FINAL REPORT

Support to NASA's Advanced Space Technology Program

Reference: Purchase Order # H-31405D Mod 02/03

December 6, 2000

Lee & Associates, LLC

Final Report

Reference: PO # 31405D, Mod 02/03

Introduction

During the period of May through September 2000, Lee & Associates, LLC completed the following tasks as specified in the purchase order SOW:

- Assessment of current processes and structure and recommended improvements
- Reviewed and commented on restructure options
- Participated in closure of the Fastrac Delta Critical Design Review actions,
- Participated in the Fastrac Test readiness review(TRR) process for test planned at SSC and Rocketdyne
- Participated in the investigation of any anomalies identified during the Fastrac engine test data reviews

These tasks were accomplished through the efforts of Mr. Otto Goetz, Mr. John Thomas, and Mr. Thomas J. Lee representing Lee & Associates, LLC. Due to the program demands for immediate responses, the results from the various reviews were made in real or near real time directly to Fastrac project representatives during meetings orally or in written reports. Following is a listing of the major reviews in which representatives participated from May through September 2000.

- Test Readiness Review(TRR) for RA-01, 5/8/00
- Fastrac Engine Test Plan Assessment, 5/26/00 (attachment # 1)
- Red team review of restructured X-34 Proposal, 5/31-5/1/00 (attachment #2)
- TRR for R2-1, 7/10/00
- Monitor R1-2b static test, 7/12/00
- Monitor R1-2b static test, 7/18/00
- Review MSFC/OSC Contract NAS8-40887, 7/2700 (attachment #3)
- TRR for R2-1, 7/27/00
- Delta TRR for test R2-1, 7/28/00
- TRR for MC-1 test R2 Series and R2-2, 8/3/00
- Delta TRR for MC-1 Test R2-2, 8/9/00
- TRR for MC-1 test R2-3a, 8/16/00
- TRR for MC-1 test R2-3b, 8/25/00
- TRR for MC-1 test R2-3b, 8/30/00
- TRR for test R2-4, 9/6/00
- R0,R1&R2 Test Data Review, 9/22/00 (attachment # 4)

ATTACH #1

To: Mark Fisher

From: T. J.Lee

Subject: Fastrac Engine Test Plan Recommendations, May 2000, Review

Reference: Meeting on May 26, 2000 to Review of The Fastrac Engine Test Plan Recommendations

Date: May 27, 2000

The referenced meeting was held at MSFC for the purpose of having representatives of Lee & Associates review and comment on the subject Plan Recommendations. Mr. Mark Fisher, Mr. Mike Ise et al represented the X-34/Fastrac Project Office and Mr. Lee , Mr Goetz and Mr Thomas represented Lee & Associates.

Since time did not permit a complete review of the briefing material, it was requested that other comments that may be appropriate after further study be included.

It should be noted the Fastrac Engine Test Plan Recommendations presented for review were limited to a high level schedule and in the amount of details supporting the briefing material. Therefore, the following comments should not be considered as all inclusive and in sufficient detail to correct all planning deficiencies.

1. Test hardware availability: It was stated in the meeting that there was limited spare hardware available to support the test plan, that the spares were on the "back end" of engine build needs, and that cannibalization would the necessary. It is axiomatic that cannibalization is not an accepted practice as it is likely to slow both the test and production schedule.

   Recommendation: It is recommended that the Project develop a projected spares utilization list for both planned and optional tests based on historical data. Using this spares requirement and projected availability, determine the impact on the planned (and optional) test schedule and engine build schedule. The result of this analysis may suggest that additional funds may be required for more hardware if the test and flight schedules are to be achieved.

2. System and component test facilities and geographical locations: As understood during the meeting, there will be tests conducted on the engine at SSFL, on the MPTA somewhere else, on components at MSFC, on some type cold-flow on Vehicle A2 at yet another location, and on PTA at E2-Cell2 at SSC. Experience has shown that it has been difficult for MSFC to support testing at one facility; and therefore a major question exists concerning the X-34/Fastrac Team's capability to support such a test program particularly considering the new roles and responsibilities in the restructured Program.

Recommendation: It is recommended that parallel testing resource (manpower and facilities) requirements be well understood and that a detailed plan be developed demonstrating how it is possible to support the residual parallel testing.

3. Verification philosophy: The verification phase appears to take on an artificial meaning when one reviews the objectives and approach. The first stated objective is to "verify requirements not met in development" and the approach is "separate phase from development due to aggressive schedule and man power shortage". Ideally, the verification phase is to verify that two engines meet the design and performance requirements. It appears that the verification phase here is a continuation of development called verification.

