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MARTIN MARIETTA

Crusader Solid Propellant Best Technical Approach

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AMMUNITION LOGISTICS PROGRAM

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EXECUTIVE SUMMARY

The goal of the Solid Propellant Resupply Team is to develop Crusader system concepts capable of automatically handling 155mm projectiles and Modular Artillery Charges (MACs) based on system requirements. The system encompasses all aspects of handling from initial input into a resupply vehicle (RSV) to the final loading into the breech of the self-propelled howitzer (SPH). The team, comprised of persons from military and other government organizations, developed concepts for the overall vehicles as well as their interior handling components. An intermediate review was conducted on those components, and revised concepts were completed in May 1995. A concept evaluation was conducted on the finalized concepts, from both a systems level and a component level.

The team's Best Technical Approach (BTA) concept was selected from that evaluation. Both vehicles in the BTA have a front-engine configuration with the crew situated behind the engine–low in the vehicles. The SPH concept utilizes an automated reload port at the rear of the vehicle, centered high. The RSV transfer boom will dock with this port to allow automated ammunition transfer. The SPH rearm system utilizes fully redundant dual loaders. Active magazines are used for both projectiles and MACs. The SPH also uses a nonconventional tilted ring turret configuration to maximize the available interior volume in the vehicle. This configuration can be rearmed at any elevation angle but only at 0° azimuth. The RSV configuration is similar to that of the SPH. The RSV utilizes passive storage racks with a pick-and-place manipulator for handling the projectiles and active magazines for the MACs. A telescoping transfer boom extends out the front of the vehicle over the crew and engine.

1. INTRODUCTION

The U.S. Army's next generation artillery system, Crusader, will consist of a self-propelled howitzer (SPH) and its resupply vehicle (RSV) and will provide the Army with the leap-ahead lethality and performance never before available to the artillery soldier. To meet operational requirements, the Crusader Program's currently preferred technical solution is to develop and utilize a Regenerative Liquid Propellant Gun. However, this is also a high-risk technology. A solid propellant backup system, the Modular Artillery Charge (MAC), is being developed concurrently as a risk mitigator. A team was formed to develop a conceptual design for an SPH and an RSV, which were based on the MAC technology.

The multiagency group is comprised of persons from the following organizations:

- Project Manager, Crusader (PM-Crusader)
- System Project Officer, Defense Ammunition Logistics Activity
- Oak Ridge National Laboratory (ORNL)
- Tank-Automotive and Armaments Command (TACOM)
  - Armaments Research, Development, and Engineering Center (ARDEC)
    - Benet Laboratory Systems Engineering Branch (AMSTA-AR-CCB-DA)
    - Close Combat Armament Center, Advanced Concept and Engineering Team (AMSTA-AR-CCH-A, referenced as CCAC)
    - Fire Support Armament Center, Artillery and Indirect Fire Division (AMSTA-AR-FSA-C, referenced as FSAC)
  - Tank-Automotive Research, Development, and Engineering Center (TARDEC)
    - Development Business Group (AMSTA-TR-D)

The main purpose of this study was to address and optimize the resupply process and ammunition handling systems from the palletized load system flatrack to the SPH breech. The concepts generated for this study were used to represent the mission equipment (upload, storage, handling, transfer, and loading of projectiles and propellant), which would have to be developed and integrated into a given ground vehicle. There was little attempt to fully optimize the system based on survivability, mobility, deployability, etc. However, the SPH and RSV concepts were developed to address the Crusader Operational Requirements Document (ORD). To achieve a truly optimized system, the concepts would require extensive supporting analysis, such as MANPRINT and mobility and structural analysis.

Four of the organizations—Benet, CCAC, FSAC, and ORNL—developed conceptual designs for the two- vehicle Crusader system. After an interim review by the entire team of the subsystems used in the initial concepts, those concepts were refined and finalized. In July 1995 the final concepts were reviewed and compared by the team in order to develop a Best Technical

Approach (BTA) for a Crusader resupply system capable of handling 155mm projectiles and solid propellant charges. This report summarizes that review and evaluation process.

During the study the TACOM-TARDEC organization provided multiple vehicle configurations and their mobility/deployability ramifications to the organizations developing the conceptual designs. These configurations varied the powerpack and crew location within the vehicle. The overall vehicle configuration met the mobility and transportability requirements.

The system configuration chosen for the solid propellant BTA was a chassis designed with the powerpack located in the front of the vehicle with the co-located crew situated in a crew compartment behind the powerpack and the mission equipment (armament and projectile/propellant handling system) located to the rear of the vehicle. The automotive subsystems configured in the chassis were chosen to meet the U.S. Army requirements for an artillery system that has sufficient mobility and agility to keep up with the supported maneuver force.

The chassis configuration chosen exemplifies the proper design rules. As a general rule, the vehicle center of gravity (c.g.) must be considered as well as the center of suspension. For a tracked vehicle to maneuver effectively, its vehicle c.g. position must not stray from its center of suspension. Also, the vehicle c.g. vs center of suspension impacts the gun firing forces affecting the vehicle's pitch and roll characteristics. Therefore, weight drivers that help shape the c.g. location, such as the powerpack, armament, and ammunition are critical. Considering all factors, the best approach to obtain an ideal weight distribution across the vehicle would be to locate the armament at or near the vehicle center with the powerpack located opposite of the ammunition.

The Advanced Integrated Propulsion System, which includes the LV100 turbine engine and a transversely mounted hydrokinetic transmission, was selected. This powerpack met the automotive requirements and space/weight goals for the system. The powerpack placement for a self-propelled artillery system entails two choices. The first is at the front of the chassis, and the second is at the rear. Both locations have their advantages and disadvantages, but the main reasons for selecting the front location were to (1) maximize the space available for the armament and ammunition handling systems and (2) enable the weapons compartment to be easily accessed by the crew compartment or the outside. Currently, most self-propelled artillery systems employ a front powerpack, but a few examples of rear powerpack artillery systems exist which are based on readily available tank chassis.

The suspension system in the concepts consists of externally mounted hydropneumatic suspension units located at each roadwheel station (7 per vehicle side; 14 total) . Additionally, the suspension units are capable of providing variable height control and lockout capability for the vehicle with driver inputs. The current 25-in.-diam M1A1-designed roadwheels are employed 2 per station, for a total of 28 roadwheels. The 25-in.-wide XT158LL track is used to reduce system weight, and an automatic hydraulically powered track tensioner, which is controlled by the driver, provides track tension control.

The ability of the suspension units to allow the vehicle to traverse variable terrain by absorbing ground inputs and damping the pitch and roll while reducing shock and vibration induced to the crew and equipment is a major characteristic, but the variable height control adds an additional capability to the system. The ability of the vehicle to raise and lower and pitch and roll gives increased capability of the system to perform resupply operations and meet the transportability requirements. With the addition of the variable height suspension, the complexity of the resupply transfer boom and port can be significantly reduced. Although this system reduced the resupply complexity, it raised the complexity and cost of the suspension system, which is minor compared to the associated complexity and cost of the resupply components.

With the automation available to the Crusader system, the artillery crewmen are not required to leave the crew station. This allows the vehicles to have one crew compartment "encapsulated" within the vehicle. This design provides numerous advantages for the crew as well as the overall vehicle design. With the crew encapsulated, the crewmembers are co-located, which allows for interaction between themselves and gives the Chief of Section readily available oversight. Additionally, encapsulating the crew simplifies armor and nuclear, biological, and chemical protection, which translates into reduced subcomponent complexity and overall vehicle weight.

2. SCORING OVERVIEW AND EXAMPLE CALCULATION

The evaluation methodology used in ranking the concepts was based on the Kepner-Tregoe Decision Analysis technique, named after its developers. This systematic approach allows relevant data to be organized and analyzed in a meaningful way. The decision to be made was to select a BTA for a MAC resupply system. The criteria to be used to make the selection were chosen, and weighting factors were applied to the criteria which determined their relative importance. Each vehicle concept was evaluated with a score of 0 to 5 relative to each criteria by the participating organizations. The criteria scores were then multiplied by the corresponding weighting factor and then totaled to give the overall concept score.

The MAC resupply system is comprised of two vehicles, the SPH and the RSV. Each vehicle proposed was evaluated as a concept. There were a total of ten vehicles evaluated, six SPHs and four RSVs. Each concept was evaluated from a system-level (vehicle) perspective and a subsystem-level (component) perspective. The BTA was to be determined by the vehicle-level scores only; the component-level scores would be used as a measure of the technical risks associated with the particular concept.

2.1 VEHICLE-LEVEL SCORING

The vehicle criteria and their corresponding weights which were used in the evaluation of the SPH are shown in Table 1. The criteria were grouped by categories for scoring. These categories were *Mission performance*, *Survivability*, *MANPRINT*, *Sustainability*, *Loading*, and *Mfg/Dev*. As shown, the evaluation criteria chosen as most important were *System reliability*, *Crew vision*, *Crew firing dynamics*, and *Rate of fire*.

The vehicle criteria and weights for evaluating the RSV concepts are shown in Table 2. The categories that the criteria fell into matched those of the SPH. The most important criteria used in the RSV evaluation included *Docking*, *Transfer*, *System reliability*, and *Crew vision.*

2.2 COMPONENT-LEVEL SCORING

Each vehicle was divided into various functional resupply subsystems. Each subsystem was assigned a weight factor to gauge its relative importance to the other subsystems. These are shown in Table 3 for both vehicles.

One objective of the evaluation was to obtain an estimate of how well the components of the various concepts rated against each other. While this ranking would not be used as the overall concept ranking, it would provide some beneficial information regarding possible improvements to the BTA. The criteria used to evaluate the SPH components are shown in Table 4.

