industrial engineering techniques have been applied."

Undoubtedly at that time both the customer and AGC were enthusiastic about the technical advantages of an aluminum coated nozzle, and were also of the opinion that its development could be prosecuted with relatively few problems. It should be borne in mind that the quoted statement reflects the considered judgments of competent individuals in both SNPO-C and AGC.

The history of the nozzle development is the type of experience one should have expected, since it was not a state-of-the-art development. A large number of difficulties in manufacture were uncovered and AGC has worked diligently to solve them. It is my opinion that AGC has done no better nor any worse than one could expect from a qualified rocket engine contractor engaged in the same endeavor. The rating of below normal for Subtask 1.4 appears to me to be rather harsh.

(3d) Subtask 1.6 (Engine Destruct System)

The SNPO-C evaluation for Subtask 1.6 is presented below:

Quarter				
(1)	(2)	(3)	(4)	(Final)
Normal	Above Normal	Below Normal	Below Normal	Below Normal

My competence to judge the detailed technical accomplishments under Subtask 1.6 are, of course, open to some question. Nevertheless, from my review of the major documentation, discussions with the department manager responsible for that subtask, and answers to questions I posed, I have some "feel" for the accomplishments under Subtask 1.6; they are presented as Attachment F.

To one not an expert in the field of destruct systems, it appears that much was accomplished, and that most of the objectives for CY 1963 were either accomplished or nearly accomplished.

From my investigation, it appears that there was not a complete meeting of the minds between the contractor and the customer as to the details of what was required under Subtask 1.6. It appears possible that this misunderstanding may have led to differences of opinion regarding the accomplishments during CY 1963, and their value as contributions to the state-of-the-art.

The customer in evaluating the final report used terms which reflected on the technical quality of the report. My study of the changes requested by the customer indicated that most of them were of an editorial nature. If I am correct in my opinion, the rather harsh criticism of the report is hardly fair.

(3e) Item 1.9 (Radiation Effects Program)

The SNPO-C evaluations for Subtask 1.9 are presented below:

Quarter				
(1)	(2)	(3)	(4)	(Final)
Above Normal	Below Normal	Below Normal	Below Normal	Below Normal

Subtask 1.9 is also in an area where I do not consider myself too competent. It is noteworthy that the AGC effort for the first quarter was rated "above normal." A detailed examination of Subtask 1.9 revealed that there was a change in technical leadership at the end of the first quarter. Moreover, until quite recently it appears that the effort on the subtask did not have the type of technical leadership one would expect from a contractor having the capabilities of AGC. I am assured that Subtask 1.9 is now in good hands, and in the future the quality of the work done under that subtask will be greatly improved. The rating of "below normal," in my opinion, is correct.

4. Summary

In closing, I wish it to be understood that my investigation of the NERVA development program for CY 1963 was based on information furnished by AGC personnel, and documents written to or received from SNPO-C.

It appears to me that the evaluation does not give sufficient consideration to the fact that the effort under CY 1963 was an R and D effort. Moreoever, since human beings are involved, some mistakes are bound to occur. Nobody is perfect, even under supervision. Furthermore, there appears to be a belief on the part of the customer in some areas, that analyses are a "cure all"; that they will uncover all of the development problems. Undoubtedly, they may uncover some of them. But one must realize that science and engineering are based primarily on experiment, and without adequate data obtained from experiment one cannot deduce principles or laws for predicting what will happen in other situations. The R and D phase of an engine development program always involves experimentation for obtaining the information for designing the final engine, and during the R and D phase one must expect many different difficulties will be encountered. It is a characteristic of the rocket engine development business that one is "either in trouble, just getting out of trouble, or just getting into trouble." That should not alarm anyone since successful rocket engines have been developed and scaled up faster than it was possible to "scale up" piston engines.

From my review of Subtasks 1.1, 1.2, 1.4, and 1.6, I conclude that AGC was diligent and intelligent in the prosecution of the NERVA program, and under those subtasks did not do worse than any other qualified contractor would have done under similar circumstances. On the other hand, the performance of AGC under Subtask 1.9 was unsatisfactory.

M. J. Zucrow

ATTACHMENT A

PROF. ZUCROW'S QUESTIONS PERTAINING TO SNPO EVALUATION OF AEROJET'S PERFORMANCE ON SNP-1

I. Was the Mark III pump ever considered to be more than a step in developing the final TPA for the hot bleed cycle?

II. Is missing the milestones as serious as the customer indicates it to be? When was the reactor delivered to NRDS? When was the nozzle delivered to NRDS? List the delivery dates of all hardware required for the NRX assembly and show whether or not they held up the assembly process. Was there any delay due to parts from WANL not being received? Who has responsibility for assembly of the NRX flow test? What is holding up the test for NRX reactor now?

III. Was the nozzle pacing as of the time the evaluation was written? Was the nozzle pacing at the end of CY 1963? Is the nozzle pacing as of now?

IV. Why was there an overrun on the pump? Why was there an overrun on the nozzle? How much was the overrun for each? Were there any unanticipated problems encountered? How does Aerojet justify the overruns? Were any new problems encountered?

V. Was this due to unanticipated problems?

VI. How are mitigating and non-mitigating circumstances defined? If there are mitigating circumstances for the TPA and nozzle overruns, what are they?

VII. How much engineering time has been expended on analyses?

VIII. Why was the rework necessary? How many gages were made? How many had to be reworked? Why was the rework necessary? What additional information is necessary to obtain an accurate and complete story pertaining to the gages and face plates?

IX. When was the head versus flow characteristic curve decided upon (negative slope)? How many engineering hours and dollars were spent on analyses? What were the data employed for calculating the balance piston thrust and bearing loads?

X. Was missing these milestones serious? If not, why not?

XI. How much money was expended on nozzle development?

XII. Were any analyses made at all? If so, what can be said about the reliability of the results?

XIII. Why was there excessive time lag?

XIV. Was the rewrite of the technical report satisfactory? Was the task completed on schedule? Please describe in summary what the 1.6 task was supposed to accomplish during 1963 and what portion of it was accomplished? What is the reason for the change in rating from the second quarter?

XV. Is the complaint here more related to coordination than to technical adequacy? Please clarify. Why was the rating lowered after the third quarter?

XVI. Is this correct? What are the details? Has there been any improvement in the performance on Task 2.4 since 30 September, since report was written, and to date? If so, please summarize.

ATTACHMENT B

ACCOMPLISHMENTS UNDER SUBTASK 1.1

CY	Status	Major Reports	$ Expended	Manpower	Key Events	Results of Event
62	Work funded under 1.2 and 1.5	Cycle selection Analysis			SNPO-C Selection of cycle & reactor concept	Work concentrated on hot bleed engine and defined operating map & component constraints
	Analyses made for 2 cycles & 3 reactor concepts	Heated bleed cycle equations for analog				
		CY 1962 Final Report Subtask 1.2				
63	Work funded under 1.2 & 1.5	ETS-2 criteria			Evaluation of ETS-2 criteria	Engine start-up evaluated for various environmental pressures for ETS-2
63	Work funded under 1.2 & 1.5	Steady state engine model			Steady state digital program complete	Revision of engine operating maps & constraints started
		HFDTS study				Definition of E-engine performance
					Power range analog model complete	Revision of control system & definition of engine start-up started
					Cooldown analog model complete	Analysis of engine cooldown

Accomplishments under Subtask 1.1 (cont.)

Quarter	CY	Status	Major Reports	$ Expended	Manpower	Key Events	Results of Event
3	63	Work funded under 1.1.6	CY 63 AGC Systems Analysis Program CY 63 NERVA Systems Analysis Program	REON $225,000 LRP 50,000 $275,000	REON 28 LRP 6 34	Reorganization of systems analysis effort	Systems analysis program plan
			Analog cooldown equations			SNPO-C approval of systems analysis plan	Test analyses started for CFDTS
							CFDTS data analysis program started
			Diluent extraction study			Review of assumptions in systems analysis effort started	Bleed port equations revisions started
							Tolerance studies started for engine start-up & shutdown
4	63	Work funded under 1.1.6	CFDTS analysis	REON $175,000 LRP 50,000 $225,000	REON 22 LRP 6 28	Review of assumptions (continued)	Analog chilldown analysis effort emphasized
							Test plan analysis for CFDTS completed
			FX-Engine start-up				Engine start-up & shutdown tolerance studies completed
							Revision of MK III TPA Equations started (H_2)
							Digital reactor system model complete
			CY 63 Final Report - Subtask 1.1.6			Instrumentation error analysis started for CFDTS & NRX-A	NRX-A2 operating conditions checked

Accomplishments under Subtask 1.1 (cont.)