   Suggestion: It is suggested that the objectives and approach be modified to stand alone for a verification program.

4. Certification philosophy: It is shown that one objective of certification is to "define engine-to-engine variation". Is does not seem practical to demonstrate this variation in a statistically meaningful way due to the small sample size of engines to be tested.

   Suggestion: Change the objective to read "gather data toward defining engine-to-engine variation".

5. Performance approach – The approach does not contain one of the most important factors in demonstrating total system performance.

   Recommendation: It is recommended that the project include as part of the approach and success criteria that the engine be tested with the X-34 induced start and run boundary conditions simulated as accurate as possible.

6. Performance approach, nozzle LRU: It was apparent from discussions during the meeting that the Project has decided to test the engine for some number of seconds preflight and change the nozzle before flight. This decision seems to fly in the face of high reliability in that the engine's integrity is demonstrated under the most realistic conditions and then all the just-verified connections are disturbed to change the nozzle. This not only affects reliability, but it also is a significant economic factor in total Project cost.

   Recommendation: Initiate through a dedicated team study the advantages and short comings of the proposed acceptance tests:
   a) a 24 second acceptance test without nozzle change out, and without a full duration (159 seconds) test exposure of the remaining hardware i.e. turbopumps, GG's , etc.
   b) a 159 second acceptance test with subsequent nozzle change out which requires breaking x number of joints and flying an untested nozzle.

c) To test all hardware using a slave nozzle for 159 seconds and test the same hardware tested hardware for 24 seconds with the actual flight nozzle.

7. Performance approach: There is no mention of pogo/combustion stability verification.

   Recommendation: This was discussed considerably during DCDR and should be resolved before the Test Plan is finalized.

8. Margin approach: It is suggested that considerable attention be devoted to establishing the margins to be tested and that both specification values and test experience be used to set the test parameter extremes. It is also suggested that consideration be given to some testing near the end of the development phase devoted to exploring the limits to which the engine can perform successfully.

9. Sequence approach – It is not evident that the Delta CDR RID/Action to increase the He available to Fastrac for spin start has been adopted.

   Recommendation: The results of this decision must be a part of the SSFL testing from the beginning.

10. Inlet effects approach – The approach states "understand engine to engine variations (1 development / 1 verification)".

    Comment: It is doubtful that one can discern much about engine to engine variations from just two engines.

11. Gimballing approach – It is stated that gimbal verification is still being assessed. This is a major functional requirement the influence of which can propagate into increased stress levels in many areas.

    Recommendation: This issue should be resolved immediately before system level test facility configuration becomes frozen and very expensive to change.

12. Integration/ system/component test planning: There are no component or integration tests included in this Test Plan and therefore it is difficult to determine the relationship between the three levels of test.

    Recommendation: It is recommended that this Plan be revised or a new one developed to integrate the Project test planning and control including MPTA.

13. Negative structural margins: It does not appear the test plan was closely coordinated and structured to address the open Negative Structural Margins.

Recommendation: Identify the remaining open negative structural margins and address each in the test plan with special emphasis on the required special instrumentation, both on the engine and the supporting test facility. The Alpha facility has less high frequency special data recording capability than SSC , therefore, clear advanced planning and coordination is required in order to obtain the data on a schedule that supports the completion of development by May 2001.

14. Rocketdyne Test Support: The Fastrac schedule success is dependent on the Rocketdyne test support in the Alpha facility where the Fastrac engine may be competing with the RS 27 for test support.

    Recommendation: Have a clear documented understanding with Rocketdyne in regard to their timely support to the Fastrac testing with advanced mitigation planing for potential conflicts. Consider incentivizing the Fastrac testing at the Alpha facility.

15. LOX Inducer: Only two rather late tests (R6-6 & R6-7) appear to be dedicated to the LOX inducer problem, which does not allow for any configuration or inlet condition iterations.

    Recommendation: Present a matrix of potential solution to the inducer vibration problem, i.e. inducer redesign, housing redesign, inlet pressure change, inlet line configuration, etc. and assess the adequacy and timeliness of the supporting test plan to address more than one solution.

16. Engine Support Hardware: It did not appear that there is a complimentary detailed plan and requirements document for the required test support engine hardware.

    Recommendation: Generate a complementary hardware requirements document that clearly delineates to all supporting program elements the hardware need dates to support the test plan. Start contingency planning for backup hardware, i.e. if possible have an assembled turbopump on stand-by.