Table 1. SPH vehicle criteria and weights

Category	Criteria	Weight	Description
Sustainability	System reliability	10	How dependable will system be? Might be inversely proportional to system complexity
MANPRINT	Crew vision	10	Unobstructed view from crew compartment
MANPRINT	Crew firing dynamics	10	Forces on crew resulting from firing of cannon
Mission performance	Rate of fire	10	Continuous rounds/minute
Mission performance	Automated upload	9	Efficiency of upload system
Mission performance	Automated cannon loader	9	Efficiency of autoloader system
MANPRINT	Crew interaction	9	How are crewmen positioned relative to each other?
Loading	Vehicle center of gravity	9	Is it at a central location?
Mfg/Dev	Integration/technical risk	9	Assessment of technologies utilized. Can development meet cost and schedule constraints?
Survivability	Crew (threat to)	8	Protection of crew compartment
Loading	Combat load	8	Ammunition placement
Loading	Curb weight	8	Total weight
MANPRINT	Ingress/egress	8	How easily crew can enter/leave vehicle
Mfg/Dev	Cost	8	Estimate of system cost
Mission performance	Gun orientation awareness	7	Can crew visually tell the orientation of the gun?
Mission performance	Manual upload	7	How well the SPH could be uploaded without the automated systems
Mission performance	Manual cannon loader	7	How well the cannon could be loaded without the automated systems
Sustainability	Mission equipment accessibility	7	Can crew access the subsystems?
Sustainability	Powerpack accessibility	7	Can crew access the powerpack?
MANPRINT	Crew safety	6	Location within vehicle, protection available
Survivability	Crew (distance from center of mass)	6	Farther away is better from survivability standpoint
Survivability	Projectiles (threat to)	6	Location within vehicle, degree of protection
Survivability	Projectiles (venting feasibility)	6	Can storage be vented?
Survivability	Projectiles (crew distance from)	6	How far from projectiles is the crew positioned?
Survivability	Projectiles (distance from center of mass)	6	Farther away is better from survivability standpoint
Survivability	MACs (threat to)	6	Location within vehicle, degree of protection
Survivability	MACs (venting feasibility)	6	Can storage be vented?
Survivability	MACs (crew distance from)	6	How far from MACs is the crew positioned?
Survivability	MACs (distance from center of mass)	6	Farther away is better from survivability standpoint
MANPRINT	Crew ride quality	5	Dependent upon location within vehicle. How far from center of mass?
Mfg/Dev	Subsystem commonality	5	Utilizes similar components for multiple subsystems

Table 2. RSV vehicle criteria and weights

Category	Criteria	Weight	Description
Mission performance	Docking (RSV to SPH)	10	Ability of RSV to dock with SPH
Mission performance	Transfer (RSV to SPH)	10	Ability of RSV to transfer ammunition to SPH
Sustainability	System reliability	10	How dependable will system be? Might be inversely proportional to system complexity
MANPRINT	Crew vision	10	Unobstructed view from crew compartment
MANPRINT	Crew interaction	8	How are crewmen positioned relative to each other?
Survivability	Crew (threat to)	8	Protection of crew compartment
MANPRINT	Ingress/egress	8	How easily crew can enter/leave vehicle
Mfg/Dev	Integration/technical risk	8	Assessment of technologies utilized. Can develop-ment meet cost and schedule constraints?
Loading	Vehicle center of gravity	8	Is it at a central location?
Loading	Combat load	8	Ammunition placement
Loading	Curb weight	8	Total weight
Mfg/Dev	Cost	8	Estimate of system cost
Mission performance	Docking (RSV to RSV)	7	Ability of RSV to dock with RSV
Mission performance	Transfer (RSV to RSV)	7	Ability of RSV to transfer ammunition to RSV
Sustainability	Mission equipment accessibility	7	Can crew access the subsystems?
Sustainability	Powerpack accessibility	7	Can crew access the powerpack?
Survivability	Crew (distance from center of mass)	6	Farther away is better from survivability standpoint
MANPRINT	Crew safety	6	Location within vehicle, protection available
Survivability	Projectiles (threat to)	6	Location within vehicle, degree of protection
Survivability	Projectiles (venting feasibility)	6	Can storage be vented?
Survivability	Projectiles (crew distance from)	6	How far from projectiles is the crew positioned?
Survivability	Projectiles (distance from center of mass)	6	Farther away is better from survivability standpoint
Survivability	MACs (threat to)	6	Location within vehicle, degree of protection
Survivability	MACs (venting feasibility)	6	Can storage be vented?
Survivability	MACs (crew distance from)	6	How far from MACs is the crew positioned?
Survivability	MACs (distance from center of mass)	6	Farther away is better from survivability standpoint
Mission performance	Transfer (RSV to ground)	5	Ability of RSV to transfer ammunition to ground
MANPRINT	Crew ride quality	5	Dependent upon location within vehicle. How far from center of mass?
Mfg/Dev	Subsystem commonality	5	Uses similar components for multiple subsystems

Table 3. Vehicle components and weights

SPH		RSV	
Component	Weight	Component	Weight
Projectile storage	8	Vehicle upload	6
MAC storage	8	Projectile storage	7
Autoloader	10	MAC storage	7
		Ammunition handling	8
		Docking	10
		Ammunition transfer	8

Table 4. SPH component criteria and weights

Criteria	Weight
Complexity	10
Selectability	10
Transfer rate	9
Volume	8
Technical risk	8
MAC zoning	6
Weight	6
Accessibility	6
Projectile compartmentation	6
MAC compartmentation	6
Component commonality	5

All the criteria in Table 4 were applied to each component subsystem in the SPH (Table 3), except for the *Transfer rate* criteria. It was applied to the various transfer systems within the SPH, which were assigned weights, as shown in Table 5.

Table 5. SPH transfer and verification systems and weights

System	Weight
Projectile/MAC verification	9
Manual upload	8
Manual download	6
SPH to RSV	6
SPH to ground	6

The component-level criteria used to evaluate the RSV were very similar to those used for the SPH (see Table 6). The difference in the two sets of criteria is that *MAC zoning* in the SPH was replaced with *Manual backup* in the RSV.

Table 6. RSV component criteria and weights

Criteria	Weight
Complexity	10
Selectability	10
Transfer rate	9
Volume	8
Technical risk	8
Projectile compartmentation	6
MAC compartmentation	6
Weight	6
Accessibility	6
Manual backup	6
Component commonality	5

Again, all these criteria (except for *Transfer rate*) were used in evaluating the six RSV subsystems. *Transfer rate* was used for the following transfer and verification systems found in the RSV (see Table 7).

Table 7. RSV transfer systems and weights

System	Weight
RSV to SPH	10
RSV to RSV	4
RSV to ground	4
Manual upload	8
Manual download	5

2.3 EXAMPLE SCORING

Because of the large amount of criteria and weighting factors used in the evaluation, a description of their usage would be confusing. This section of the report will show how the numbers would be used in an example evaluation. This example concept will be an RSV; the methodology would be the same for an SPH. An RSV was used as an example because it had more evaluations at the component level. Table 8 shows an example system-level scoring sheet. Each participating organization completed a form similar to this one for each concept, grading each criteria on a scale of 0 to 5, with 5 being high. By taking the average of the corresponding numbers from each organization's scoring sheet, a "final" scoring sheet was developed that would lead to the final score for that concept. The numbers shown in the table represent a final scoring sheet. In Table 8 the *Weighted score* value is obtained simply by multiplying the *Average score* for that criteria by its *Weight.* The total score is obtained by adding the *Weighted scores*. This example concept has a total score of 684.5. A "perfect" concept (every criteria received a 5 rating) would have a total score of 1035.

Table 8. Example RSV system score

Category	Weight	Criteria	Average score	Weighted score
Mission performance	10	Docking (RSV to SPH)	3.1	31.0
	7	Docking (RSV to RSV)	2.7	18.9
	10	Transfer (RSV to SPH)	2.8	28.0
	7	Transfer (RSV to RSV)	2.9	20.3
	5	Transfer (RSV to ground)	3.2	16.0
Survivability	8	Crew (threat to)	2.1	16.8
	6	Crew (distance from center of mass)	4.3	25.8
	6	Projectiles (threat to)	3.6	21.6
	6	Projectiles (venting feasibility)	2.9	17.4
	6	Projectiles (crew distance from)	3.0	18.0

Table 8. (continued)

Category	Weight	Criteria	Average score	Weighted score
Survivability	6	Projectiles (distance from center of mass)	1.8	10.8
	6	MACs (threat to)	3.5	21.0
	6	MACs (venting feasibility)	3.9	23.4
	6	MACs (crew distance from)	2.6	15.6
	6	MACs (distance from center of mass)	4.0	24.0
Sustainability	10	System reliability	4.2	42.0
	7	Accessibility to mission equipment	2.9	20.3
	7	Accessibililty to powerpack	3.8	26.6
MANPRINT	10	Crew vision	3.9	39.0
	6	Crew safety	4.1	24.6
	8	Crew interaction	4.4	35.2
	8	Ingress/egress	3.1	24.8
	5	Crew ride quality	3.4	17.0
Loading	8	Center of gravity	2.8	22.4
	8	Combat load	3.3	26.4
	8	Curb weight	3.7	29.6
Mfg/Dev	8	Integration technical risk	2.9	23.2
	5	Subcomponent commonality	4.0	20.0
	8	Cost	3.1	24.8
		Total score		**684.5**

The component-level scoring for this example is shown in Table 9, which closely resembles the actual scoring sheet used by the evaluators during the process. The vehicle subsystems and their corresponding weighting factors are shown across the top of the table. The evaluation criteria are down the side of the table, along with their weights. As mentioned earlier, the vehicle transfer rates were judged separately, so they, along with their associated transfer system weights, are shown at the bottom of the table.

Each subsystem was evaluated using those criteria which were applicable. The scores shown in Table 9 represent averages of the inputs from several evaluators. The score for each criteria is shown in the rightmost column of the table. Summing this column gives the total component-level score for this concept, which is 279.8. A "perfect" concept would have a total score of 400.

The calculation used in obtaining each weighted score is also shown in the table. The basic approach in this calculation was to multiply the score by the weight of the particular subsystem and total them. The total was divided by the sum of the weights to normalize the data. This number was then multiplied by the criteria weight to give the final criteria score. The formulas shown appear different from each other because only those subsystems evaluated against a particular criteria were summed for the normalization process.

Table 9. Example RSV component score

Wt.	Criteria	Uploading	RSV Projectile Storage	RSV MACS Storage	RSV Handler	Docking Mechanism	Transfer Mechanism	Calculation	Weighted Score
	Subsystem Weights:	6	7	7	8	10	8		
10	Complexity	3.4	2.6	3.2	3.9	4.2	2.7	$\frac{6(3.4)+7(2.6)+7(3.2)+8(3.9)+10(4.2)+8(2.7)}{(6+7+7+8+10+8)}*10$	33.9
8	Volume	3.6	2.2	3.0	4.2	2.1	3.3	$\frac{6(3.6)+7(2.2)+7(3.0)+8(4.2)+10(2.1)+8(3.3)}{(6+7+7+8+10+8)}*8$	24.2
6	Weight	2.8	4.1	3.0	3.7	4.4	2.4	$\frac{6(2.8)+7(4.1)+7(3.0)+8(3.7)+10(4.4)+8(2.4)}{(6+7+7+8+10+8)}*6$	20.8
6	Accessibility	2.7	3.2	3.9	4.4	4.0	2.9	$\frac{6(2.7)+7(3.2)+7(3.9)+8(4.4)+10(4.0)+8(2.9)}{(6+7+7+8+10+8)}*6$	21.4
10	Selectability (projectiles, MACS)	NA	4.1	3.1	3.4	NA	NA	$\frac{7(4.1)+7(3.1)+8(3.4)}{(7+7+8)}*10$	35.3
6	Manual backup	4.0	4.1	3.5	3.0	NA	3.8	$\frac{6(4.0)+7(4.1)+7(3.5)+8(3.0)+8(3.8)}{(6+7+7+8+8)}*6$	21.9
5	Commonality	2.9	3.6	3.8	NA	NA	NA	$\frac{6(2.9)+7(3.6)+7(3.8)}{(6+7+7))}*5$	17.3
6	Projectile compartmentation	NA	4.2	NA	3.7	NA	NA	$\frac{7(4.2)+8(3.7)}{(7+8)}*6$	23.6
6	MACS compartmentation	NA	NA	3.6	NA	NA	NA	$\frac{7(3.6)}{7}*6$	21.6
8	Technical risk (5 = low risk)	2.0	3.9	4.0	2.7	4.4	4.2	$\frac{6(2.0)+7(3.9)+7(4.0)+8(2.7)+10(4.4)+8(4.2)}{(6+7+7+8+10+8)}*8$	29.0
	Subsystem Weights:	10	4	4	8	5			
Wt.	**Criteria**	**RSV to SPH**	**RSV to RSV**	**RSV to Ground**	**Manual Upload**	**Manual Download**		**Calculation**	**Weighted Score**
9	Transfer rate (download/upload)	4.1	2.4	2.7	3.3	3.7		$\frac{10(4.1)+4(2.4)+2(2.7)+8(3.3)+5(3.7)}{(10+4+4+8+5)}*9$	30.9
								Total score	**279.8**

3. SPH CONCEPTS

3.1 BENET A

Benet SPH Concept A, shown in Fig. 1, utilizes a front-engine configuration with a forward-positioned crew in a delta configuration. Projectiles are stored in a 26-round ready magazine to the right of the gun. This magazine rotates with the turret. Additional storage for 34 projectiles is provided in the lower rear hull area. Transfer from the hull storage to the ready magazine is accomplished at 0° azimuth. MACs are stored in the bustle area behind the gun and are zoned and staged in a revolving drum. Projectiles are transferred to a load arm on the right side of the gun, aligned with the gun in elevation, and rammed into the gun chamber. The desired number of MACs are transferred from the drum to the left load arm that aligns with the gun and loads the charges into the chamber.