Quarter	CY	Status	Major Report	$ Expended	Manpower	Key Events	Results of Event
1	64	Work funded under 1.8		$205,000	12	Development of digital program for engine emphasized	CFDTS data analysis program complete
							Rough cut engine program started
							Digital program efforts on chill-down started
						FX-Engine start-up re-evaluated	TPA NPSP require-ments studied
							Redefinition of engine sequence of events started
						Test condition evaluation	Error analysis of instrumentation complete for NRX-A 1 & 2 & CFDTS
							Mixer analysis of Test Cell "A" system started

ATTACHMENT C

ACCOMPLISHMENTS UNDER SUBTASK 1.2

Sub-Subtask 1.2.0 - PFS ASSEMBLY

Major Component	CY-63 $ Expended By Quarters: Qtr.	$	No. of Eng. Men on Dev. Program By Qtrs. in CY62		Development Goals	Accomplishments
Static Seals Remote Disconnects	1. 2. 3. 4.	57,000 13,000 89,000 68,000	1. 2. 3. 4.	3 5 5 4	*1. Leakage rate of 1×10^{-6} scc/sec. 2. Temp. operating range from LH_2 temp. to hot H_2 turbine gas temp. *3. Satisfactory for Rad environment. *4. Remote assembly & disassembly capability.	1. Leakage rates achieved. 2. Low temp operational requirements satisfied. 3. Initial Rad test results were satisfactory. 4. Preliminary seal selection made for E-1 engine. 5. Preliminary disconnect selection made for E-1 engine.

Sub-Subtask 1.2.1 - PFS LINES

Major Component	Qtr.	$	Qtr.	No.	Development Goals	Accomplishments
Pump Suction Line Pump Discharge Line Turbine Inlet Line Turbine Exhaust Line	1. 2. 3. 4.	5,000 21,000 106,000 197,000	1. 2. 3. 4.	1 1 4 5	1. Temp. operating range from amb. to LH_2 except turbine inlet line which operates at high temp. 2. Satisfactory for rad environment. 3. Regeneratively cooled turbine inlet line.	1. Line analysis completed. 2. Line designs completed. 3. Suction line water tested and LH_2 tested with TPA. 4. Suction line problem areas established with LH_2. 5. Regeneratively cooled turbine inlet design completed.

Sub-Subtask 1.2.2 - PFS VALVES

Major Component	Qtr.	$	Qtr.	No.	Development Goals	Accomplishments
Tank Shutoff Valve (TSOV)	1. 2. 3.	190,000 215,000 234,000	1. 2. 3.	16 19 18	*1. Very high flow and low ΔP-TSOV.	1. TSOV tests indicate high flow; low ΔP can be achieved.

*Indicate areas where little or no prior engineer knowledge available and required significant new development and advancement of the "state-of-the-arts."

Sub-Subtask 1.2.2 - PFS VALVES (cont.)

Major Component	CY-63 $ Expended By Quarters: Qtr.	$	No. of Eng. Men on Dev. Program By Qtrs. in CY62	Development Goals	Accomplishments
Reactor Cooldown Valve (RCDV)	4.	178,000	4. 13	*2. Leakage rate of 1×10^{-6} scc/sec for TSOV and RCDV dynamic seals.	2. LH_2 operational tests with first configuration TSOV were satisfactory.
Turbine Power Control Valve (TPCV)					
				*3. RCDV electric actuation motor for LH_2 and rad environment.	3. Rad effects tests with Conf. 1 TSOV were satisfactory.
				*4. TSOV & RCDV capable of thermal shock from ambient to LH_2 temp.	4. Dynamic double-seals developed for TSOV and RCDV which have achieved leakage rate of 6×10^{-6}. Seal improvements to satisfy the extremely low leakage requirements were in process.
				5. High temp - low torque TPCV.	5. Design of TSOV with remote disassembly capability completed.
				*6. Valves capable of operation in rad environment.	6. Design and fabrication of high temp TPCV completed.
				*7. Remote disassembly capability.	7. Development tests of second Conf. TSOV started.
					8. DC and AC actuation motors for RCDV designed and fabricated.

*Indicate areas where little or no prior engineer knowledge available and required significant new development and advancement of the "state-of-the-arts."

Major Component	CY-63 $ Expended By Quarters Qtr.	$	No. of Eng. Men on Dev. Program By Qtrs. in CY62
Sub-Subtask 1.2.3 - TURBOPUMP ASSEMBLY			
Pump	1.	510,000	1. 33
Power Transmission	2.	771,000	2. 53
Turbine	3.	713,000	3. 63
	4.	742,000	4. 63

Development Goals

*1. Centrifugal pump to operate with LH_2 at very high flows, high head rise, very low NPSP, and over a very wide flow range.

*2. Power transmission with very low power loss and LH_2 cooled ball type thrust bearings and roller radial load bearings.

3. Thrust balance system for MK IV TPA.

4. Efficient turbine drive operated with hot H_2 gas.

*5. Hot pump start capability with no chilldown for starting.

*6. Long endurance capability.

*7. Capable of operation in radiation environment.

*8. Remote installation and disassembly capability.

Accomplishments

1. TPA LH_2 pumping demonstrated over flow and pressure ranges that extend below and above the FX engine operating range.

2. Tests at specific values of Q/N and at NPSP's below 2 psi were run at full and reduced speeds.

3. TPA operational recovery from the stall region has demonstrated at a wide range of speeds below 50% of design speed.

4. Operational recovery from cavitation conditions was accomplished.

5. Total turbopump operation of 3613 secs was accomplished with LH_2 cooled power transmission.

6. TPA operated at FX power condition for accumulated time of 157 sec., with 130 sec. accumulated on one unit.

7. Engine simulator and TPA tests indicate hot pump start can be accomplished.

*Indicate areas where little or no prior engineer knowledge available and required significant new development and advancement of the "state-of-the-arts."

Sub-Subtask 1.2.3 - TURBOPUMP ASSEMBLY (cont.)

Major Component	CY-63 $ Expended By Quarters Qtr.	$	No. of Eng. Men on Dev. Program By Qtrs. in CY62	Development Goals	Accomplishments
					8. TPA ball and roller bearings operated at full load and speed in non-rad environment for accumulated time of 75 min. on one set.
					9. TPA bearing set operated in non-rad environment at full loads and 67% full speed for accumulated time of 3 hrs.
					10. Bearings tested in a rad environment at full speed with no detrimental effects.
					11. Materials, material combinations and fits for the TPA component parts were evaluated at cryogenic and high temps during TPA testing.
					12. Evaluation of turbopump thrust was accomplished during TPA testing.
					13. TPA test results provided data for verification or refinement of analyses and design calculation techniques.
					14. High speed measuring techniques for use in an LH_2 environment on the TPA was established.

[redacted]

Sub-Subtask 1.2.3 - TURBOPUMP ASSEMBLY (cont.)

Major Component	CY-63 $ Expended By Quarters Qtr.	$	No. of Eng. Men on Dev. Program By Qtrs. in CY62	Development Goals	Accomplishments
					15. MK IV TPA (FX engine prototype) design completed with following improvements: a. Impeller designed for improved cavitation characteristics, negative slope H-Q curve over engine operating range, & growth potentials. b. Thrust balancing system incorporated. c. Turbine designed for optimum efficiency. d. Space provisions included for shaft seal, if wet pump start requirements become necessary.

