BLOCK II SOLID ROCKET MOTOR (SRM) CONCEPTUAL DESIGN STUDY CONTRACT NAS 8-37295

FINAL REPORT - VOLUME I APPENDICES

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rating is due to thermal performance. The candidate with the least reliability was an EPDM silica. The best three candidates for weight were EPDM carbon fiber, EPDM silica and EPDM silica/Kevlar. All of these have an EPDM binder which has the lowest specific gravity. All the candidates were close on cost except for the EPDM carbon fiber which is the most expensive because of the solvent process used in manufacturing the material. A diagram showing the overall ratings for each of the candidates in the three categories is given in Figure 2.4.2. The best three insulations are Hypalon silica/Kevlar, USR-3800 and the EPDM Kevlar/cellulose/silica. Design studies using these materials are presented in Section 3.4.1.

2.5 PROPELLANT TRADE STUDIES

The objective of this task was to improve SRM performance and reliability via propellant, liner, and igniter propellant formulations. The constraints set for the selection process were existence of a solid data base, retention of the thrust-time trace, unchanged or improved variability, maintained structural margins, a 0.364 in/sec burning rate requirement (625 psi), and asbestos elimination. These issues are summarized in Table 2.5.1.

An examination of available propellants quickly eliminated the higher performance aluminized Class 1.1 propellants because of the increased hazards, and the alternate or "clean" propellants based on ammonium nitrate because of performance degradation and their not yet being state-of-the-art. The trade candidates were therefore limited to a PBAN formulation such as TPH-1148 in the SRM and an improved performance HTPB propellant. The evaluation factors were heavily weighted for reliability (motor integrity, producibility, etc.) which was assigned 60%. Hazards and payload impact were each assigned 15% with cost considerations having the least influence (10/%).

ARCADENE 360B, the HTPB propellant used in these trade studies, is compared to TPH-1148 in Table 2.5.2. ARCADENE 360B must be slightly modified to meet the burning rate requirement by reducing Fe_2O_3 percent which becomes very similar to that used in TPH-1148. ARCADENE 360B has been extensively characterized over a wide range of burning rates. Atlantic Research Corporation (ARC) has produced over 28 million pounds of this propellant at our Camden, Arkansas facility. The current production rates for the Vought MLRS program is over 70,000 lbs/day, making it one of the most produced propellants in the world.

TABLE 2.5.1. PROPELLANT AND LINER TRADE STUDY.

OBJECTIVE:

- SELECT PROPELLANTS (MOTOR AND IGNITER) AND LINER WITHOUT ASBESTOS.

CONSTRAINTS:

- SOLID DATABASE (MUST EXIST OR BE CREATED)
- MAINTAIN THRUST vs TIME
- MAINTAIN OR IMPROVE VARIABILITY
- MAINTAIN STRUCTURAL MARGINS
- BURNING RATE - 0.364 AT 625 PSI
- ELIMINATE ASBESTOS

SCOPE:

- PBAN vs HTPB (HIGH SOLIDS)
- LINER
- IGNITER PROPELLANT (TPH - 1178 vs IMPROVED COMPOSITION)

TABLE 2.5.2. PROPELLANT FORMULATIONS.

	TPH-1148	ARCADENE 360B
BINDER	PBAN/EPOXY	R-45HT/IPDI
Fe_2O_3	0 - 0.3%	0.1 - 0.3%
AL POWDER	16%	18%
TOTAL SOLIDS	86%	88%
AP (COARSE/FINE)	70/30	70/30

Table 2.5.3 summarizes the trade studies showing slightly higher rating for the current PBAN propellant, primarily because of demonstrated reliability in numerous flights and full scale motor firings in which a problem or malfunction due to propellant has never been identified to our knowledge.

ARCADENE 360B outscores the PBAN propellant in all other categories except for initial non-recurring costs for D&V to qualify the propellant in full scale SRM motors.

However, in the event that higher performance (payload) is required, ARC offers a very credible approach with ARCADENE 360B with a vast database and production proven reliability and producibility.

More details of the trades in each category follow.

Propellants are compared for producibility and reliability in Table 2.5.4.