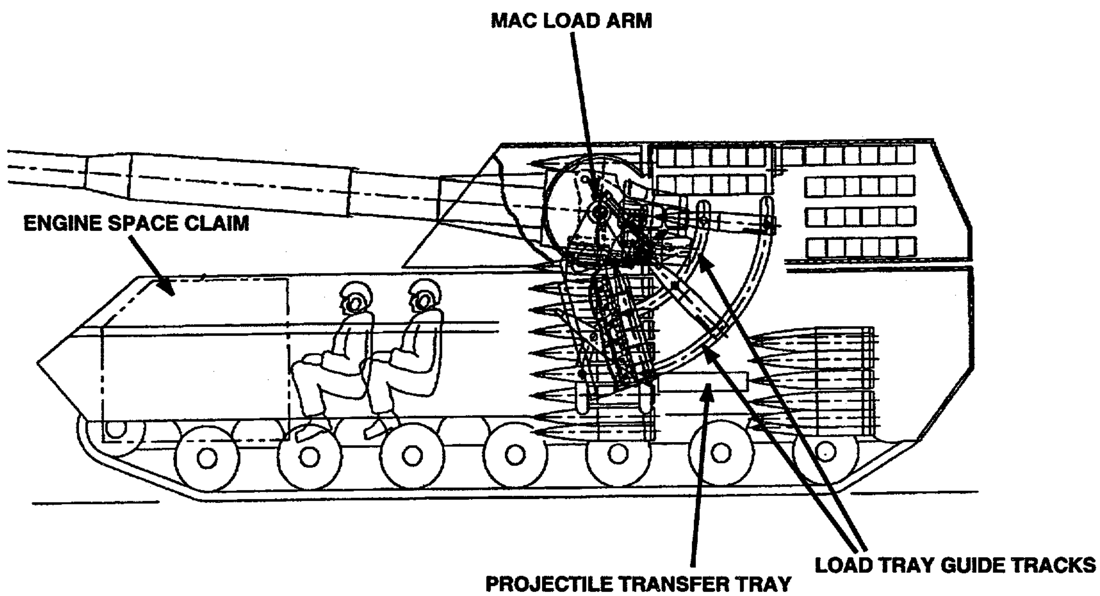

Fig. 1. Benet SPH Concept A.

Resupply is accomplished through a single conveyor from the RSV that docks in the left rear of the SPH. Projectiles and MACs are alternately received into the howitzer, with the MACs being handed up through a door in the bottom floor of the bustle and the projectiles being handed off to the hull storage magazine and onto the ready magazine.

3.2 BENET B

Benet SPH Concept B, shown in Fig. 2, utilizes a rear-engine configuration and is based on a preliminary United Defense concept for the liquid propellant (LP) SPH. In this concept the crew is in the forwardmost area of the vehicle in an "L" configuration. Projectiles are stored in two 30-round magazines located in the forward hull area behind the crew. These magazines extend out to the sponson area to a point adjacent to the resupply conveyor. Projectiles are passed from the storage magazines rearward to a turntable in the floor area under the gun. This platform rotates to align the projectiles with the gun in azimuth. A load arm to the right of the gun moves down to pick up the projectile, indexes up to align with the gun in elevation, and rams the projectile into the gun chamber.

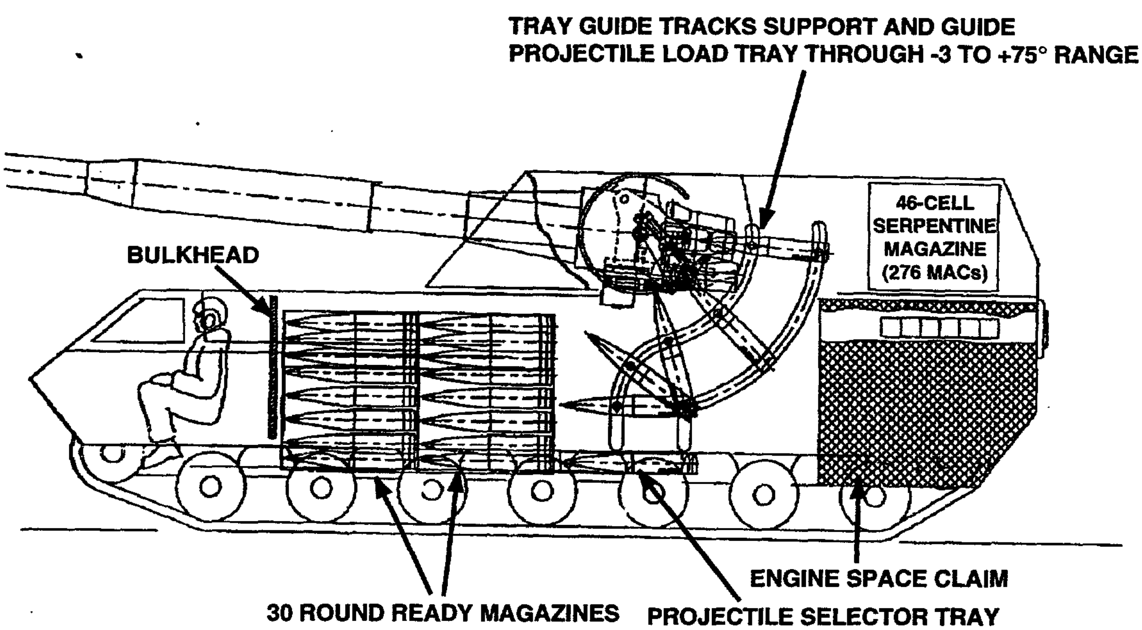

Fig. 2. Benet SPH Concept B.

The MACs are stored in a serpentine magazine in the bustle area. As in Concept A, they are zoned and transferred to the load arm through a revolving drum. The MACs are handed off to a load arm on the left of the gun, aligned with the gun in elevation, and loaded into the chamber.

Resupply is accomplished utilizing a conveyor mounted above the right sponson. Two projectiles travel along the conveyor, followed by a group of six MACs. Once the projectiles are alongside the projectile magazines, they are transferred into the storage magazine. MACs are positioned on the conveyor such that they are stopped under the bustle overhang of the sponson. They are lifted off the conveyor, passed through a door in the bottom of the bustle, and handed off to the MAC magazine.

3.3 CCAC A

CCAC SPH Concept A utilizes an unconventional "mini-turret" mounted on a tilted ring (see Fig. 3). The tilted ring approach maximizes the interior volume of the vehicle by eliminating the "shelf" created by the turret ring and hull in a conventional howitzer. The disadvantage of this approach is its limited traverse capability of ±5°. However, the turret itself has a lower inertia than conventional turrets, which should decrease the size and power of the hardware required to drive it.

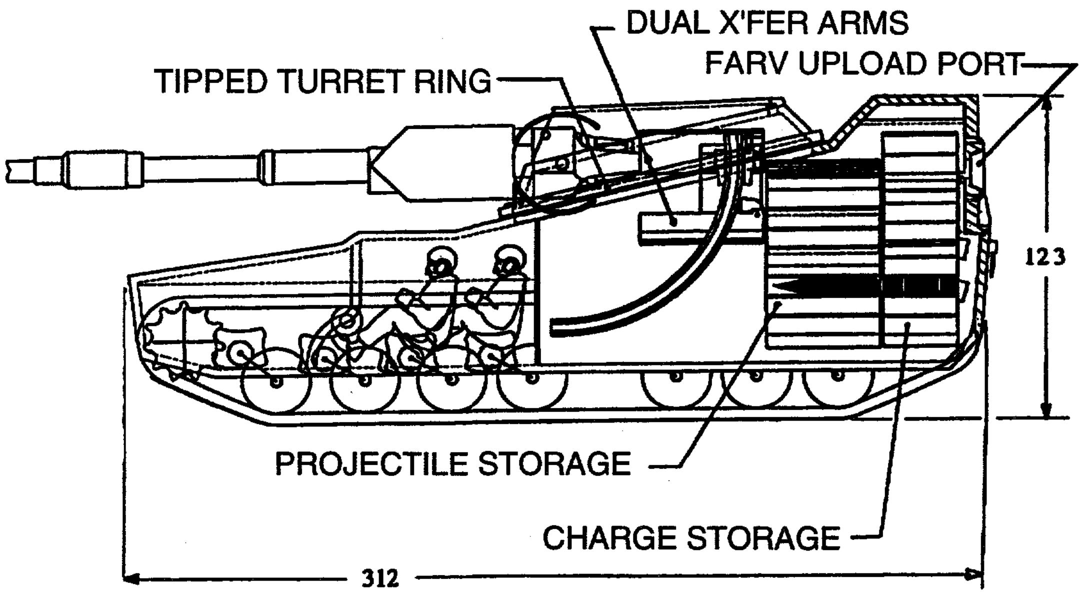

Fig. 3. CCAC SPH Concept A.

It has two fully redundant autoloader systems which operate in sequence to maximize the firing rate. The gun must be loaded at 0° azimuth in this concept but can be loaded at any elevation. There are four active magazines in the rear of the vehicle—two contain projectiles and two contain MACs. The charges are stored in the rear two magazines in cells of four. A zoning chamber is used to bring the MACs in line with the projectiles so that the autoloader can access both simultaneously. The autoloader then travels down the curved supports to line up with the gun axis for ramming. While the first projectile is being rammed and fired, the other loader is being prepared for the second projectile.

3.4 CCAC B

CCAC SPH Concept B was submitted to provide a more conventional alternative to the tilted ring configuration of Concept A. Shown in Fig. 4, Concept B utilizes a "half-turret" (sans bustle) in which the hull extends into the space normally occupied by the bustle, thus allowing the ammunition storage cells to use the entire height of the vehicle. All the ammunition storage systems and performance characteristics of this concept would be identical to those in Concept A.