ATTACHMENT D

CHRONOLOGICAL NOZZLE HISTORY

July 1961 Item 13 of the original NERVA contract initiated in July 1961 called for design of a hydrogen cooled or partially cooled exhaust nozzle which shall be part of the NERVA engine system. The design included heat transfer, stress, and fluid dynamic analyses. The design selected was a stainless steel tube bundle configuration with an external cast aluminum jacket to provide longitudinal and hoop support. (See AGC NERVA Monthly Report No. 4, October 1961).

21 October 1961 Authorization was received via NASA SNPO-C TWX No. 17, LC Corrington to LB Bridges to proceed with fabrication of two Kiwi-B nozzles to the above design for LASL use, according to Item I of Aerojet Proposal VE-61012, Vol. II. One nozzle was to be used in LO_2/LH_2 development testing with fabrication scheduled for completion on 5 March 1962. Nozzle No. 2 was to be fabricated by 28 March 1962 for use as a backup test unit to No. 1, but primarily to be delivered for reactor testing as a backup to the Rocketdyne Kiwi-B nozzle design. Work was initiated on an overtime basis to meet this schedule.

December 1961 The SNP-1 contract amendment, AGC Proposal No. 61004 Vol II, provided for fabrication of the above two Kiwi-B (LASL) nozzles in March 1962, and one heated bleed NERVA nozzle for development testing in September 1962.

27 February 1962 Discussions were held at Aerojet with LASL and SNPO-C personnel which resulted in the suspension of fabrication of the two Kiwi-B coated nozzles beyond procurement of the tube bundles to the NERVA nozzle configuration.

6 March 1962 In a letter from LC Corrington to WC House confirming telecon AA Medeiros to B Mandell on 5 March 1962, Kiwi-B No. 001K (for LASL) was to be utilized in hot firing simulation tests and a hold was placed on Kiwi-B nozzle No. 2 (for LASL) after tube brazing so that it could be used for Kiwi-B No. 001K backup.

20 March 1962 In AGC TWX No. 830 GL Ryland to LC Corrington, Aerojet requested authority to proceed with fabrication of the two Kiwi-B coated nozzles to a Hybrid nozzle configuration to be utilized as LASL reactor backup nozzles instead of coated nozzles for use in the NERVA development program.

April 1962 A revision to AGC Report No. 2199, Program Plan for 11 January 1962 thru 30 September 1962, provided for fabrication of those two Kiwi-B nozzles for LASL to the same schedule as above, plug two additional Kiwi-B nozzles for development testing in May 1962, one hot bleed and one heated bleed nozzle for development testing by 15 September 1962.*

4 April 1962 Verbal instructions were received from LC Corrington, SNPO-C, and JL Wilson, SNPO-C, to GL Ryland for Aerojet to proceed with design and fabrication of two Hybrid nozzles for the Kiwi-B reactor test program. These two nozzles were diverted from the coating evaluation test program. (See Supplement 5 to AGC Work Order 0570-xx thru 0575-xx, dtd 5 April 1962).

10 April 1962 Kiwi-B nozzle No. 1 (LASL) failed in hydrotest at LRP due to separation of the tubes from the aluminum jacket caused by a pressure leak in this circuit. A redesign was initiated for submission to LASL and SNPO-C to preclude the possibility of this malfunction re-occurring in subsequent nozzles.

11 April 1962 AGC TWX 452 documented telecon F. Durham, LASL, and WD Stinnett/B Mandell, AGC, in which Kiwi-B nozzle No. 002K was released to complete fabrication with the understanding that any design changes incorporated were to be approved by LASL and SNPO-C representatives.

13 April 1962 AGC Program No. 62007 was submitted for fabrication of these two Hybrid nozzles for delivery FOB Sacramento, on 15 August 1962, per above verbal authorization.

*Design of the hot bleed nozzle was delayed pending completion of the bleed port tests utilizing XLR-87 chambers. By the time these tests were completed, Aerojet had selected the heated bleed cycle and all work was discontinued on hot bleed components.

25 April 1962 In a meeting at LASL with Aerojet and SNPO-C personnel, it was agreed to incorporate wire interlocks on the nozzle tube bundle exterior to mechanically secure the cast aluminum jacket to the nozzle tube bundle. At this time, disposition of S/N 001K Kiwi-B nozzle was made to utilize it for handling and plumbing procedures on the C-6 test stand at LRP. (See LASL memo CR King to VL Zeigner dtd 25 April 1962).

8 May 1962 In SNPO-C TWX LC Corrington to WC House, action taken in the 25 April meeting at LASL was approved by SNPO-C.

15 May 1962 SNPO-C TWX No. 1 authorized fabrication and delivery of two hybrid NERVA nozzles.

24 May 1962 Supplement 9 to AGC Work Order 0570-xx thru 0575-xx was issued deleting the coated nozzle tests and authorizing fabrication and delivery to the schedule in No. 62007.

1 June 1962 SNPO-C TWX RW Schroeder to GL Ryland, clarification of SNPO-C TWX No. 1 dtd 15 May 1962 was received to delete the two Kiwi-B coated nozzles from the SNP-1, Mod III contract and fabricate them to the Hybrid nozzle configuration.

8 June 1962 During the casting procedure on Kiwi-B Nozzle No. 022K, aluminum penetrated the nozzle tube bundle in many areas along the nozzle length causing suspension of further fabrication of this unit.

20 June 1962 In telecon B Mandell and AA Medeiros, SNPO-C, Aerojet was advised that SNPO-C was considering funding three additional NERVA nozzles in the Contract Year 1962 program for delivery in Contract Year 1963.

29 June 1962 LRP TWX JJ Peterson to WC House - authorization was requested to strip the aluminum jacket from both Kiwi-B nozzles 001K and 002K and resume fabrication of two Hybrid nozzles and one NERVA nozzle in accordance with revised casting procedures.

30 June 1962 In telecon AA Medeiros, SNPO-C, and B Mandell, AGC, SNPO-C agreed to repair Kiwi-B S/N 001K and 002K nozzles pending receipt of AGC TWX outlining revised casting procedure.

3 July 1962 In SNPO-C TWX LC Corrington to WC House it was agreed to complete fabrication Kiwi-B X/N 001K and 002K to gain fabrication experience prior to commitment of Hybrid nozzles to fabrication beyond tube bundle assembly.

3 July 1962 In AGC TWX WD Stinnett to VL Zeigner, repair procedure for Kiwi nozzles S/N 001K and 002K was submitted.

5 July 1962 In LASL letter VL Zeigner to WD Stinnett, concurrence in repair procedure on S/N 001K and 002K Kiwi-B nozzles was granted by LASL subject to approval by SNPO-C.

7 July 1962 In a meeting at AGC with SNPO-C personnel, results of the hot gas side scale model heat transfer tests conducted in Contract Year 1961 were discussed with their attendent effects on the design of nozzles currently in fabrication. Based on the result of these scale model tests, it was concluded that nozzle tube wall temperatures were excessive and required a reduction of coolant flow passage areas.

On this date AA Medeiros, SNPO-C, requested that a hold be placed on fabrication of the two Hybrid nozzles and one NERVA heated bleed nozzle until Aerojet presented recommendations for redesign to incorporate the required flow areas to SNPO-C for approval.

10 July 1962 In SNPO-C TWX 1307 R, LC Corrington to WC House, approval was granted to continue with repair of Kiwi-B S/N 001K and 002K nozzles using casting procedures outlined in AGC TWX WD Stinnett to VL Zeigner, LASL, on 3 July 1962. AGC action was subject to LASL concurrence.

20 July 1962 In AGC letter No. 62013, GL Ryland to RW Schroeder, Aerojet proposed the fabrication of three additional NERVA nozzles for the Kiwi-B reactor backup program. Fabrication completion dates for these nozzles were scheduled for 12 November 1962, 26 November and 10 December 1962, with simulation testing of each nozzle following a week beyond this date. These schedules were based on initiation of work on 9 July 1962.

23 July 1962   In AGC TWX 924, WC House to RW Schroeder, recommendations were made for incorporation of cables in brazed tube bundle to reduce the coolant flow area to that required for satisfactory wall temperatures. Aerojet requested release of the two Hybrid nozzles and one NERVA nozzle up to the casting operation to incorporate assembly of these cables.

