Rocket Propellants Engine Design/Operations/Validation

Final Report

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Background:

Lockheed Martin Astronautics Operations(LMA) was competitively awarded a contract May 21, 2001 for next generation launch system architecture definition and technology maturation. The Second Generation Launch Vehicle Program objectives include reducing the technical and programmatic risk of proceeding to full scale development of the system by establishing requirements for the next generation launch system and maturing critical technologies needed by the system. LMA will conduct analyses and trades to optimize the architecture ETO elements including configuration, conceptual designs, and preliminary operations definition.

Scope:

To fully understand the engine and propellant trades were conducted by LMA to yield the optimized architecture system from the operability, reliability, safety and cost perspectives. A government/industry team addressed the required trade studies, the parameters and weighting factors, and the most critical trades were addressed. This report summarizes the participation of JCM Consulting, Inc. in the propellant trade study.

Results:

The majority of hours expended were in the generation of cost data for cluster testing of booster and orbiter stages. The data were generated by Mr. Harry Johnstone in conjunction with Stennis Space Center personnel with coordination with personnel at Edwards Air Force Base and Marshall Space Flight Center. Facility modification and test operations data were generated for both Lox/LH2 and Lox/RP-1 configurations and considered available facilities at Edwards Air Force Base, Marshall Space Flight Center and Stennis Space Center. These data were provided to LMA and factored into the trade study.

The assumptions and recommendations for stage testing are:

1. Fifteen R&D Tests for first and second stage to be completed in one year.
   a. one test per month for six months.
   b. two tests per month for next six months if required.
2. All R&D Tests must be completed one year prior to IOC.
3. It was recommended that the first and second stage be tested on B-2 Test Stand at SSC and Building 4670 at MSFC.
4. SSC may have to purchase more barges if they test the Hydrogen Stage.
5. We need to know the location of thrust take out loads. Is it the forward stage attach location or the rear stage location.
6. We need to know the height of each stage.
7. These recommendations were discussed with middle management at SSC are in agreement with the above.

A presentation summarizing the facility/test operations data is enclosed as Appendix A. It is recognized that the decision for facility utilization will be a SLI Program decision but the cost data and operations assumptions recommended should be representative and are valid for the trade study.

During the formation of the parameters and weighting factors utilized by the study, six telecons were held with inputs were provided real-time. LMA presented the final matrix and results of the scoring by their internal team. The overall scores were 0.299 for Hydrogen and 0.701 for Kerosene. The detailed matrix is included as Appendix B. The matrix was then utilized to generate an independent assessment and a sensitivity study. Nine versions of the matrix were generated. The first matrix (Jan Monk) was scored by Jan Monk and the second (Garry Lyles) was scored by Garry Lyles from the SLI Program Office. These are included as Appendices C and D. The third matrix (Hydrogen Bias) was scored with an assumed Hydrogen bias, i.e., hydrogen scoring was higher and kerosene scores was lower than that of the author. The fourth matrix (Modified Pugh) utilized the Modified Pugh Method. This version used Hydrogen as the reference (scored Neutral) and scored the Kerosene as better or worse as compared to Hydrogen. The fifth version (Modified Pugh #2) was also a Modified Pugh Method with Kerosene as the reference. The sixth matrix (Single Scoring) limited the scoring difference between the propellants to a single value. The seventh (Revised Weight Factors), eighth (Revised Weight Factors – Hydrogen Bias) and ninth (Revised Weight Factors – Pugh Method) matrices were repeats of the Jan Monk, Hydrogen Bias and Modified Pugh versions but the weighting factors were changed from the SLI values of 0.200 for Technical, 0.300 for Costs, 0.500 for Safety/Reliability to 0.333 for each of the areas. These matrices are attaches as Appendices E thru I. The results of the scoring is summarized below:

Propellant Trade Study Matrix
Scoring Summary

	Scores		
Method Used	**Hydrogen**	**Kerosene**	**Delta**
Baseline	0.299	0.701	0.402
Jan Monk	0.362	0.639	0.277
Garry Lyles	0.485	0.515	0.030
Hydrogen Bias	0.450	0.551	0.101
Modified Pugh	0.454	0.547	0.093
Modified Pugh #2	0.416	0.584	0.168
Single Scoring	0.342	0.659	0.317
Revised Weight Factors	0.356	0.643	0.287
Revised Weight Factors - Hydrogen Bias	0.457	0.542	0.085
Revised Weight Factors - Pugh Method	0.444	0.555	0.111

Mean	0.407	0.594	0.187
1 σ	0.0620	0.0621	0.1241
3 σ	0.1860	0.1863	0.3724

It should be noted that in no cases did Hydrogen outscore Kerosene providing some assurance that the process has some validity.

Recommendations:

Recommendation 1 - SLI Program Office select a team of experienced personnel and score the LMA developed matrix.

Recommendation 2 - a complementary matrix should be developed that places emphasis of vehicle design and development risks.

Recommendation 3 - a complementary matrix should be developed that places emphasis of engine system design and development risks.

Enclosures

Appendix A - RP vs LH2 Test Ops
Appendix B - LMA Baseline Matrix
Appendix C - Jan Monk Matrix
Appendix D - Garry Lyles Matrix
Appendix E - Hydrogen Bias Matrix
Appendix F - Modified Pugh Matrix
Appendix G - Modified Pugh #2 Matrix
Appendix H - Single Scoring Matrix
Appendix I - Revised Weight Factors Matrix
Appendix J - Revised Weight Factors – Hydrogen Bias Matrix
Appendix K - Revised Weight Factors – Pugh Method Matrix