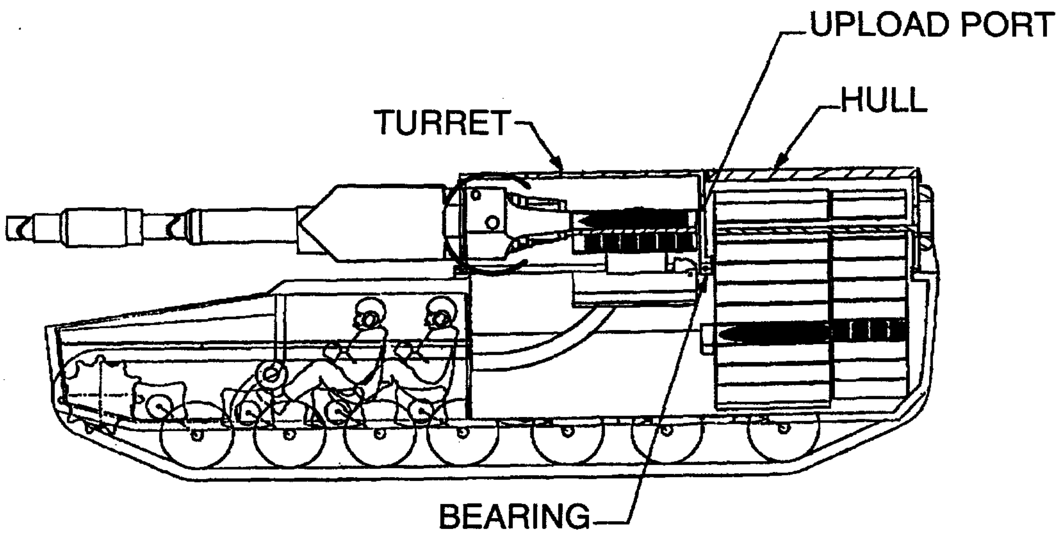

Fig. 4. CCAC SPH Concept B.

The circular interface of the rotating front turret has openings in each section which align for rearm. Ammunition flow during firing takes place under the ring within the lower hull. Since azimuth traverse is limited, the rearm openings are never exposed and need not have doors; however, an interface seal is required.

3.5 FSAC A

In FSAC SPH Concept A, shown in Fig. 5, the turret ring is lowered to the sponson level. This creates a large- volume turret which permits the storage magazines and loading arms to be aligned with the cannon at all times. This configuration allows large azimuth adjustments without affecting the potential rate of fire capability.

There are two complete ammunition handling systems within the vehicle, one on each side of the vehicle. Each system consists of a resupply port, storage magazines, and a cannon loading arm. These systems can operate independently, providing redundancy and increased reliability.

The cannon loading arm handles a projectile and one to six MACs. Ammunition is loaded from the storage magazines to the loading arm at a fixed location. The loading arm elevates to the gun elevation for loading.

This concept's resupply port consists of separate projectile and MAC ports, one above the other. End loading storage magazines are arranged so that projectiles and MACs can be transfered from the storage system on one side of the vehicle to the storage system on the other side of the vehicle. This capability allows the complete vehicle to be loaded using one resupply port with the other resupply port available as a backup.

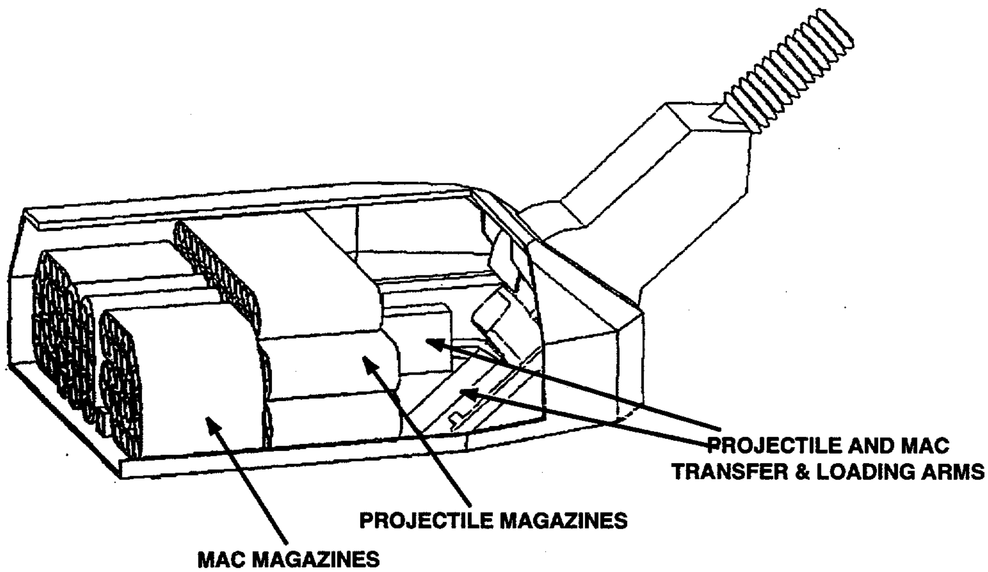

Fig. 5. FSAC SPH Concept A.

3.6 FSAC B

FSAC SPH Concept B (see Fig. 6) is similar to Concept A except that the storage magazines have been reconfigured to a side loading design, which allows projectiles and MACs to be uploaded using the same port. The storage magazines can be completely filled using either of the two redundant resupply ports. This concept, like Concept A, is completely redundant, allowing increased firing rates and increased reliability.

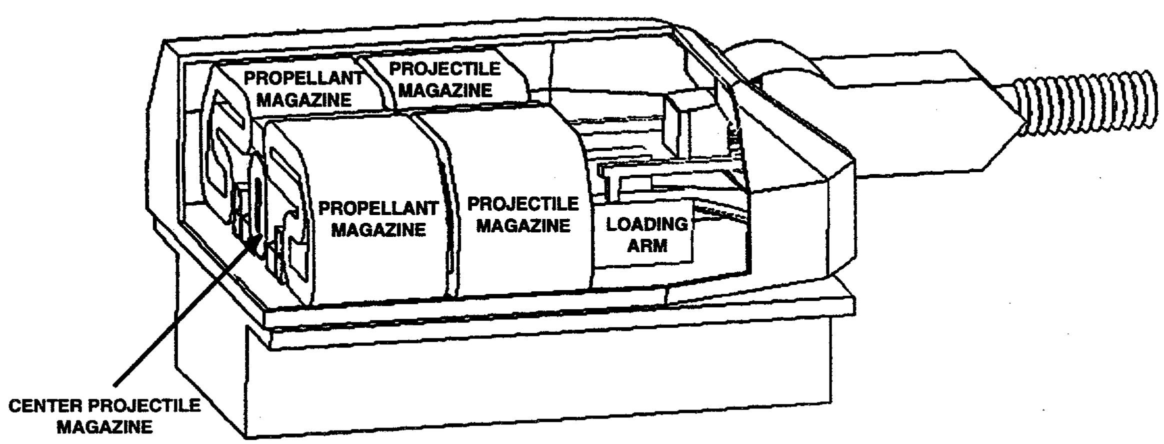

Fig. 6. FSAC SPH Concept B.

4. RSV CONCEPTS

This section describes each of the submitted concepts for the Crusader Solid Propellant RSV. Four concepts were evaluated– two from Benet and one each from CCAC and ORNL.

4.1 BENET A AND B

Both Benet concepts, shown in Figs. 7 and 8, utilize similar resupply vehicles. Concept A utilizes a conveyor over the left sponson, while Concept B utilizes a conveyor over the right sponson. Concept A is a front-engine configuration, while B is a rear-engine configuration. These configurations match their corresponding howitzer's layout. Both vehicles have the crews positioned in a delta layout in the front of the vehicle. Projectiles are stored in 4 magazines with 32 cells in each, for a total vehicle capacity of 128. MACs are stored in 2 magazines of 49 cells each, 6 charges per cell, for a total of 588. Hand-offs occur between magazines and from the appropriate magazine onto the resupply conveyor.

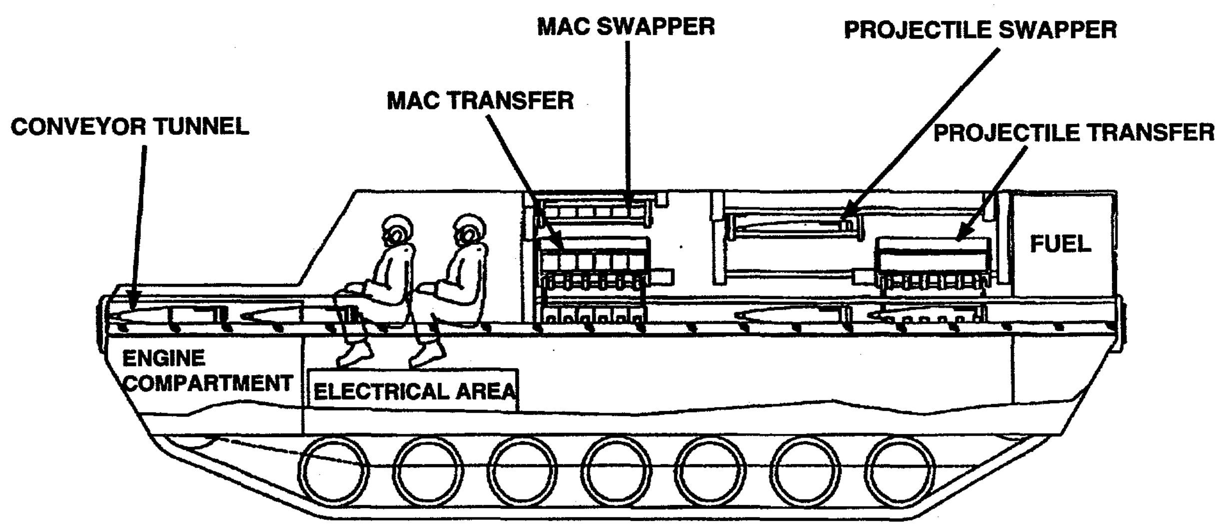

Fig. 7. Benet RSV Concept A.

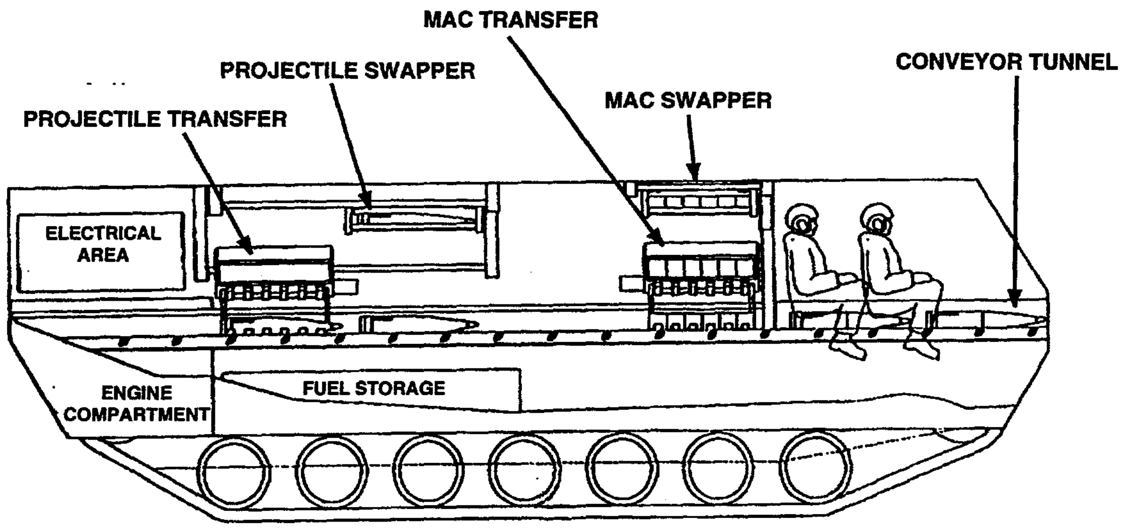

Fig. 8. Benet RSV Concept B.