ATTACH #2

TO: T. J. LEE

FROM: JOHN W. THOMAS

SUBJECT: RED TEAM X34 RESTRUCTURE

DATE: MAY 31, 2000

Per request of Mr. Mark Fisher, MSFC, Otto Goetz and I attended a meeting where Mr. Fisher presented his X-34 restructure proposal to a Red Team chaired by Chris Singer, Mr. Row Rogacki, and others in Building 4203 R6002 on may 31, 2000. We did not receive a copy of the briefing material and due to an opening statement regarding the sensitivity of the information, I did not request a copy. The Red Team along with the other participants seemed to see the briefing package in real time and were not privy to what was described to be a large amount of supporting information. Therefore, some of the comments and recommendations below could be negated by existing information. The following is a combination of Otto's and my comments:

1. Mr. Fisher presented one chart that was not a part of the briefing material handed out dealing with open items (8) related to the restructured proposal. Any one of the open can make a significant difference on the bottom line cost and schedule of the proposal. In addition, there was a final chart on threats (more on this topic in a later comment) that could also be a major driver. The combination of these open items and threats could dramatically change the restructure impact. It is therefore recommended that the Project assess the open items and probability of occurrence and potential of the threats to bound the possible impact. This results of this assessment should be a part of any presentation to Center or Agency management.
2. There was much discussion about the fidelity and validity of cost impact of six "critical areas" preliminarily estimated to create just over $100M increase in run-out cost, without as I understood, any open items or threats. We did not have access to the derivation of the cost estimates; but, it has been my experience, without exception, that cost estimates done in a manner as this one, that is without preliminary design, detailed integrated planning and schedules, and bought into by the performing elements, have been substantially low. This is particularly true in a restructure type exercise where there is some tacit apprehension of deep-sixing the program. It is believed to be essential that whatever time is need be set aside to gather all the performing organizations and contractors for a session to understand the restructure proposal and then to have adequate time to impact the technical and programmatic implications. It is further recommended that to preserve early schedule time, that the first six weeks or so of the restructure effort be authorized to proceed while this indepth look is being taken.
3. It may be that I am more familiar with the MC-1 project than the X-34, but it appears that the impact definition is swayed toward the MC-1. This leads one to be apprehensive about the depth to which the risks and threats on X-34 have been assessed. It is recommended that OSC, highest management levels,

be instructed to provide the new Project with their top 10 –15 risks and/or threats and compare them to what is formulated in the restructure proposal This should be accomplished before going to MSFC Management on June 9, 2000. In addition, it appears that the list of threats identified to date are not as thorough as necessary to gain a full understanding of safety, cost, and schedule implications. It is recommended that all the product teams and their department management be asked to do the same as OSC was instructed above. Then have a small staff assess the total and assign some level of probability/risk and impact to arrive at a comprehensive list of threats. One such threat that was discussed, but not listed as I recall, is the meager amount of hardware; engines, component, and piece parts; available to the MC-1 test program. It is suspected that a similar condition exists for X-34 vehicle and should be addressed just as vigorously as the engine. It was recommended in our recent assessment of the MC-1 Recommended Test Plan, May 2000, that a list of projected spare hardware required be compiled based on historical data, that is actual usage to date. This list should then be compared to that available and funded in the Project to ascertain the shortfall. It could then be determined how much added cost is necessary to properly support the tests planned or to gage the risks of entering a critical test program hardware poor. It is our belief that more hardware is needed to have any probability of successfully completing the tests anywhere near on as planned. Another threat that was briefly discussed but not listed is the LOX Pump inducer cracking problem. It is not carried as a costed threat and as such could consume a significant of the general contingency shown for the Project.

4. The proposition of transitioning testing from SSFL back to SSC should be approached with caution. The decision to move to SSFL in the first place was made in an accelerated manner much the same as is this restructuring effort. It was the right decision then, but for the wrong expectations. The first test was to be in the first quarter of CY00 based on a November go-ahead. That was an ambitious assertion fostered by a lack of definition and assessment. With this experience, it is recommended that any decision or commitment of moving MC-1 back to SSC be put on hold until a very thorough assessment of cost and schedule is completed based on a detailed transition plan. This assessment should be started now if there is to be any potential gains from moving back to SSC. And, it is understood that some portion of the sentiment to move back to SSC is based on cost and performance at SSFL now. It is my view that this perception is a management issue and can be fixed with assigning the proper personnel with experience and motivation to lead the test effort along with appropriate contractor motivation. It is understood that there are more factors involved in the motivation to move back to SSC for testing, but, it is my view that leaving it at SSFL will remove on giant worry that will distract from the many other urgent tasks necessary to implement this restructure.
5. There are at least three critical areas that have the potential to be show-stoppers; adding a backup avionics system, a new MPT test article and facility, and integrating the MC-1 and X-34. The details of the backup avionics system has not been reviewed, but the implications of adding computers talking to computers