25 July 1962   In SNPO-C TWX LC Corrington to WC House, fabrication of the two Hybrid nozzles and one NERVA nozzle was held prior to brazing of the tube bundle assembly. SNPO-C did not concur with installation of cables in a brazed tube bundle and wanted the fabrication held until these modifications were reviewed in detail by SNPO-C.

30 July 1962   In AGC TWX 1209, WC House to RW Schroeder, these detailed modifications for installation of cables were outlined and concurrence requested by SNPO-C for resumption of fabrication.

2 August 1962   Aerojet received authorization to proceed with the installation of cables in tubing in SNPO-C TWX 1544 R, R.W. Schroeder to WC House. This approval included two conditions that Aerojet must comply with prior to assembly of the cables into the tube bundle; namely, that tube wall temperatures shall be no higher than 1500°F, or higher temperatures are justified, and that analyses of the effect of cables on the pressure shell shall be performed.

3 August 1962   In SNPO-C TWX JL Wilson to GL Ryland, Aerojet was authorized to proceed with the fabrication of three additional nozzles.

15 August 1962   In AGC TWX, WC House to RW Schroeder authorization was requested to proceed with installation of the cables in the tubes.

27 August 1962   AGC nozzle heat transfer correlations for the hot gas side and liquid side were mailed to LC Corrington SNPO-C and CL King, LASL. These correlations were the result of the scale model and liquid side heat transfer work funded under this contract and form the basis for the redesigned nozzle tube bundles. The three additional reactor backup nozzles were designed to this configuration. The design was completed on 13 November 1962. The NRX-A nozzle tube bundle design was completed to these heat transfer correlations and submitted to SNPO-C in letter WD Stinnett to AA Medeiros dated 18 December 1962.

7 September 1962   At a meeting at LASL with representatives of SNPO-C and AGC attending, F. Durham of LASL stated that the Hybrid S/N 001H and 002H and NERVA 001N nozzles were no longer required for backup to the LASL Kiwi-B reactor program.

10 September 1962   Aerojet TWX WD Stinnett to RW Schroeder requested the release of the two Hybrid and one NERVA heated bleed nozzle from the Kiwi-B reactor program to the NERVA component development test program.

14 September 1962   Approval was received by SNPO-C in TWX LC Corrington to WD Stinnett to fabricate one Hybrid nozzle with (cable) inserts and one Hybrid and one NERVA heated bleed nozzle without (cable) inserts. Utilization of these nozzles in the NERVA development program, rather than as reactor backup units, were to be discussed at a later date.

November 1962   AGC Report No. 2322 presented the following nozzle delivery schedules in accordance with the negotiated heated bleed NERVA engine program. The two Hybrid and Kiwi-B nozzles and NERVA nozzle No. 001N were considered Contract Year 1962 carry-over items and were not included in the hardware demand schedule.

Hybrid S/N 001H (shown in milepost chart)	8 Dec 1962
Hybrid S/N 002H (shown in milepost chart)	29 Jan 1963
Reactor backup nozzle No. 001LL	30 Mar 1963
Reactor backup nozzle No. 002L	13 April 1963
Reactor backup nozzle No. 003L	27 April 1963

7 December 1962   A revised nozzle delivery schedule was presented by letter WC House to RW Spence, LASL.

December 1962   Aerojet Report No. 2434, Contract SNP-1 Mod VII, was submitted for the hot bleed NERVA engine program.

18 December 1962   Kiwi S/N 001K nozzle successfully passed hydrotest to 780 psig and was available for start transient simulation firing tests on C-6 test stand. These tests were delayed pending completion of work on C-6.

4 January 1963 Kiwi-B nozzle S/N 002K failed in hydrotest due to cracked aluminum jacket, resulting in its loss to the program for further testing. This failure was attributed to different casting procedures followed by the alternate casting vendor. A failure analysis was initiated.

11 January 1963 A major fire at LRP stores resulted in loss of tubing for reactor backup nozzle S/N 002L and components required for simulation tests (mainly seals).

19 January 1963 Hybrid nozzle S/N 001H was hydrotested as an assembly with the ACFI pressure vessel. At 95% rated pressure the nozzle shear lip cracked releasing the pressure. This shear lip (which is not part of the Kiwi-B nozzle design) will be redesigned according to results of a failure analysis for all future nozzles fabricated. Hybrid nozzle S/N 001H will be utilized in simulation tests to checkout the tube bundle heat transfer design correlations.

21 January 1963 Heat transfer computer runs for the NRX-A nozzle at four flow rates were mailed to GK Sievers, SNPO-C.

23 January 1963 The NRX-A nozzle drawing was mailed to GK Sievers, SNPO-C.

31 January 1963 Conversion of C-6 test stand was complete; however, simulation tests could not begin until items lost in the fire were replaced.

February 1963 It was determined that the hybrid nozzle (S/N 001H) shear lip failure during hydrotest in January was due to jacket physical properties being substantially below design allowables. Jacket thickness and shear lip dimensions are being increased in accordance with new allowable values for ultimate and yield strengths.

Fabrication drawings were released for the "U" tube nozzle having a one-piece forged shell.

March 1963 An AGC nozzle task force consisting of specialist in all of the disciplines involved in the design and fabrication of the nozzles was established to expedite the resolution of the various problems involved.

Failure analysis for Kiwi-B nozzle S/N 002K which cracked during hydrotest was completed. Results were published in REON Report No. RC 6415.

April 1963 S/N 001K Kiwi-B Nozzle (recast) was LOX-hydrogen test fired and after 3 seconds of operation cracked at the flange and throat and broke into several pieces. (This malfunction was subsequently attributed to thermal stresses and stress concentrations in the aluminum jacket combined with pressure loading.)

Fabrication of the forging for the first "U" tube nozzle neared completion.

May 1963 Reactor back-up nozzle S/N 002L was cast at Pacific Brass Foundry. As a result of low ductility, it was decided to wrap it with fiberglass tape for LOX-hydrogen testing.

NRX-A nozzle S/N 0000004 was cast.

Detail drawings were completed for the hot bleed nozzle. Fabrication of S/N 0000010 tube bundle was initiated.

June 1963 Reactor back-up nozzle S/N 002L was wrapped with fiberglass tape to offset the effects of low ductility of the jacket during LOX-Hydrogen testing.

One 8 second firing was conducted with nozzle S/N 002L. The nozzle flange cracked between bolt holes for approximately 90° of the bolt circle.

NRX-A S/N 0000010 hot bleed nozzle was selected for the NRX-A1 cold flow test. Two ports for lights and one port for movie and TV cameras were provided in the convergent section of the tube bundle.

July 1963 Hybrid nozzle S/N 001H was cast at Howard Foundry (Chicago). Round gas porosity was detected in the convergent section.

Hybrid nozzle S/N 002H was cast at AGC Sacto Foundry. Ultimate, yield and longation were 41 ksi, 27 ksi and 15% respectively. Round gas porosity observed will be repaired by grinding and weld repairing.

NRX-A S/N 0000004 nozzle was completed.

NRX-A S/N 0000010 nozzle was cast at LRP.

U-tube braze samples for the advanced nozzle were subjected to satisfactory proof and leak tests. Fabrication of the first U-tube nozzle shell is continuing at Marquardt.

August 1963 NRX-A S/N 0000005 was cast at LRP. NRX-A S/N 0000006 was cast at LRP.

NRX-A S/N 0000004 was fiber-glass wrapped, hydrotested and hot-fire tested for 9 sec when malfunctioning of test setup caused premature shutdown of the test.

September 1963 NRX-A S/N 0000004 nozzle was hot-fire tested for three successful 5-second duration periods. Subsequent hydrotesting (after removal of the fiber-glass wrap) revealed only 3 small internal leaks.

During hydrotest of S/N 0000010 NRX-A1 ported nozzle, the tubing buckled inward around one light port at 1040 psig. Fabrication of hybrid nozzle S/N 002H was completed and made ready for hydrotest.

October 1963 Fabrication continued on (8) cast aluminum jacketed nozzles and (3) steel jacketed nozzles.