4.2 CCAC

The CCAC RSV concept, shown in Fig. 9, is a front-engine configuration with the crew placed low in the hull. The ammunition is in the back of the vehicle and consists of two fixed storage racks for the projectiles and active magazines for the MACs. The active magazines, not shown in Fig. 9, would be located around the perimeter of the fixed storage racks (see Fig. 27). The projectiles are accessed using a pick-and-place device. Because of the volume swept out by the pick-and-place device, manual access to the projectiles is easily accomplished. The RSV can store 132 projectiles and 590 charges.

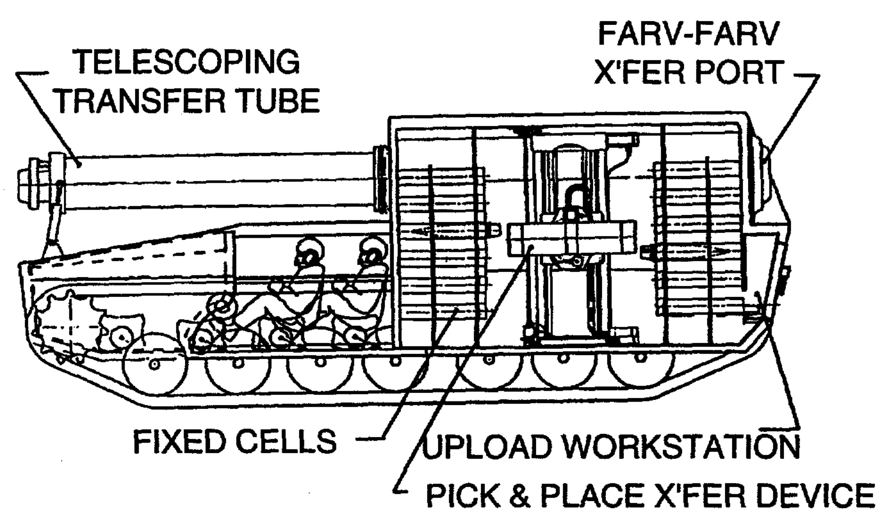

Fig. 9. CCAC RSV concept.

Ammunition is uploaded by an upload port at the rear of the RSV. This port swings down and provides a tray on which the projectiles are placed during the loading process. MACs will be loaded directly into the active magazines through a door on the side of the vehicle.

The transfer system is a telescoping boom over the engine area which will dock with a compliant port on the SPH. The boom will have pitch and yaw adjustment at the shoulder and will be controlled remotely by the RSV operator. Inside the boom will be an extendible conveyor system.

4.3 ORNL

The ORNL RSV concept (see Fig. 10) utilizes passive storage for its projectiles and has two robotic manipulators which access the rounds. This redundancy reduces the speed at which either manipulator must move while still meeting the required transfer rate. Each storage cell has some type (pneumatic or mechanical) of ejector to push the round out of the cell and into one of the transfer tubes.

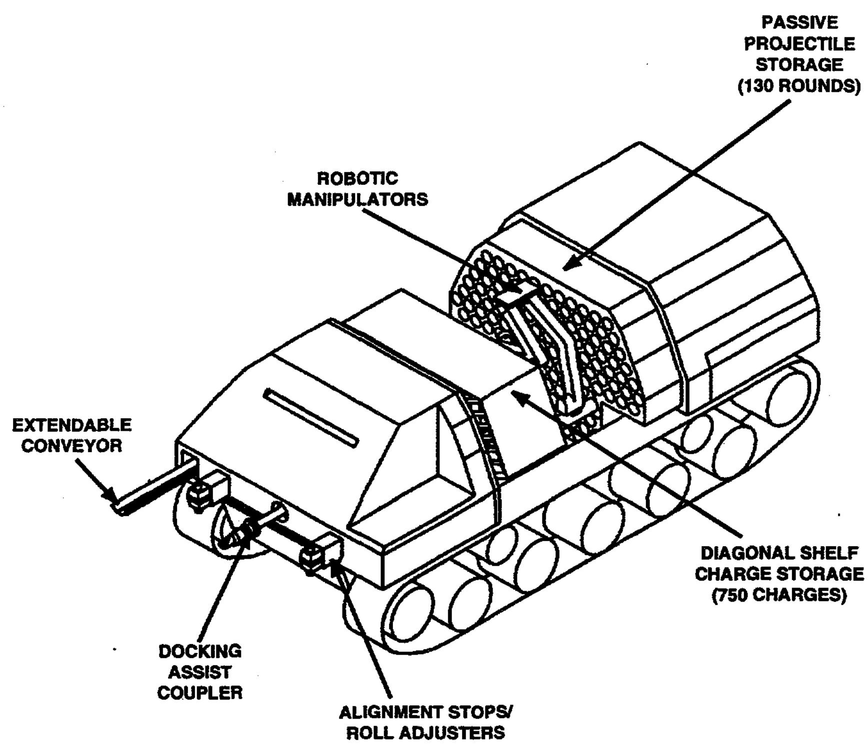

Fig. 10. ORNL RSV concept.

MACs are stored in a diagonal-shelf hopper and are gravity fed to the conveyor transfer system. The hopper is divided into 12 separate compartments, and all charges within a compartment would be of the same type. Because of the circular arrangement of the MAC handling conveyors underneath the hopper, the distribution of charges within the compartments is reconfigurable. When performing an inter-vehicular transfer, the RSV will place a projectile on the transfer conveyor and follow with six MACs. By having independent handling systems for projectiles and charges within the RSV, a higher transfer rate can be achieved.

A hard docking concept is utilized between the RSV and the SPH to minimize any misalignment between the transfer conveyors on each vehicle. Initial contact will be with a shock-absorbing coupler. Two active stops will then be deployed, and the SPH transmission can be put out of gear. The RSV can then force alignment in yaw and roll. Pitch misalignment can be minimized by the vehicle's assumed hydropneumatic suspension with height adjustment capability. To facilitate an RSV-to-RSV transfer, the rear of the RSV will have the same appearance as the back of an SPH (docking port and hard docking system).

5. SCORING RESULTS

5.1 SPH

Six SPH concepts were evaluated. A component-level scoring comparison is shown in Table 10. CCAC Concept B received the highest total score, while the CCAC A, Benet A and B, and FSAC B concepts were virtually tied for second.

Table 10. Comparison of SPH component scores

	Benet A	Benet B	CCAC A	CCAC B	FSAC A	FSAC B
Complexity	30.2	29.0	31.6	33.1	28.2	29.7
Volume	23.4	23.8	23.9	25.2	24.5	23.2
Weight	16.6	17.3	18.9	21.0	16.7	16.8
Accessibility	18.6	18.0	17.5	20.1	13.9	13.7
Selectability	33.5	33.8	33.8	40.0	33.7	36.7
Zoning	20.4	20.4	21.4	18.0	20.2	22.0
Commonality	16.4	16.1	15.9	21.9	17.5	20.0
Projectile compartmentation	17.6	18.4	19.4	18.0	19.0	18.0
MACs compartmentation	20.4	20.6	19.4	18.0	19.0	18.0
Technical risk	24.4	24.1	25.3	28.0	22.8	25.4
Transfer rate	27.0	27.6	23.8	19.3	23.4	24.8
Total scores	**248.4**	**249.1**	**250.9**	**262.6**	**238.7**	**248.3**

Table 11 shows the results of the SPH system-level scoring. The CCAC concepts received the highest system scores, followed by the Benet concepts, and the FSAC concepts. The two Benet concepts had the most differences between themselves, and their scores are more varied because of the differences. FSAC's two concepts were more similar to each other, as were the CCAC concepts. In some instances, however, the similar concepts received different scores even though they used identical subsystems. The basic reason for this discrepancy is that not all concepts were evaluated by all the participating organizations, which is explained in Sect. 5.4.

Table 11. Comparison of SPH system scores

	Benet A	Benet B	CCAC A	CCAC B	FSAC A	FSAC B
Gun orientation awareness	19.3	27.4	21.0	28.0	21.6	23.3
Rate of fire (SPH reload speed)	29.2	32.8	30.8	20.0	43.3	45.0
Vehicle upload (automated)	27.3	30.3	31.3	33.0	26.4	29.3
Vehicle upload (manual backup)	18.1	18.3	19.8	23.3	18.9	21.0
Cannon loader (automated)	25.8	30.3	30.8	33.0	37.3	40.5
Cannon loader (manual backup)	21.0	18.7	25.9	28.0	17.9	17.5
Crew (threat to)	29.1	26.7	29.8	32.0	24.0	24.0
Crew (distance from center of mass)	19.7	21.3	17.3	18.0	14.8	15.0
Projectiles (threat to)	18.2	16.8	19.5	24.0	16.0	16.5
Projectiles (venting feasibility)	15.5	13.0	20.3	20.0	18.3	16.5
Projectiles (crew distance from)	14.0	9.3	25.2	28.0	24.3	27.0
Projectiles (distance from center of mass)	15.7	16.8	20.8	24.0	17.8	19.5
MACs (threat to)	16.2	16.3	20.5	24.0	16.0	16.5
MACs (venting feasibility)	23.3	23.2	22.5	24.0	20.3	19.5
MACs (crew distance from)	26.8	26.8	24.4	26.0	24.0	27.0
MACs (distance from center of mass)	21.0	21.0	23.2	28.0	19.2	21.0
System reliability	27.0	29.0	33.0	30.0	27.0	27.5
Accessibility to mission equipment	21.4	17.9	23.9	25.7	14.0	14.0
Accessibility to powerpack	26.8	21.6	26.8	30.3	19.1	21.0
Crew vision	25.3	41.4	29.2	30.0	26.7	30.0
Crew safety	21.8	20.2	23.8	28.0	19.0	21.0
Crew interaction	34.5	31.3	34.3	36.0	28.2	31.5
Crew firing dynamics	37.5	21.0	39.6	45.0	27.5	30.0
Crew ingress/egress	20.5	34.9	23.7	24.0	20.7	24.0
Crew ride quality	20.0	12.6	20.7	25.0	13.3	15.0
Center of gravity	38.5	35.5	33.0	36.0	11.7	9.0
Combat load	28.0	26.7	29.9	34.7	17.1	16.0
Curb weight	23.2	23.7	23.0	24.0	22.4	24.0
Integration technical risk	22.0	25.3	21.8	27.0	16.3	15.8
Subcomponent commonality	13.1	13.9	16.3	21.7	17.1	17.5
Cost	21.6	22.0	22.0	24.0	17.2	16.0
Total system scores	**721.1**	**725.9**	**783.9**	**854.7**	**657.3**	**691.3**

5.2 RSV

A comparison of the RSV component-level scores is shown in Table 12. As shown, the CCAC concept scored slightly higher than the other three. There was not enough difference in the totals of the Benet and ORNL concepts to put any kind of ranking on them. The CCAC concept received higher scores in the *Complexity* and *Manual backup* criteria but lost points in the *Volume* criteria.