each controlling other elements; software development, verification, simulations, and integration; and ground interaction at this late stage of vehicle development carries with it the potential to consume substantially all contingency. It is recommended that a plan be developed that contains several gates early on where decisions can be reached to proceed or abandon this add-on. The MPTA is now recognized as an essential part of the verification program and will require special attention to bring it to fruition at an early enough time to prevent the potential of impacting the flight hardware with knowledge gained from its testing. In the interest of conserving critical MSFC resources, this effort could be farmed out to SSC since they will be getting that facility ready to accept it anyway. It is recognized that MC-1 and X-34 integration at all levels has lagged individual element development to date. This situation must now be reversed and get integration out front and yet there are no identified resources to do that task. There were some options discussed at the briefing, but it was not apparent that there was any leading candidate. It is paramount that this decision be made now to get the resources

ATTACH #3

To: Mark Fisher
From: T.J.Lee

Subject: MSFC/OSC Contract NAS8- 40887 Review

Date: July 27, 2000

Per your e-mail request, I have reviewed the subject contract and my comments are contained in the following paragraphs.

General comments:

1. I do not have extensive experience with these joint NASA /Contractor Programs but this Contract is a FFP instrument but the provisions and SOW seem to be more oriented toward a cost plus type contract. This conclusion is based on the amount of NASA involvement required of the contractor work and reporting.
2. It is very difficult to determine what is expected of the Contractor from the Contract because there is no deliverable items list and only three-book DRL. Additionally, there are two SOWs that appear unrelated and leave it to the reader to deduce how many vehicles are to be built, the tests desired, and the options that have or have not been exercised.
3. I cannot find any article, clause, or attachment addressing any penalties for failure to complete program objectives or contact SOW. And, you can see from a later comment that only about 7% of the milestones and value of the progress payments are related to flight milestones. This suggests that the program could progress to the flight phase and discover a significant fault after which the contract could be terminated, and all could walk away after expending 90% of the Program funds.

Paragraph G.6: This states that at the conclusion of the Program, all X-34 hardware will transfer to the Government. This is setting the stage for conflict at the time of transfer due to the lack of definition of X-34 hardware. It seems that at least a general definition or category of that which is expected to be transferred would be appropriate at this time.

Paragraph H.2: There is only one key personnel listed. It seems that some technical individual(s) would be listed to maintain some continuity in development, test, and operations.

Paragraph H.7: Third party liability or indemnification has typically been a source of extensive negotiation and impasses. It is surprising that OSC has apparently signed up to no indemnification and reimbursement for 50% of any insurance premium.

Appendix B, Section F Delivery Schedule: It appears that the payment milestone and value are weighted heavily toward hardware milestones, about 53%. Requirements and design, test, and flight related milestones are weighted at 20%, 20%, and 7% respectively. The Project may want to revisit this distribution and shift more emphasis toward successful flight. In addition, the hardware milestones are oriented more toward subassembly and subsystems milestones rather than end item completions. Seems like

more emphasis should be placed on end items or major assembly phases. I have no information on the specified dates for each milestone with which to draw any conclusions.

Attachment J-1, Statement of Work, Scope: As mentioned above, it is very difficult to correlate J-1 and J-1A SOWs to get a composite SOW. It is suggested that the SOW be rewritten to meld the into a more explicit set of expectations that not only sets the vehicle requirements but also addresses the hardware, types of tests, and flight regimes involved.

Attachment J-1, Statement of Work, 1.1 Program Management, Task Description: There are a number of reviews called for in this section and one, a Systems Verification Review, required by J-1A as part of Option Part 2. None of these reviews, as described, require that analyses be delivered (as part of J-8) or presented that show that the vehicle meets all requirements. As stated, only test data review is required at the Systems Verification Review.

Attachment J-1, Statement of Work, 2.1 Configuration Management: There should be a statement added that requires OSC's database to be capable of producing an as built/as flown configuration including serial numbers.