S/N 0000010 NRX-A1 nozzle - Stiffener bars were added to the tubes adjacent to the view ports. Leakage occurred during the subsequent hydrotest and attempts are being made to reduce the leakage to an acceptable level.

S/N 0000011 NRX-A1 nozzle - Following the tube deformation on nozzle S/N 0000010, the view port area tube support mechanism was redesigned to support the tubes at all points. This was incorporated in the design of NRX-A1 nozzle S/N 0000011. The jacket was poured using a special gating system to increase the rise rate of entering metal above the throat. X-ray films established that the jacket was free of sponge, but it did contain moderate to severe round gas porosity. An improved method of detecting gas in the melt before pouring is being implemented.

November 1963 Fabrication continued on (9) cast aluminum jacketed nozzles and (3) steel jacketed nozzles.

S/N 0000010 NRX-A1 nozzle - Testing was performed on several candidate sealant materials to determine the best material for repairing leaks in the nozzle tubes. Two aluminum-powder-filled silicates, an iron-powder-filled epoxy, an unfilled epoxy, and a combination aluminum-powder-filled silicate-epoxy material were evaluated as repair materials by pressure testing at 400 psi and -320°F. The combination silicate-epoxy material was chosen as a result of these tests. The nozzle tubes were repaired using this procedure.

S/N 0000011 NRX-A1 nozzle - This nozzle was rough machine and heat treated. Final machining is approximately 50% complete and no major problems have been encountered.

December 1963 Fabrication continued on (9) cast aluminum jacketed nozzles and (3) steel jacketed nozzles.

NRX-A Nozzle S/N 0000010 - Armstrong C-2 and lithium silicate were applied to the tube leakage area where tubing had pulled away from the jacket. Since the area of leakage could not be well enough defined when applying the sealant, some leakage continued. No additional repair was attempted. The nozzle will be utilized for vibration testing with a propellant inlet line.

S/N 0000011 NRX-A nozzle - Fabrication was completed including hydrotest at 135 psig and the nozzle was delivered to Sub-Subtask 1.1.8 for NRX-A1 non-nuclear component cold-flow testing.

January 1963 Fabrication continued on (6) cast aluminum jacketed nozzles and (3) steel jacketed nozzles.

S/N 0000011 NRX-A1 nozzle - Cold flow tested at LRP. Dropped while handling at LRP - re-hydrotested satisfactorily and shipped to NRDS.

ATTACHMENT E

ACCOMPLISHMENTS UNDER SUBTASK 1.4

Subtask		1963 Exp.	Accomplishments
1.4.0	Thrust Chamber Assembly	$409K	Designed a thrust chamber assembly for NRX-A tests. Designed NRX-A propellant inlet line for both Aerojet and Rocketdyne nozzle. Structural analyses demonstrating adequate bolt design for forward closure bolts were completed. NRX-A2 and A3 TCA design was completed. TCA layout for E-1 Engine was maintained current. Structural analysis of the thrust chamber established dynamic ranges of instrumentation for TCA dynamic test were completed. A non-graphite dummy reactor core was designed and fabricated. Thrust chamber seals were tested and a development problem was found. The seal development was initiated. Dynamic testing of a thrust structure assembly and pressure vessel was completed.
1.4.1	Nozzle Development	$2,017K	A water cooled nozzle adapter for skirt development was designed. A cast aluminum jacket nozzle fabrication problem was identified. Laboratory work to identify alloying constituents in the pour having major influence on the properties of the cast jacket were completed, this extended the state-of-the-art in this field. A development program to improve the elongation and structural properties of the cast jacket was brought to a successful conclusion. The demonstration of wire interlocks as a satisfactory substitute for a metal bond was completed.

Subtask		1963 Exp.	Accomplishments
1.4.1 (continued)			Designs were completed for alternate nozzle design concepts and fabrication initiated on 2 alternate designs. ("U" tube and "J" tube). Nine nozzles were fabricated and processing on 13 additional nozzles carried forward. In addition 4 nozzles were stripped and recast. An injector development program was found to be necessary and initiated for simulation testing of the nozzles. Three nozzles were hot fired to simulate NERVA conditions. This test indicated problem areas to be investigated further. Nozzle chilldown characteristics and heat transfer information was obtained. Preliminary testing of hot bleed port was carried out sufficiently to establish the design of the NERVA hot bleed nozzle.
1.4.2	Thrust Structure and Gimbal Development	$652K	Fixtures were designed and fabricated for static and dynamic testing of the thrust structure. Test plans were completed for the thrust structure static and dynamic tests. Thrust structures and gimbals were fabricated to support the dynamic tests. Resonance tests and static tests were completed on the thrust structure and gimbal.
1.4.3	Pressure Vessel	$802K	The Rocketdyne nozzle-to-pressure vessel joint was analyzed showing satisfactory margin. Aluminum pressure vessels were fabricated to support the component test program. An aluminum pressure vessel was modified for a WANL criticality test. An NRX-A aluminum pressure vessel was fabricated. A program to demonstrate the feasibility of titanium pressure vessels was completed. This effort involved development of sources for large titanium forgings and welding and machining techniques. Thrust chamber seals were procured for the test program.

Subtask		1963 Exp.	Accomplishments
1.4.4	Roll Control Assembly	No expenditure	No work accomplished.
1.4.5	NRX Nozzle	$235K	Two nozzles were completed and one hot fire tested. Other nozzle components were fabricated and diverted to the development program of Subtask 1.4.1.
1.4.6	Applied Research Program	$401K	Investigations were conducted on a forged jacket for the "J" tube and "U" tube nozzle configurations. Stainless steel and selected. Brazing alloys and fabrication techniques were investigated and a final choice made. Materials investigations were carried out on the material for TCA bolts and the pressure vessel. LH_2 heat transfer tests to define the conditions in the nozzle were completed confirming the analysis. Scale model hot bleed port tests were conducted. These data were interpreted in terms of a hypothesis which explains the data in terms of momentum effects. Heat transfer data was confirmed by a model test program confirming nozzle heat transfer conditions. Model tests showed the parameters affecting heat transfer under streaming conditions such as might occur with a cooled metal bottom support plate were completed. Tests showing the reactivity of graphite with H_2/O_2 combustion gases were completed.
1.4.7	NRX-A and Reactor Backup Nozzles	$1,270K	Fabrication of the NRX-A inlet lines was committed. Fabrication of 7 NRX-A nozzles was begun. Modification of 2 units to incorporate a camera and light ports was initiated. One nozzle was complete and hot fire tested. Fabrication of 2 propellant inlet lines was begun. Test planning for acceptance test of the Rocketdyne nozzle for use on NRX-A was carried out.
1.4.8	Hydrotest Program	$42K	A hybrid NERWI nozzle and ACFI pressure vessel were instrumented and pressure tested. The results confirmed the analysis made.

ATTACHMENT F

ACCOMPLISHMENTS UNDER SUBTASK 1.6

S/S/T	Total $ Expended	SMM	HMM	Material $	Goals or Objectives	Accomplishments
1.6.1	251,378	78.8	67.5	18,099	1. To study FRACTURE MECHANISMS associated with fragmentation of graphite materials. 2. To obtain MATERIAL CORRELATION data relating crude graphite simulant materials to accurate geometry & composition fuel elements.	1. Prime core fragmentation mechanism indicated to be mechanical inter-action between elements and structures - not explosive shock effects except close to detonation center. 2. Equivalent energy input results in greater fragmentation of B-4 type unfueled element than AGS x 3/4" diameter solid simulant rod. 3. Material correlation at temperatures indicated additional tests not warranted on simulants. B-4 material (GFE) not received in time.
1.6.2	35,149	3.84	.1	25,261	1. To construct & develop a TEST FACILITY at the Garfield Flats area near Hawthorne, Nevada to support the test and development program for an ACDS and PODS.	1. Security Guard service was provided. 2. Two temporary trailers were provided. 3. H-NAD funding was provided and used to a. Grade test area approaches. b. Prepare two 300' diameter test pads.