Table 12. Comparison of RSV component scores

	Benet A	Benet B	CCAC	ORNL
Complexity	30.3	30.1	34.9	31.2
Volume	27.2	27.6	22.6	26.3
Weight	19.2	19.2	19.8	20.8
Accessibility	18.5	18.5	22.4	20.2
Selectability	35.8	36.5	37.6	36.8
Manual backup	15.5	15.2	22.1	17.4
Commonality	18.3	18.3	17.0	14.7
Projectile compartmentation	19.3	19.2	19.1	16.0
MACs compartmentation	20.0	18.9	21.0	16.2
Technical risk (5 = low risk)	24.3	23.9	27.3	25.5
Transfer rate	28.6	28.6	26.9	31.7
Component total score	**257.0**	**256.0**	**270.7**	**256.7**

Table 13 shows a comparison of the RSV system-level scoring. Again, the CCAC concept received the highest total score. The Benet A and ORNL concepts received approximately the next highest scores, which were close enough to each other to be indistinguishable for purposes of ranking, followed by Benet B.

5.3 SCORING SUMMARY

The BTA was to be determined by the concepts with the highest system score. In both the RSV and the SPH, the CCAC concepts had the highest scores. Table 14 summarizes the concept scoring for both vehicles. The risk score shown in the table came from the component-level scores and should be an indication of the evaluators' assessment of the risks inherent to the subsystems used in each concept. As with all the evaluated criteria, a higher number in the risk criteria is better.

Table 13. Comparison of RSV system scores

Criteria	Benet A	Benet B	CCAC	ORNL
Docking (RSV to SPH)	28.1	27.8	36.1	34.4
Docking (RSV to RSV)	19.6	19.4	24.9	24.3
Transfer (RSV to SPH)	32.2	32.2	30.0	36.7
Transfer (RSV to RSV)	22.2	22.2	20.6	25.9
Transfer (RSV to ground)	14.2	14.4	14.4	16.4
Crew (threat to)	24.2	25.3	30.7	25.3
Crew (distance from center of mass)	19.8	22.5	20.3	21.0
Projectiles (threat to)	19.3	17.3	19.3	16.2
Projectiles (venting feasibility)	23.4	22.3	23.8	20.3
Projectiles (crew distance from)	23.7	23.8	15.0	23.8
Projectiles (distance from center of mass)	17.3	17.3	15.5	20.3
MACs (threat to)	18.3	18.2	19.3	17.2
MACs (venting feasibility)	21.3	21.3	23.8	20.3
MACs (crew distance from)	14.2	14.0	20.0	13.2
MACs (distance from center of mass)	17.5	18.2	19.5	15.8
System reliability	28.6	28.9	37.2	35.6
Accessibility to mission equipment	23.1	22.0	28.8	23.7
Accessibililty to powerpack	26.6	18.9	23.3	18.7
Crew vision	43.9	40.8	25.3	45.3
Crew safety	20.0	21.2	21.4	20.9
Crew interaction	30.9	30.7	29.1	28.5
Crew ride quality	17.1	13.5	20.8	14.3
Ingress/egress	30.4	30.7	20.3	29.8
Center of gravity	27.6	27.6	31.1	25.8
Combat load	28.3	23.2	31.2	23.7
Curb weight	28.0	26.4	26.7	26.9
Integration technical risk	24.2	24.0	27.1	21.6
Subcomponent commonality	16.5	16.7	15.4	9.9
Cost	25.6	25.6	28.3	28.8
Total system scores	**686.2**	**666.4**	**699.4**	**684.6**

Table 14. Solid propellant concept scoring summary

RSV			SPH		
Concept	System score	Component risk	Concept	System score	Component risk
CCAC	699	27.3	CCAC B	855	28.0
Benet A	686	24.3	CCAC A	784	25.3
ORNL	685	25.5	Benet B	726	24.1
Benet B	666	23.9	Benet A	721	24.4
			FSAC B	691	25.4
			FSAC A	657	22.8

5.4 BTA SELECTION

The CCAC RSV concept was selected by the MAC resupply team to be the BTA concept. In the case of the SPH, the team chose CCAC Concept A as the BTA to be considered.

The reasoning behind choosing the second-highest rated SPH concept over the first was because of the averaging used in compiling the total scores. Six different organizations participated in the evaluation process and evaluated all four of the RSV concepts and all the "A" howitzer concepts. However, CCAC Concept B was evaluated by only three organizations, while FSAC Concept B was evaluated by four. The basic reason for this was that the evaluation package did not adequately distinguish them as separate concepts, only as variations of the A concepts.

The three organizations which evaluated CCAC Concept B typically gave higher scores to all concepts than did the three organizations which did not evaluate CCAC B. The average of three relatively high scores was higher than the average of three high and three low scores, and this caused CCAC Concept B to receive the highest overall score. This can be seen in Table 15. The average score given by evaluating organization No. 1 for the four concepts it evaluated was 585. The three organizations which evaluated every SPH concept (Nos. 4, 5, and 6) all typically gave higher scores than the three that did not evaluate CCAC B. Without the lower scores incorporated into its average, CCAC B had a higher overall score than CCAC A.

Table 15. Evaluating organizations

	No. 1 (4 concepts)	No. 2 (4 concepts)	No. 3 (5 concepts)	No. 4 (6 concepts)	No. 5 (6 concepts)	No. 6 (6 concepts)
Average SPH score given	585	538	581	586	802	658

Because CCAC Concept B was submitted only as a more conventional alternative to CCAC Concept A, the team felt that Concept A should be used as the BTA. This concept had some advantages over Concept B, including better utilization of the interior volume, elimination of the interface between the half-turret and the rear of the vehicle, and improved sealing around the tilt ring. Although a tilt ring howitzer is unconventional compared to current designs, the team decided to pursue this concept while continuing study on the configuration.

6. BTA DESCRIPTION

The following section describes in more detail the Crusader Solid Propellant SPH and RSV BTA concepts submitted by CCAC.

6.1 OVERALL CONCEPT

The BTA is built upon a front-engine chassis for both the SPH and the RSV, with variable height suspension and counter-rotation handoff to either the SPH fire control system or the RSV operator. Each vehicle has a crew of three placed low in the hull forward of the machinery.

The SPH (shown in Fig. 3 and repeated below as Fig. 11 for convenience) has a limited traverse mini-turret mounted on a tilted ring. A fully redundant dual autoloader system transfers projectiles to the gun and performs zoning and transfer of MACs to the gun from active storage magazines. These loaders operate both simultaneously and sequentially to maximize the firing rate. The gun is loaded at 0° azimuth and at any elevation angle.

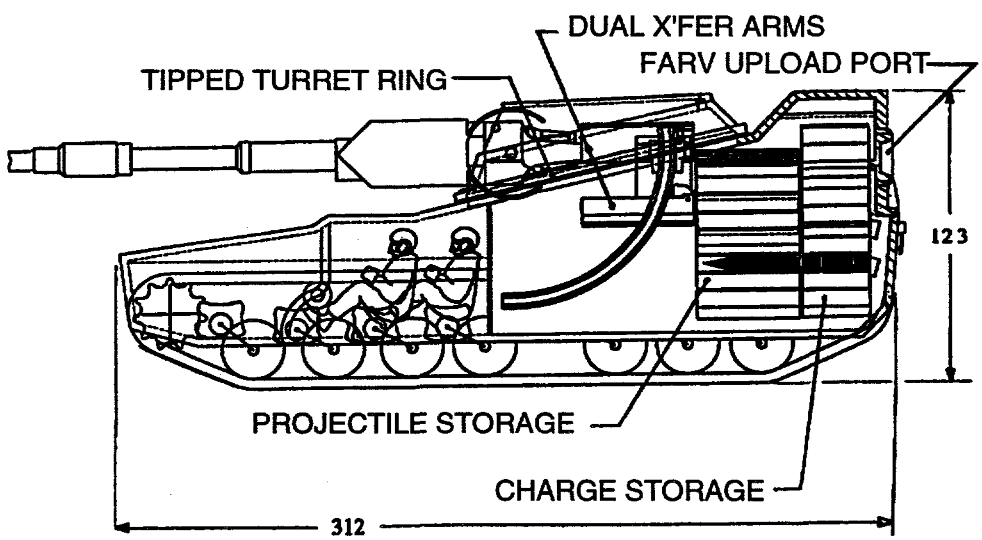

Fig. 11. CCAC SPH Concept A.

The RSV (shown in Fig. 9 and repeated as Fig. 12) contains a pick-and-place device which transfers projectiles from fixed storage cells to the exit conveyor. MACs are contained and transported by active magazines. This approach provides full manual access to both projectiles and charges.

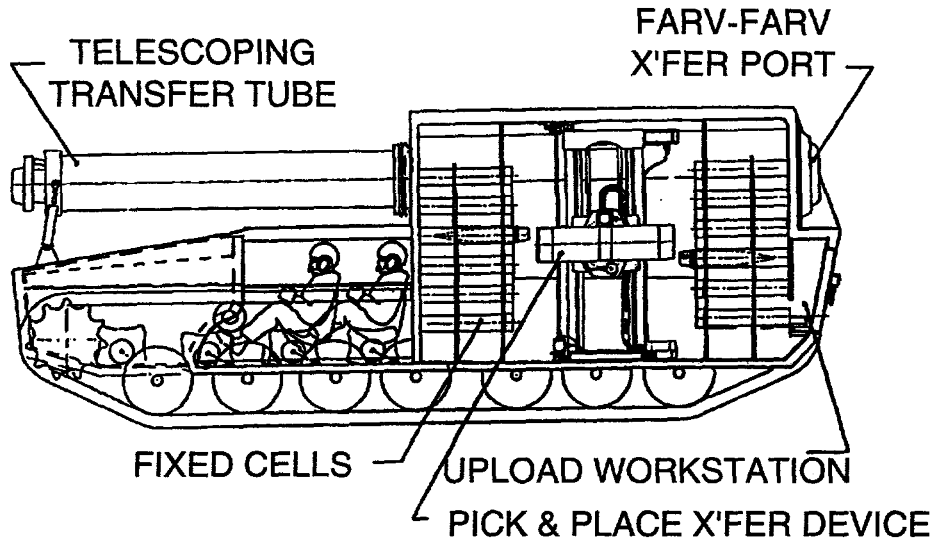

Fig. 12. CCAC RSV concept.

Ammunition is transferred between vehicles via a telescoping transfer tube positioned over the engine area (see Fig. 13). It is remotely guided to the upload port of an SPH or another RSV. The SPH and the RSV both have separate stations for manual upload.

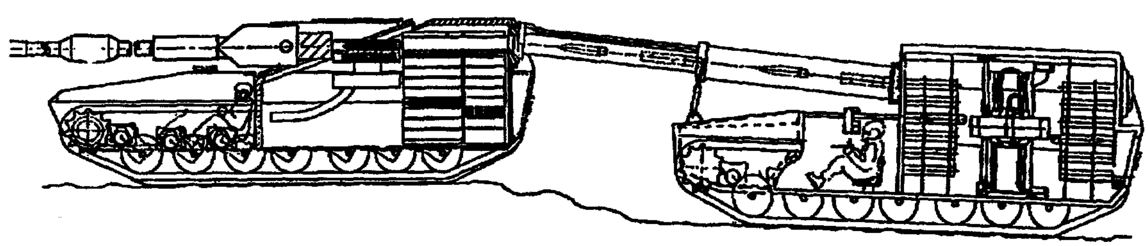

Fig. 13. RSV-to-SPH ammunition transfer.