Attachment J-1, Statement of Work, 5.4 Propulsion System, Task Description: There are only two lines that I can find in this contract that address the MC-1 (Fastrac) Engine. One is in this section regarding integration, and the other is in the GFP list. There should be more instruction to OSC on what their responsibilities are versus MSFC, SSC, SUMA, et. al. for the MC-1.

Attachment J-8, Statement of Work, Data List: It is stated elsewhere n this contract that the X-34 Hardware will be transferred to the Government at some time in the future and thus this list should specify the data/documentation that is expected to accompany the hardware when transferred.

It is recognized that contracts are sometimes general in nature to allow for program alteration without constant contractual modifications, however in a FFP instrument such as this one, the scope and expectation should be rather explicit, particularly at this stage of the Program. There may also be other documents, all though not referenced in the contract, that are more explicit regarding program requirements and plans. This practice is good, but in the finality, the contract governs and should be comprehensive.

ATTACH # 4

To: Mark Fisher
X-34 Program Manager
From: T.J. Lee
Subject: Fastrac Tests Data Review Comments and Recommendations
Date: 9/27/00
Ref.: Purchase Order # H-31405,Mod 02

The subject reviews were held at MSFC on September 18 and 22, 2000 to review the data from the engine RO, R1, and R2 test series conducted at the Rocketdyne Santa Suzanna Field Laboratory. Mr. Otto Goetz, Mr. John, and Mr. T. J. Lee represented Lee & Associates, LLC in the meeting. In addition Mr. Thomas participated in all the Test Readiness Reviews(TRR) conducted by the Project Office prior to each test in the series.

This report includes a summary of the more significant observations and associated recommendations resulting from these meetings.

I. GENERAL

A. Observation: It appears the data reviews are conducted in an environment of only examining the data acquired, and in some cases comparing it to predictions. There is seldom any conclusions on how these data effect the course of the project and there is rarely any action assigned for follow-up or to conduct more tests/analysis to resolve poorly understood data. It is not obvious there is a mechanism or methodology in place to address any matter related to the data review. It seems that at the conclusion of the review, all participants depart to prepare for the next test.

Recommendation: It is proposed that each presenter provide conclusions that addresses the significance of the test series and data acquired. This should include but not limited to the following:

1. Project plan or schedule
2. Current design configuration
3. Current test plan
4. Specifications and requirements
5. Engine performance
6. Interface/requirements for X-34

It is suggested the project instruct the presenters for the R2 Series Data Review to submit their conclusions related to the above categories.

B. Observation: There were a number of instances in the Review where the presenter stated the data observed was not as expected and could not offer an explanation for why. Examples are as follows:

1. Unknown decrease in stiff arm strain data during test
2. There is a definite change in the sound produced by the engine at 60 Sec.
3. Turbine inlet pressure is greater than GG Pc.
4. Pressure spike at cutoff

5. LOX pressure at 290-deg. Location much lower than other locations.
6. LOX discharge flange strain oscillations.
7. Two adjacent strain gages reading differently.
8. LOX inlet temperature not as expected.
9. GGOV discharge pressure slump stops at ~ 40 sec.
10. GG Pc dampened at ~ 40 sec.

Recommendation: Each data anomaly or variance must be rigorously evaluated and understood if at all possible. It is suggested the Systems Group initiate a record listing each of these that cannot be explained as " Unexplained Anomalies". This list should be addressed at major reviews like TRR's and later FRR"s.

C. **Observation**: It was reported that the dynamic loads are not as severe as predicted. This leads to the question of if/ when will the loads criteria be revised. **Recommendation**: A plan should be developed to alert all disciplines when revised loads will be forthcoming and how they are to be treated.

D. **Observation**: There was some speculation that it may be necessary to perform two calibration tests before committing the engine to flight. It appears from nozzle performance reports that it will not be necessary to replace the nozzle after the calibration/acceptance test. This would be a substantial safety and reliability improvement as well as a very beneficial economic consideration. Adding another calibration/acceptance test would possibly negate the beneficial attributes of not having to change nozzles before each flight.
Recommendation: Perform a study to determine what would be involved in analytical model enhancement and and/or component testing to assure that only one calibration test is necessary.

II. NOZZLE

A. **Observation**: There was some speculation that cold soaking the nozzle at temperatures below the required level of –90 deg F. may influence the nozzle physical performance. This hypothesis was derived from the fact that the unit used on this test series was inadvertently soaked to –130/177 deg F. and it has demonstrated excellent erosion and bonding performance.
Recommendation: Some analysis and sample or coupon tests should be performed to verify or refute this hypothesis.