S/S/T	Total $ Expended	SMM	HMM	Material $	Goals or Objectives	Accomplishments
1.6.2 (Cont'd)						4. The Garfield Flats Test Site was fully utilized for the performance of scheduled tests under adverse weather and working conditions even though all of the support facility items were not completed or even furnished.
1.6.3	64,427	20.7	19.0	6,967	1. To determine the effects of radiation on certain selected explosives.	1. A five phase program for investigating the effects of radiation on explosives and detonators was formulated (in conjunction with P.A. & G.E.).
						2. A radiation facility was identified for performance of this work (GETR at Vallecitos, California) & test reactor modifications indicated.
						3. The capsule to contain the explosive for the irradiation tests was designed, developed and brought to the point of its qualification.
						4. The Phase I planned radiation effects on explosive experiments were not accomplished because of the delays encountered in negotiating a subcontract with G.E. Corporation for use of the GETR facility at Vallecitos, Calif.

S/S/T	Total $ Expended	SMM	HMM	Material $	Goals or Objectives	Accomplishments
1.6.4	560,389	109.0	163.7	132,403	1. To determine feasibility of explosive technique. 2. To compare and evaluate a number of candidate ACDS. 3. To determine the configuration of a candidate ACDS for an EJECTABLE and a NON-EJECTABLE ACDS. 4. To complete preliminary design and integration studies of a selected most promising EJECTABLE ACDS concept.	1. The feasibility of using explosive techniques as an Anti-criticality countermeasure was demonstrated. 2. A number of ACDS concepts were screened and their performance evaluated against simulated engine targets. 3. The Mark A (Mod 1) concept was selected as the most promising EJECTABLE ACDS and the Mark D as the NON-EJECTABLE ACDS indicating the bi-functional capability of a Mark D PODS. 4. Design and integration studies were completed for the Mark A EJECTABLE ACDS concept.
1.6.5	441,635	79.9	119.6	142,715	1. To determine feasibility of explosive technique for Post-Operation Disposal. 2. To compare and evaluate a number of candidate PODS. 3. To select a candidate PODS for further parametric development.	1. The Mark D internal burster explosive projectile concept, in a test at APG, with 1/4 target core utilizing depleted B-4 elements provided extremely encouraging results (52% < 1/32" and only 0.03% > 1"). 2. A number of PODS concepts were screened and their performance evaluated against simulated engine targets.

S/S/T	Total $ Expended	SMM	HMM	Material $	Goals or Objectives	Accomplishments
						3. The Mark D PODS concept was selected for further parametric development.
						4. Design studies & investigations beyond the scope of work were undertaken in the areas of mechanical feasibility, system integration and component design.

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PASADENA, CALIFORNIA 91109

DIVISION OF ENGINEERING
AND APPLIED SCIENCE

19 February 1964

Mr. W. C. House, Vice-President
Aerojet-General Corporation
Azusa, California

Re: Evaluation of SNPO. Comments re NERVA program.

Dear Mr. House:

Subsequent to our recent telephone conversation I discussed various aspects of the SNPO comments in Mr. N. Slater's office with him, Professor Rannie, D. Nickerson, D. Holzmann and H. Bornemann, all of REON, at some length. Later I had further telephone conversations with Mr. J. Farquahr of the rotating machinery group L. R. P. Sacramento and again with Mr. Bornemann of REON. My impressions of all this, the SNPO evaluations and comments by REON personnel are contained in the attached report. Unfortunately, they can be no more than impressions as the amount of time involved in getting more detailed and substantive information is prohibitive now. Nevertheless, I hope you find them of some possible use.

Because I had some slight prior knowledge of the NERVA pumping problem and because I am more familiar with this type of engineering in general, I have limited my comments to sub-task 1.2, the propellant feed system.

Sincerely yours,

A. J. Acosta
Associate Professor of
Mechanical Engineering

AJA:rt
Encl.

Remarks on S. N. P. O. Comments on Sub-Task 1. 2

The S. N. P. O. report is really in two parts: a more-or-less overall statement on technical and administrative matters; and a detailed review of technical performance by sub-tasks. The tenor of the comments in the first portion are very strong; e. g., the remarks of page 6--whereas those of pages 1 and 2 of the detailed evaluation are not nearly as severe. The following remarks are directed toward evaluating these comments as they pertain to sub-task 1. 2. The evaluation comments of Mr. H. N. Bornemann document well the various technical directions issued by S. N. P. O. to R. E. O. N. As a result of studying these, and discussing the development of the turbo-pump with a few of the personnel of Aerojet-General Sacramento and Mr. Bornemann, a number of points have emerged:

1. The NERVA turbo-pump is the result of a long, gradual evolution of changing conditions and requirements.

2. At all times throughout this evolution SNPO was kept fully acquainted with all technical and design problems encountered.

3. It appears that SNPO participated in the technical design process to a high degree. In addition, it directed REON to adopt certain mechanical and hydraulic design features which had a major outcome on the development of the feed system.

On these bases it appears to me that SNPO must certainly share the responsibility for the present design and status (good or bad) of sub-task 1. 2. Clearly, many of the features of Mk IV insisted on by SNPO are--as is put by C. C. Ross--"designers choice". It is possible--even probable--that in some cases REON did not insist sufficiently on its own "design choices

One of these seems clear: the substitution of the developed Mk III bearing system for the balancing piston of Mk IV. Undoubtedly both systems will or can be made to work well, but REON should have resisted this change more vigorously, as this SNPO directive undoubtedly greatly lengthened the development time and increased the costs of the Mk IV unit. In any case, it is hard to see how REON can be accused in this instance of "insufficient foresight . . . . " as they were in fact following the technical direction of the customer.

Another area subject to various possible technical interpretations is that of the negative-slope design criterion for the pump. Now, it is by no means necessary that a pump always have a negative slope for stable operation. However, in some hydraulic systems, a downward sloping characteristic may be necessary for stable operation while in others even a negative slope may not absolutely guarantee stability. To my knowledge no criteria for stable operation of the proposed feed system are extant (although REON is now addressing itself to this problem). It may well be that the proposed Mk IV turbo-pump design will satisfy the negative slope directive, as the designers believe it may. In any event, the necessity of the negative slope is not yet clear, although I will agree that it is usually a desirable one to have. Because, however, of the importance attached to this point in the "comments" it should be recognized here that this requirement may not actually be needed. In any event, technical direction on this point was issued in April 1963, and subsequent hydraulic design approval by SNPO was granted in August. Thus, while the necessity of this provision is not, in my view, established, REON certainly complied with it insofar as this can be judged without actual test.

I can see no reason, therefore, that this portion of the task be judged as below normal. Probably REON could have been more active in setting up system analyses to investigate this question. Without, however, the results of such work available it becomes arbitrary to specify any particular characteristic slope of the pump.

In view of these remarks and in the close and continuous involvement of SNPO in all phases of this work, it is difficult to understand the assertion "performance appreciably below normal". The development of a complex system containing a great many unknowns of a hydraulic and mechanical nature is obviously difficult and requires an immense background of a technical and industrial nature such as that possessed by the contractor. In the past, certainly, Aerojet-General has made greater contributions to the art of cavitating radial flow pumps than any other single company or agency and are therefore particularly well qualified for this type of work. From studying the SNPO comments, the evaluations thereof, my own observations at Aerojet-General Sacramento, and general knowledge of the field, I would conclude that the technical performance under this sub-task has been generally satisfactory. I would also conclude that SNPO has been as deeply involved in the hydraulic and mechanical design decisions as the contractor.

A. J. Acosta
Assoc. Prof. of Mech. Eng.
California Institute of Technology

19 February 1964

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Corporation, or the sponsoring agencies of the NERVA program (AEC and NASA) or the Space Nuclear Propulsion Office. The report is solely an assessment of the evaluation system as it was developed and applied.

SUMMARY AND CONCLUSIONS

Summary and conclusions will be broken down into three sections. The three sections of the body of the report are identical.

1. Desirable features of an evaluation system for research and advanced development efforts. We have outlined the requirements for a satisfactory evaluation system for projects of the magnitude and in the development stage of the NERVA program. These include (a) the identification of objectives and agreed-upon standards; (b) the development of appropriate methods for comparison at a particular stage of the development process; (c) the dissemination of the standards as a means of accomplishing unity of direction; (d) the recognition of the consequences of failure on the enterprise.