6.2 TILTED RING/SPH CONCEPT DESCRIPTION

The objective of the tilted ring configuration (see Fig. 14) is to maximize the space available for autoloader machinery, primarily by eliminating the "shelf" created by the turret ring and hull in the conventional howitzer design. This unified space enables a simpler and more efficient loader design. This approach provides a limited gun traverse capability and requires loading of the gun at 0° azimuth but provides a low inertia turret resulting from the placement of all ammunition and loading machinery in the hull.

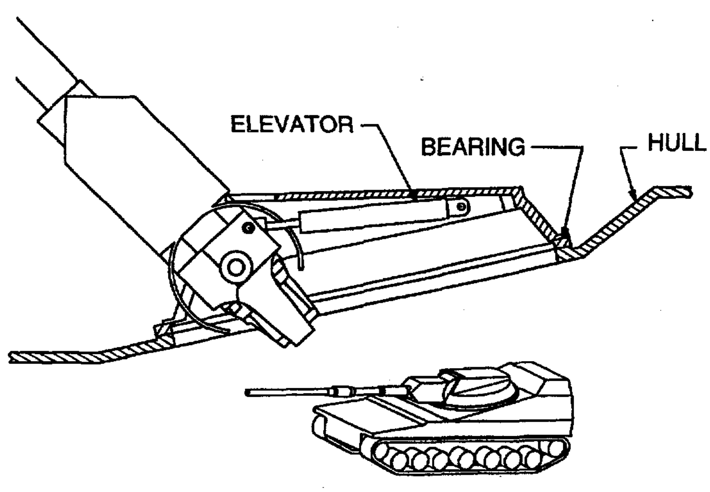

Fig. 14. Tilted turret ring.

The tilt angle of 13° was selected with a goal of minimizing the amount of ring rotation necessary to achieve the required azimuth. Figure 15 shows the maximum ring rotation required as a function of tilt angle for several azimuth ranges. While higher angles provide more space and better ring loading, the selected angle requires only 34° of rotation to achieve 5° of azimuth at maximum elevation (worst case) and is less likely to affect the firing rate. The amount of ring rotation required to achieve a specific azimuth is proportional to the elevation and is thus greatest at the highest elevation. The moment of inertia of the turret, however, is inversely proportional to the elevation since the center of gravity of the gun moves closer to the axis of turret rotation, thereby permitting higher drive speeds for the larger angles.

The ±5°azimuth range of the turret is assumed to meet typical mission needs. However, this range will be augmented by the counter-rotation capability of the power train. Once in place at the firing site, the vehicle counter-rotation control will be transferred to the fire control system which will use it as a coarse adjustment to the line of fire (within 3 or 4°). The turret will then take over to fine tune the gun pointing and make subsequent ballistic adjustments. Figure 16 shows the approximate azimuth capability vs elevation for a 13° tilt angle so that the gun does not contact any other interior systems during its movement. For a given elevation, the gun can rotate in azimuth until the loader line is contacted, which signifies contact with the autoloader within the vehicle. At the maximum elevation this azimuth is ±5°. Note that azimuth ranges increase with decreasing elevation. Therefore, at lower elevation angles, the vehicle's transmission may not have to be used for aiming by the fire control system. This is particularly advantageous in a direct-fire situation, where reaction time would not be impacted by the necessity to rotate the vehicle.

Because of this turret's low inertia, it can be moved at a higher rate than current conventional turrets. Loading at 0° azimuth therefore becomes feasible and eliminates the need to duplicate that capability in the loader design. As shown in the SPH firing time line (see Fig. 17) this movement takes place simultaneous with movement of the loader to and from the breech.

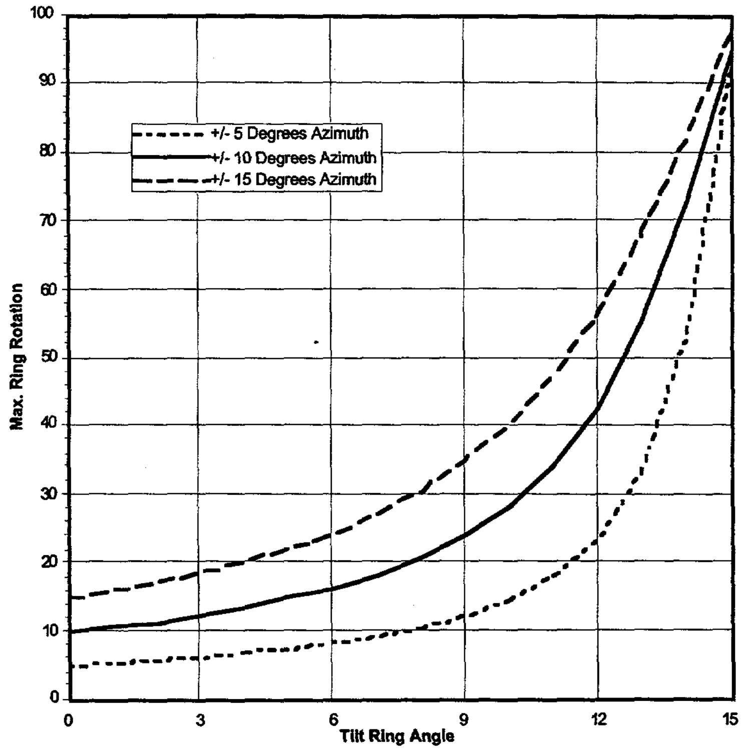

Fig. 15. Ring rotation required for azimuth range.

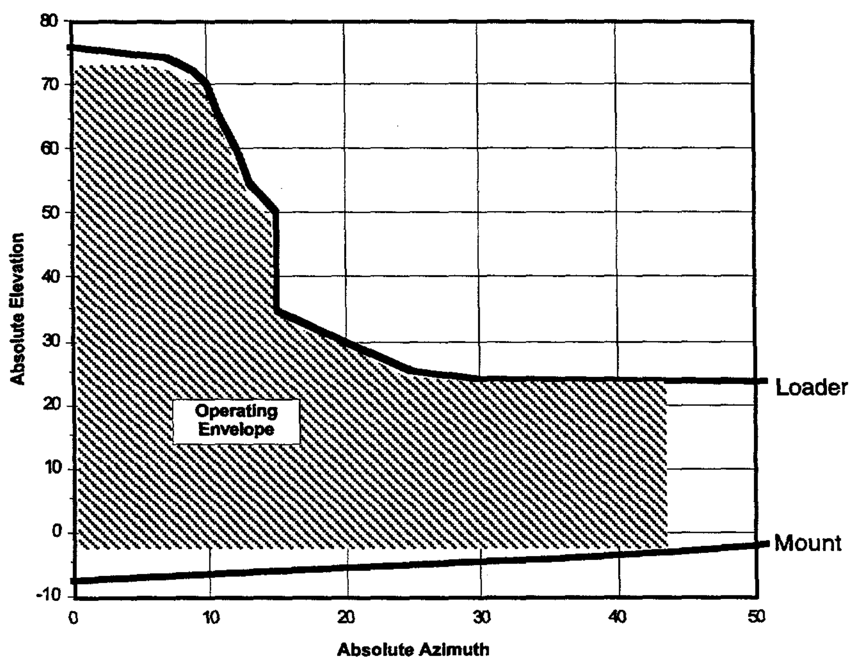

Fig. 16. SPH azimuth range limits.

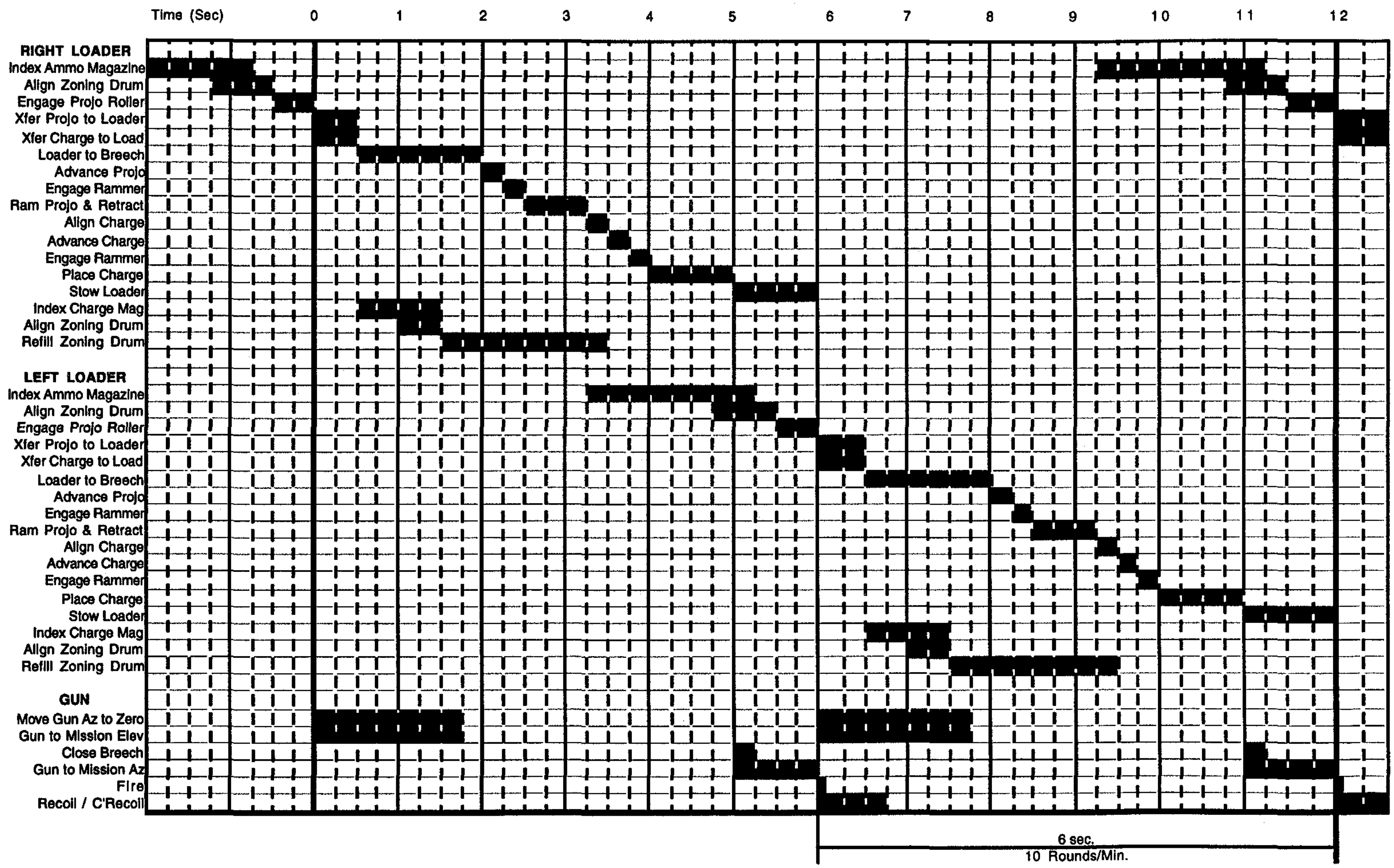

Fig. 17. SPH firing time line.

6.3 SPH AUTOLOADER

The rear section of the SPH hull (see Figs. 18 and 19) contains two pairs of active magazines. The rearward pair contains MACs in groups of four per cell, and the forward pair contains projectiles. The charge magazine may contain any mix of charges grouped in separate cells. Nested within each projectile magazine area is a two-chamber zoning drum containing six charges per chamber.