In assessing the trades, scores of 1 to 10 were assigned with 7 being the norm assumed for TPH-1148 unless a deficiency existed. ARCADENE 360B has not been cast and fired in an SRM motor and therefore lacks the full-scale demonstration. This is the primary reason for the lower score. In terms of propellant produced, 28 million is less than 70 million but the difference is not significant since both numbers are very large. The gap will close rapidly as 360B production for MLRS continues. The 360B mechanical properties are superior to any PBAN propellant and can be tailored for higher strain. Although not required in this motor, 360B mechanical properties are significantly better at low temperature.

An asbestos fire-free liner must be formulated and demonstrated for both propellants. The insulation composition will affect the liner selection. An asbestos-free liner (ARL-151) has been demonstrated with ARCADENE 360B but may require some modification for the SRM application.

Table 2.5.5 compares propellant hazards.

Both propellants exhibit similar hazard characteristics typical of state-of-the-art Class B (military 1.3) composite formulations. ARCADENE 360B is rated slightly better for exhaust products based on its slightly lower CO concentration.

TABLE 2.5.3. PROPELLANT AND LINER TRADE STUDY RESULTS SUMMARY.

		PBAN TPH-1148		HTPB ARCADENE 360B	
CRITERIA	FACTOR	SCORE	WEIGHTED VALUE	SCORE	WEIGHTED VALUE
MOTOR INTEGRITY (PRODUCIBILITY, RELIABILITY, ETC.)	0.60	6.3	3.78	4.6	2.76
HAZARDS	0.15	7.0	1.05	7.3	1.10
IMPACT ON PAYLOAD	0.15	7.0	1.05	10.0	1.50
COST: NONRECURRING RECURRING	 0.05 0.05	 7.0 7.0	 0.35 0.35	 1.0 8.0	 0.05 0.40
TOTAL SCORE			6.58		5.81

TABLE 2.5.4. MOTOR PRODUCIBILITY AND RELIABILITY TRADE (PROPELLANT LINER).

PARAMETER	TPH-1148	SCORE	ARCADENE 360B	SCORE
FULL-SCALE MOTOR DEMONSTRATION	YES	7	NO	1
QUANTITY OF PROPELLANT PROCESSED (LB)	>70 MILLION	7	> 28 MILLION	6
MECHANICAL PROPERTIES s_m (psi) e_m (%) E_o (psi)	 113 37 518	7	 170 ± 10 35 ± 5 800 ± 100	7
BURNING RATE REPRODUCIBILITY	<2% DIFFERENCE FROM TARGET	7	± 1% ON MIXES WITHIN LOT	7
PROPELLANT DATABASE	EXTENSIVE	7	EXTENSIVE	7
ASBESTOS-FREE LINER	NO	4	YES WITH MODIFICATION	4
PROPELLANT/LINER BOND (NO ASBESTOS)	UNKNOWN	4	UNKNOWN	4
D & V	MINIMAL REQUIRED	7	SUBSTANTIAL EFFORT REQUIRED	1
TOTAL SCORE		50		37
AVERAGE SCORE		6.3		4.6

TABLE 2.5.5. PROPELLANT HAZARDS TRADE.

PARAMETER	TPH-1148	SCORE	ARCADENE 360B	SCORE
PROCESSING AND HANDLING HAZARDS	SOA COMPOSITE PROPELLANT	7	SOA COMPOSITE PROPELLANT	7
CURED PROPELLANT AND LOADED MOTOR PROPERTIES	CLASS B (MIL CLASS 1.3)	7	CLASS B (MIL CLASS 1.3)	7
TOXIC PROPELLENT EXHAUST PRODUCTS (MOLES /100g) HCl Al_2O_3 CO	 0.5860 0.2965 (S) 0.8555	7	 0.5837 0.2989(S) 0.7697	8
TOTAL SCORE		21		22
AVERAGE SCORE		7.0		7.3

The ARCADENE 360B performance advantages are clearly shown in Table 2.5.6. Specific impulse and density are both higher for ARCADENE 360B. The 25,175 propellant weight is calculated only from the density difference in the HPM Motor Design. A 2000 lb. extra insulation penalty was assumed for the higher flame temperature of 360B. Using a 1.2 g/cm^3 assumed insulation density, this converts to a 22,340 lb. additional 360B propellant. Using the assigned influence coefficients, a +1490 lb. payload is calculated. This figure does not include any additional thrust contribution from the higher theoretical specific impulse of 360B since some efficiency loss must also be assumed from the extra 2% Al.