2. Development of the NERVA evaluation system. The development of the evaluation system is discussed in this section. The system was founded by a top level oral agreement to utilize financial incentives and was finally defined and applied in the final evaluation report.

3. The NERVA evaluation system as applied. This portion of the report reviews the apparent application of the system. Since the system was under development for the entire contract year, its application consequently changed over the year. The final nature of the system was revealed to Aerojet at the same time Aerojet received final ratings under the system. The NERVA evaluation system does not contain the desirable features of

such a system. It shifts from a statement of intention to determine a basis for an award fee to an extensive system which evaluates the qualitative performance on a development program. If the method of weighting and scale values were made explicit, in the system, it would then be considered adequate and have value in application.

SECTION I

FEATURES OF AN EVALUATION SYSTEM FOR RESEARCH AND ADVANCED DEVELOPMENT EFFORTS

Any program which is to be evaluated must have its objectives spelled out in reasonable detail in advance and in such terms that standards can be set and measuring sticks devised. This applies equally to development as well as production programs - only the exactness of the standards vary. If the program lends itself to qualitative evaluation only, this can be determined at the outset. If the program is to be evaluated on the basis of functional objectives, time, cost, and reliability, these must be identified before the program or evaluation period is begun. Some programs imply or depend upon technological advances of a qualitative nature. These advances must be identified and agreed upon.

The method by which such a program is to be evaluated must be made explicit. This includes factors such as the scale values or ranking of qualitative objectives. If the results of the evaluation are to have significance, either monetary or in the form of a rating of competence for the use of future selection boards, the impact of scale values on these results must be described in advance. If the program is likely to be altered during the evaluation period, the evaluation system must be designed to accomodate changes in order to permit the contractor to adapt. An evaluation system must be appropriate to the type of program to be evaluated. For example, a program which requires the development of new relationships cannot be evaluated in the same way as a program for which there are few technological constraints to be accomplishment.

The evaluation system must be agreed upon in advance by the evaluator and the group being evaluated.

Significant tasks among large groups of tasks must be highlighted and weighted in advance so that they are not relegated to the level of less significant but equally required tasks. Standards and evaluation methods must be disseminated widely in the enterprise among the evaluators in advance of their use in order to insure equitable application. The evaluation system must be applied sufficiently early and often to provide feedback to the group being evaluated and in time to permit redirection of effort, funds and time schedule.

SECTION II

DEVELOPMENT OF THE NERVA EVALUATION SYSTEM

The NERVA program is a complex research, advanced design, and development program in which many of the subsystems could only be described at the beginning of the program in functional terms at best.

Very early in the first stage of the NERVA contract, at a meeting in Washington in November 1961, The Honorable James Webb, NASA Administrator, asked Mr. W.E. Zisch, then Executive Vice President of Aerojet General Corporation, to consider the use of an incentive program on a part of the NERVA contract. Mr. Zisch was receptive to this request, and on 7 December 1961 (Reference 1) submitted his company's thinking on criteria and evaluation measurement scales. At that time, Mr. Zisch understood that an evaluation of one contract period would be used to determine a fixed fee for the following period, with a small possible range of fees during early development, but with a substantial variation possible for a later stage of the process.

During the succeeding year, NASA and AEC proceeded with the development of an evaluation system, and Aerojet provided suggestions at several points. During the latter part of the negotiations for the contract year beginning 1 October 1962, a spokesman for SNPO indicated the following features of the evaluation scheme (See Reference 3):

A. It was a trial for CY 1963 only, and was not intended to establish a precedent.

B. NASA and AEC had decided that the incentive was to be subjective, the amount discretionary and unilateral.

C. Incentive arrangements would meet the objectives of a good incentive arrangement, and yet would recognize the complexities of the program to be evaluated and the joint agency arrangements.

D. It was anticipated that performance would be evaluated by a joint group representing NASA and AEC management, with a final evaluation at a very high level.

E. Criteria for evaluation would not be cited in the contract but would be discussed on a general verbal basis with the contractor.

Aerojet management agreed to the evaluation scheme as stated. In a letter dated 6 November 1962 (See Reference 4), Aerojet indicated features which they thought appropriate to an evaluation system. In the same letter, though, Aerojet agreed to the SNPO unilateral and discretionary system.

Article IV in the contract modification for the period to be evaluated (See Reference 5) provided for an evaluation as follows:

A. Periodic evaluation of Aerojet performance by quarter

B. Final evaluation at the end of the contract year

C. Determination of fee by written unilateral action of the government, to be binding on the contractor

D. Provision for the contractor to provide additional material and data prior to fee determination

E. A Provisional fee, with the possibility of increase or decrease. Maximum fee predicated on exceptional performance. Minimum fee associated with minimum acceptable performance required in the performance of the contract.

After the contract year was four months old, and just before the results of the first quarter evaluation were provided to the contractor (Reference 6), an official statement was issued on evaluation criteria. It was noted that changes or additions to the criteria might be evolved, and that these changes would be indicated to the contractor. In addition, it was indicated that the final evaluation of performance and the determination of the total amount of fixed fee to be paid would be accomplished by a board designated by the General Manager-AEC and the Associate Administrator-NASA.

On February 12, 1963 (Reference 7) the government forwarded the first quarter evaluation. In the same letter additional information about the evaluation system was provided as follows:

A. Evaluation was done on a subtask by subtask basis, evaluating technical performance, schedule performance and administrative performance, previously defined for the contractor (Reference 6).

B. The evaluations were made by a large number of cognizant government personnel, and were screened by supervision to insure overall accuracy.

C. Overall technical performance was evaluated by combining separate subtask evaluations with appropriate weighting factors (not given) to adjust for the magnitude of the effort required for each subtask. Categories were: "Normal", "above normal" and "below normal". For the first time, the contractor was informed that "normal is defined as that which a contractor qualified in his field of endeavor would be expected to perform...."

D. Overall schedule evaluations were made by reviewing PERT networks and milestone charts.

E. Administrative performance would not be rated by comparing subtask costs with expectations, because of the way costs were accumulated, but were rated in another manner not specified.

On May 14, 1963 (See Reference 10) the government forwarded the second quarterly report, along with new information about the system as follows:

A. Administrative performance for the second quarter could not be rated by a direct comparison between actual costs and expectations because of a change order in the contract. It was therefore by indirect means.

B. Overall performance for the second quarter was established by combining over 100 separate evaluations (35 subtasks; three rating categories) with appropriate weighting factors (not stated).

In a letter on August 14, 1963 (Reference 1) in which the third quarter's performance of Aerojet was evaluated, new categories of evaluation appeared: "slightly below normal," "significantly below normal," "somewhat below normal."

The fourth quarterly report was dated December 19, 1963 (Reference 15) and arrived simultaneously with a final report of the same date (Reference 16). In the fourth quarterly report, information was provided that since the annual evaluation "currently being prepared offered better information for Aerojet for redirecting their technical effort, only brief comments would be made. A new category of evaluation appeared: "appreciably below normal."

The final annual evaluation report contained significant additional information about the evaluation system. The following excerpt illustrates this fact:

"Subtask evaluations tend to measure the performance of individual groups, project leaders and project sponsors within the contractor's establishment. The technique insulates these individuals from circumstances which affect their progress but over which they have no control. For example, it is possible to arrive at a normal or above normal rating in a given subtask because of competence and diligence demonstrated, even though the work assigned to this subtask has been in complete because of the failure of a related subtask to supply necessary hardware or technical input. While the subtask evaluation is useful in assigning credit or blame where it is deserved simple averaging of the individual evaluations tends to overstate the progress on the overall objectives of the contract. Accordingly, in order to take proper cognizance of the dominating or controlling effects of the several areas in which insufficient progress has been made, the contractor's performance was also assessed on the overall basis indicated above. Both the detailed and the overall assessment were considered in arriving at the final combined evaluation."