B. **Observation**: There appears to be a consensus that side loads created by asymmetric nozzle over expansion are acceptable; however there is a considerable amount of analytical work to resolve the question fully as long as there is still some chugging present during the shutdown transition.
Recommendation: The team should develop a plan to close this issue in the near term so as not to consume valuable resources. This should include the decision on whether another .25 second should be added to the fuel purge activation delay and the effects of the 30:1 nozzle.

III. HIGH SPEED STRAIN GAUGE DATA

A. **Observation**: There were still reports the high-speed strain data necessary to resolve the negative structural margin issue is unusable due to high noise levels.
Recommendation: This should be corrected before further testing is resumed. This has been a continuing problem that has not received adequate Project Management attention. Since it is not clear the noise level can be reduced within reasonable resources with the present facility setup, a safe assumption could be made that the noise amplitude envelopes the actual data and these amplitudes could be used as worst case for the initial analysis. If that analysis shows positive margin, the noise reduction may not be required. For HCF analyses, frequencies would have to be assumed based on structural models.

IV. HYPERGOL IGNITER MALFUNCTION

A. **Observation**: There was a hypergol fire and subsequent fuel leak on R2-4 and the test was allowed to continue to its intended duration. When questioned about test rules or criteria for cutoff for fire and leaks, it was apparent that there were none.
Recommendation: A criteria for the test conductor and any other assigned observers should be developed to specify the action to be taken in the event of fire, leaks, loose equipment, damage, etc. This is even if is to be left to engineering judgement which is not recommend.

B. **Observation:** The main chamber hypergol igniter malfunctioned during one of the test. After removal of the igniter approximately 25% of the TEA/TEB was still in the cartridge post test. It is not clear if this was previously used and/or inspected hardware. It appears the cartridge used was from an outdated configuration.
Recommendation: Clarify drawings and specifications to clearly state the allowable configuration and to delineate the inspection requirements and the accept/reject criteria.

V. PRESSURE SPIKES

A. **Observation**: There have been at least three instances where pressure spikes have been observed in the MCCPc or acoustic cavity pressure, two of which have been attributable to residual fuel present when hypergol entered the TC. The Fastrac Engine Test H4-3 Investigation Final Report recommends: " *Document Detailed Cleaning/Drying/Inspection Procedures to Insure Removal of all Possible RP-1 in the Engine System".* There have been some procedural steps taken to dry the engine between tests but they have been as needed per incident.
Recommendation: 1)The Project should perform a comprehensive systematic analysis of the engine and facility to determine the places where residual fuel

can be trapped and then develop a drying procedure to remove the fuel. This procedure should be performed prior to each test. 2) Appraise every technician and engineer in the Fastrac engine program of the explosive nature and danger of RP-1 when it is jelled by LOX during chill-down.

VI. ENGINE PERFORMANCE

A. Observation: It was reported that the calibrated engine performance would produce an Isp of about 300 to 303 sec instead of the ICD required minimum of 310 sec.
Recommendation: The Project should; 1) ascertain if this performance is acceptable or if a plan is needed to increase performance, 2) before starting any redesign effort examine the accuracy of every measured parameter that is used to calculate ISP and 3) test more engines to acquire more statistical data.

VII. LOX INDUCER OSCILATIONS

B. Observation: The presentation on the unsteady LOX flow phenomena shows that there is still a potentially serious problem with the LOX pump. The analytically based solution to the problem of avoiding the coupling frequency seems tenuous at this stage in the Project, particularly since the influence of vehicle ducting is unknown. Leaving this magnitude of potential problem hanging pending a systems test several months down stream is considered to be a high Program schedule risk.
Recommendation: The Project should develop a risk mitigation or risk management plan that clearly addresses the problem and a logical series of events that culminates in a decision point to accept, manage or fix the condition. It should include parallel actions like limiting the LOX inlet pressure such that the Nss is always higher than ~ 24,000 and tests that would minimize the impact if a redesign fix becomes necessary.

VIII. TURBOPUMP HOUSING STRAINS

A. Observation: The strain gauge data acquired during the R2 test series , when translated into the Godman Diagrams indicate from a preliminary analysis that both investment cast pump volutes have adequate life.
Recommendation: Continue to evaluate the R2 strain data. Should the final analysis show a positive structural margin, additional data from other instrumented turbopumps may not be required.