The primary requirement for the liner is to reliably bond the propellant to the insulation. Secondary requirements are environmental and process. It must also be asbestos-free. It must have a reasonable pot life for application, it must stay in place on application to vertical insulation, and it must bond to propellant after being held at the cure temperature for a 30-hour casting period. All the requirements are met by the current system except the asbestos-free one.

The trade summarized in Table 2.5.7 evaluates a minimum change (Option I) in which the asbestos is replaced by another fibrous filler against a change (Option II) in which filler, polymeric composition, and other ingredients may be changed. The strongly weighted reliability criterion forces the trade results to Option I because it offers minimum change to the current system. Option II allows a potential payload increase from an estimate of weight savings which result from a decrease in liner thickness. Decreasing the current .057" to .020" corresponds to a decrease in weight of 1,000 pounds per SRM. If the volume lost were filled with propellant, a payload gain of 296 pounds would result.

Thin liners are a strong point in ARC motor technology. These thin liners frequently owe their success to internal barriers.

The existing shuttle rocket motor liner is based on Minuteman technology in which the liner also played a signficant role in insulating the case.

TABLE 2.5.6. PROPELLANT PERFORMANCE TRADE (HPM MOTOR DESIGN).

PARAMETER	TPH-1148	ARCADENE 360B	Δ
I^{0}_{sps} (lbf-sec/lbm)	261.9	263.1	+1.2
DENSITY (lbm/in^3)	0.0635	0.0650	+0.0015
VOLUMETRIC SPECIFIC IMPULSE ($lbf\text{-}sec/in^3$)	16.63	17.09	+0.46
VACUUM SPECIFIC IMPULSE (lbf-sec/lbm)	268.5	269.7	+1.2
PROPELLANT WEIGHT (lb) (NO INSULATION CHANGE)	1,110,136	1,135,311	+25,175
INCREASE IN INSULATION WEIGHT (lb)	———	2,000	+2,000
NOT INCREASE IN PROPELLENT WEIGHT (lb)	———	———	+22,340
Δ PAYLOAD (lb)	———	———	+1490 *
SCORING RANK	7	10	———

* + 0.083 (22,340) - 0.182 (2000) = 1490

TABLE 2.5.7. LINER TRADE.

FORMULATION VARIATION	EXISTING FORMULATION	CHANGE ONLY FIBROUS FILLER		CHANGE MAIN INGREDIENTS AND FIBROUS FILLER; POSSIBLY USE BARRIER	
ADVANTAGES	HIGHLY RELIABLE	BONDING TO V44 & TP-H1148 ESTABLISHED; AGING BEHAVIOR KNOWN		MAY BE REQUIRED TO BOND TO NEW INSULATION; BARRIER ALLOWS WEIGHT SAVINGS PAYLOAD (+296 lbs)	
DISADVANTAGES	NOT ACCEPTABLE DUE TO ASBESTOS; THICK LINER CAUSES INERT WEIGHT PENALTY	NEED TO DEFINE PROCESSIBILITY & CURE CHARACTERISTICS, AND VERIFY BONDLINE PERFORMANCE		EXTENSIVE TESTING REQUIRED TO QUALIFY NEW SYSTEM	
RATING CRITERIA		SCORE	WEIGHTED VALUE	SCORE	WEIGHTED VALUE
RELIABILITY		7	4.20	4	2.40
HAZARDS		--	--	--	--
PAYLOAD IMPACT		7	1.05	8	1.20
COST		7	0.70	4	0.40
TOTAL			5.95		4.00

TABLE 3.3.1. ARCADENE 360A.

INGREDIENT	WT %
R-45 HT BINDER	10.0
DOA	2.0
Al POWDER	18.0
Fe_2O_3	1.5
AP (60/40 200μ/MA)	68.5
	100.0

TOTAL SOLIDS	88%
I°sps	260.7 lbf-sec/lbm
DENSITY	0.0655 lb/cu-in
EQUILIBRIUM T_c	3508°K
C*	5123 ft/sec
E	10.74
GAMMA	1.166
BURNING RATE (1000 PSI)	0.70
PRESSURE EXPONENT	0.48

MECHANICAL PROPERTIES (2 in/min x head)

	70°F	-40°F	+160°F
MAX. STRESS (PSI)	201	514	128
% STRAIN AT MAX. STRESS	30	43	26
TANGENT MODULUS (PSI)	1540	12,100	1010