A statement concerning the relative importance of subtasks appeared for the first time in the final evaluation:

" When reviewing the prime contractor's overall technical performance from the standpoint of a somewhat broader perspective, it becomes evident that the prime contractor's most major in-house design and development responsibilities involve the design and development of a suitable NERVA turbopump assembly and the design and development of a suitable NERVA exhaust nozzle. It has been known from the very beginning of the program that the proper design and development of these major assemblies is a prerequisite for the achievement of a NERVA engine..."

SECTION III

THE NERVA EVALUATION SYSTEM AS APPLIED

The documents reviewed indicate that Aerojet originally agreed to a unilateral and discretionary evaluation by SNPO to be submitted to a joint AEC-NASA board for the purpose of determining an award fee.

Nowhere in the original contract documents or correspondence before the first quarterly evaluation did there appear (by examination of references) the notion that the evaluation was a performance rating of Aerojet as a research, development and engineering organization.

Beginning with the submission of the first quarterly report, changes in and expansion of the evaluation system were continuous to and including the final evaluation. The following are detailed observations of the system application:

1. The objectives of the program were not spelled out in detail in advance. The contract calls for a "best effort" The evaluations were performed on schedule, cost, and technical performance factors against estimates made in documents submitted by Aerojet, but which were not part of the contract.

2. Standards of performance were not set in advance. Because of the redirection (in the form of contract changes) cost standards could not be evaluated by subtask during the first two reporting periods of the contract.

3. In the first written information (insofar as the documents indicated to the writers) on the evaluation system supplied by SNPO to Aeroject, after the contract year was one-third over, areas of evaluation were indicated, but no standards spelled out. The impact of the evaluation on the determination of the fee was not indicated to Aerojet.

4. The evaluation method shifted and expanded at each stage of evaluation. While the contractor made changes in his program based on the comments in each evaluation, subsequent evaluation did not take into account his changes. The net effect (as shown in the references) was an evaluation base which shifted each quarter.

5. The appearance in the first quarterly report of the notion of "normality" with ratings of "below normal" and "normal" and "above normal", represents the first indication to Aerojet that a qualitative judgement about the work and what was expected in performance was to be made.

6. During subsequent reports, other adjectives modifying "normal" appeared, including "appreciably", "slightly", "somewhat", and "significantly." Without a key to the relative significance of these adjectives, direction

and redirection of the contract tasks would be difficult. Is "normal" the accomplishment of all tasks, on schedule, within funding limits, at or above stated levels of reliability, and with functional excellence? Normal performance is generally the result of an optimum trade-off among the above factors to minimize the effects of unexpected problems and redirection. If one generally compares contractor performance against originally stated requirements, in any early design and development effort such as the NERVA program, he must conclude that "normal" really falls somewhare between allowed cost, stated reliability, total functional performance and on-time schedule accomplishment and total failure. Generally this "somewhere between" is the effect of the degree to which the effort is conceptual in nature, and the degree to which the effort is redirected by the sponsor.

7. SNPO's quarterly evaluations indicated a methodology based on the study of three types of performance by subtask. The relationships between the three performance categories and the 35 subtasks over the first nine months of the contract year provided the contractor with inferences about the bases of evaluation. However, the final government evaluation introduced a new element into the previously defined methodology; the "overall assessment" factor. Since the quarterly reports constituted feedback upon which the contractor identified his progress, it was not consistent with good methodology to introduce a new factor after the contract period had expired. The new factor of "overall evaluation" turned out to be significant in its impact on the final judgement of the contractor's performance.

8. In addition to introducing the new element of overall evaluation at the end of the year, it was only in the final report that the evaluator explicitly pointed out that SNPO and Aerojet entered into a project in which two out of many subsystems, the turbopump and the exhaust nozzle, constituted the primary constraints to accomplishment. This type of program can not be considered definitive, or one in which hoped-for results could be specified in a way to assess performance in quantitative terms.

9. Explicit information was not given to Aerojet on the actual weighting factors for the magnitude of the different tasks, or on the scale values. On the other hand, Aerojet did not (to the writer's knowledge) raise any questions about these items during the term of the contract, when this information might have been effective in producing performance more in line with that expected and desired by SNPO.

10. Aerojet entered into the contract with one understanding, that the purpose of the unilateral evaluation was fee determination. In the final evaluation, the reference to the usefulness of subtask evaluations for "assigning credit or blame where it is deserved" and the ratings of "normal" and their variations seem to be quite far from the original purpose. Such a rating could have an undesirable impact on selection boards in future procurements.

The above considerations have led the writers to conclude that the features of an effective system for the purpose described in the contract were not met in the application of the evaluation system to the NERVA program.

By the end of the contract period, however, the definition of the evaluation system as described in Section II, above, began to mold it into a useful system for evaluation. The addition of explicit weightings of subtask magnitudes, and the provision of scale values and their interpretations as they would affect the size of the incentive fee, combined with the extensive dissemination of the standards and their impact on the contractor and the evaluator organizations, could provide a system which would be useful in directing future developmental effort and in assigning an incentive fee.

Respectfully submitted:

L. Glen Strasburg

3 March 1964

John V. Zuckerman

REFERENCES

DOCUMENTS EXAMINED

1. Letter W.E.Zisch, Aerojet, to Honorable James E. Webb, NASA, 7 December 1961, referring to Webb's request for Aerojet's contribution to a "...basis for determining fee on subsequent increments of the contract relating to performance on the prior contract period.

2. Letter, W.C.House, Aerojet, to Robert W. Schroeder, SNPO, 6 July 1962, furnishing "preliminary comments regarding the inclusion of incentive provision contract SNP-1 during Contract Year 1963."

3. Transcript of remarks made by a staff member of SNPO during contract negotiations between Aerojet and SNPO, dated 19 September 1962, dealing with fee and evaluation approach agreed upon by NASA and AEC for contract year 1963.

4. Letter, G.L.Ryland, Aerojet to J.L.Wilson, SNPO, 6 November 1962, presenting "information in support of a proposed standard fee..."

5. Extract of Modification 6, Contract SNP-1, containing article IV - "Estimates of Cost, obligation of funds and fixed fee."

6. Letter, Robert W. Schroeder, SNPO, to Glen L. Ryland, Aerojet, dated 28 January 1963, subject "Incentive Criteria".

7. Letter, R.W.Schroeder, SNPO, to W.C.House, Aerojet, dated 1? February 1963, forwarding "the government evaluation of the performance of the prime contractor for the period 1 October 1962 through 31 December 1962."

8. Letter, G.L.Ryland, Aerojet, to R.W.Schroeder, SNPO, dated 28 March 1963 acknowledging SNPO evaluation and notifying SNPO that additional data will be brought to government's attention.

9. Letter, W.C.House, Aerojet, to R.W.Schroeder, SNPO, dated 19 April 1963, providing additional data referred to in letter of 28 March 1963.

10. Letter, R.W.Schroeder, SNPO to W.C.Hluse, Aerojet, dated 14 May 1963, forwarding "the government evaluation of the performance of the prime contractor for the period 1 January 1963 through 31 March 1963.

11. Letter, C.H.Trent for W.C.House, Aerojet, to R.W.Schroeder, SNPO, dated 28 June 1963, providing additional data.

12. Letter, R.W.Schroeder, SNPO, to W.C. House, Aerojet, dated 3 July 1963, acknowledging receipt of comments and indicating an error in Schroeder's letter to House dated 14 May 1963.

13. Letter, R.W.Schroeder, SNPO, to W.C.House, Aerojet, dated 14 August 1963, forwarding "the government evaluation of the performance of the prime contractor for the period 1 April 1963 through 30 June 1963.

14. Letter, C.H.Trent for W.C.House, Aerojet, to R.W.Schroeder, SNPO, dated 26 October 1963, providing additional data.

15. Letter, R.W.Schroeder, SNPO to W.C.House, Aerojet, dated 19 December 1963, forwarding "the government evaluation of the prime contractor for the fourth quarter of the 1963 Contract Year, covering the period from 1 July 1963 through 30 September 1963.

16. Letter, R.W.Schroeder, SNPO, to W.C.House, Aerojet, dated 19 December 1963, forwarding "the government evaluation of the performance of the Aerojet-General Corporation for the 1963 Contract Year covering the period from 1 October 1962 through 30 September 1963.