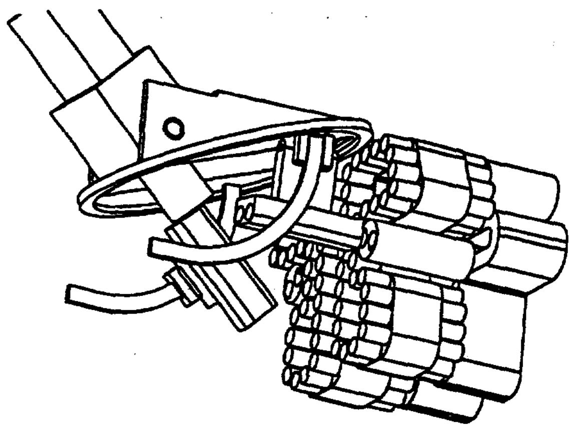

Fig. 18. SPH rearm and storage mechanisms.

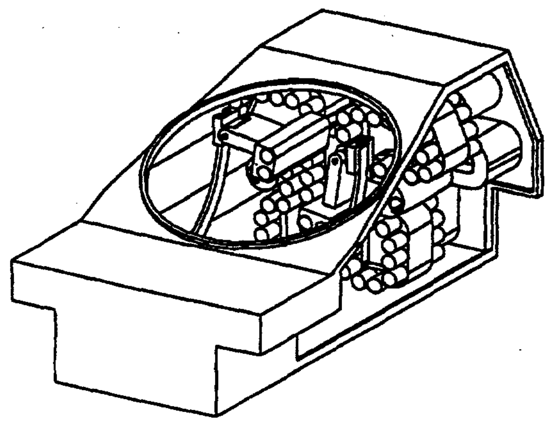

Fig. 19. SPH hull and interior.

Two loading devices, one for each side, travel on circular tracks about the trunnion axis and swing from a stowed position, adjacent to the side of the hull, to the breech (see Fig. 20). Each loader has a projectile cell and a charge cell with transfer mechanisms. In the stowed position, the projectile cell is aligned with a cell of the projectile magazine and the charge cell is aligned with one cell of the zoning drum. Thus, both projectile and charges can be transferred to the loader simultaneously.

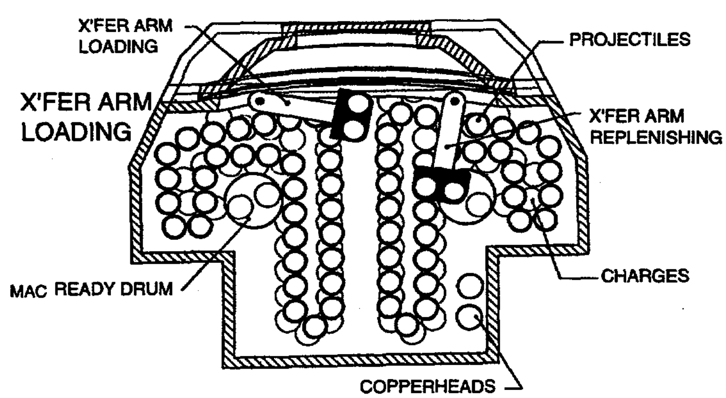

Fig. 20. SPH autoloading mechanisms.

The drum expels only the required number of charges, leaving the remainder behind (see Fig. 21). The drum is then replenished from the charge magazine directly behind it during subsequent loading operations. One chamber on the drum is devoted exclusively to main charges and the other to low zone charges. A full set of MACs is therefore always available upon zone change by rotating the drum.

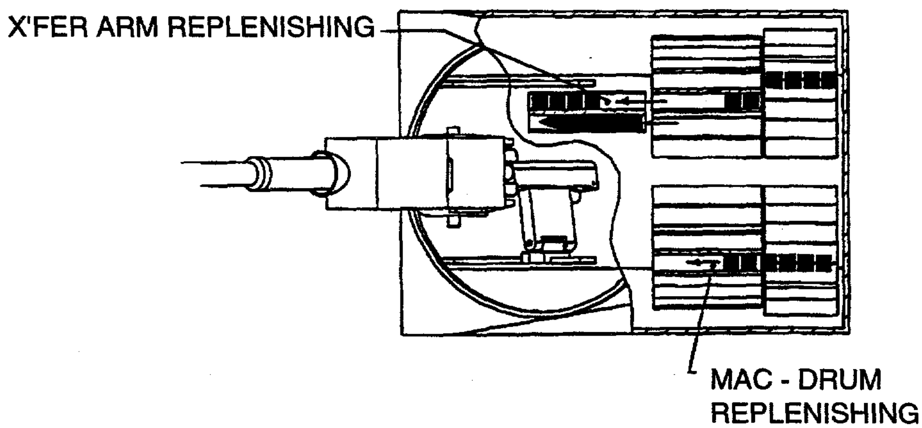

Fig. 21. SPH replenishment drum.

The loader, now filled, travels to the gun axis and successively aligns each loader cell and transfers the projectile and its charges to the gun (see Fig. 22). It then returns to the stowed position while the gun moves to mission azimuth. After firing, the loader replenishment sequence begins again while the opposite side loads the gun. Transfer between cells, chamber, etc., is accomplished by powered rollers and conveyor belts in each location operating in a push-pull manner. The gun is loaded by first advancing the item with the rollers whereupon a ramming device moves in line to push it into the gun chamber.

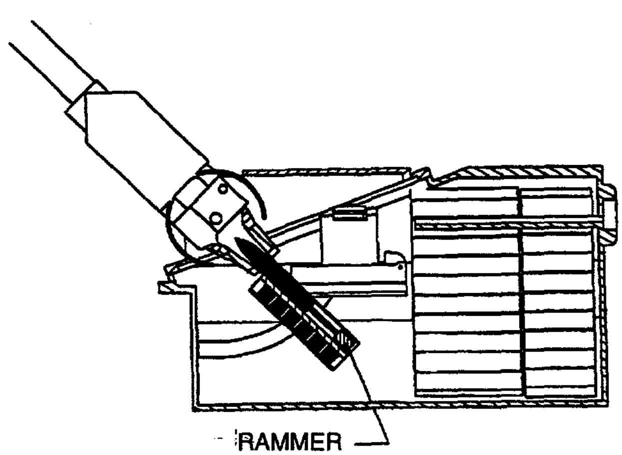

Fig. 22. SPH loader/rammer.

The relationship of these functions is depicted in the time line chart (see Fig. 17.)

The ability of this loader design to carry a full load of charges in any mix is based on the overall dimensional similarity of the two types of charges, particularly the diameter. Altering this similarity may limit the number of each charge type and preclude full capacity for some missions.

Rearming of the SPH is accomplished with the same machinery used to load the gun. A rearm port on the rear of the SPH at the gun trunnion level receives incoming projectiles and MACs on a conveyor between the dual magazines (see Fig. 23). The machinery then operates in a manner opposite to the load sequence to stow the incoming material into the respective magazines (see Fig. 24).

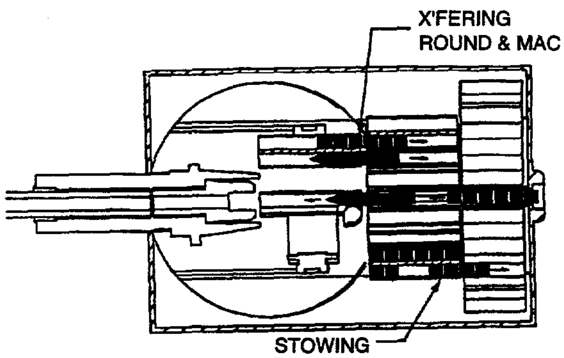

Fig. 23. SPH rearm sequence (top view).

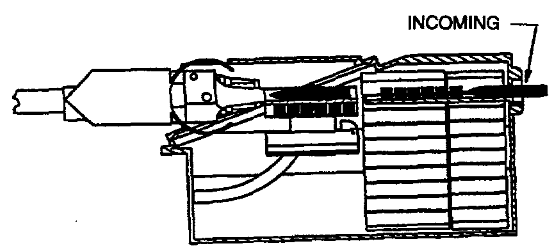

Fig. 24. SPH rearm sequence (side view).

If an RSV is unavailable, a rear door provides for semiautomatic upload via a conveyor, similar to the regular upload entrance conveyor, under the entrance conveyor at a lower level (see Fig. 25). The ammunition is transported uphill to the loader, which is positioned in line with that conveyor, and the sequence would continue as before. Copperhead projectiles are manually placed in separate compartments.

With this feature a Copperhead, accessible from the rear of the vehicle, must be manually removed from this cell to set the fuze. It can then be inserted into the manual upload port and automatically loaded directly into the gun (see Fig. 26), eliminating the need to enter the machinery area.

The SPH can carry 64 projectiles, 2 Copperheads, and 288 charges [75% of Effective Full Charge (EFC)]. The magazines hold 264 charges in any mix, in groups of 4 (of the same type), and the remainder are in the zoning drums. If only one type of charge is to be used, the maximum becomes 276 since one chamber in each zoning drum is reserved for low zone charges.

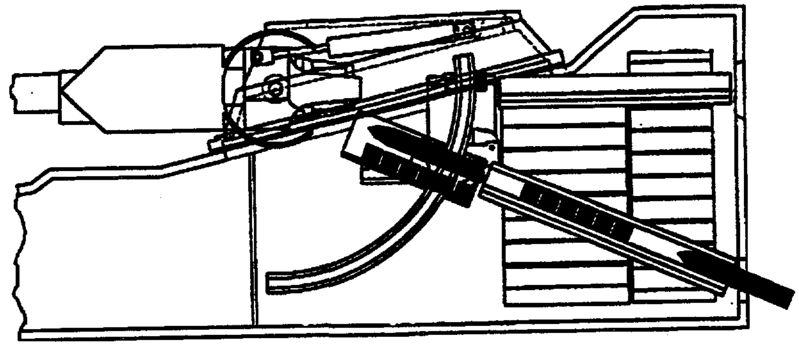

Fig. 25. SPH manual rearm.

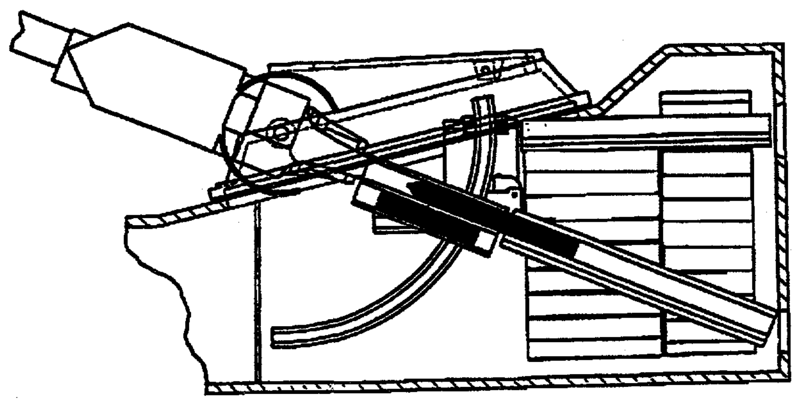

Fig. 26. Copperhead loading.

6.4 RSV CONCEPT DESCRIPTION

The RSV has an array of fixed storage cells on both the front and rear walls of the cargo compartment (see Fig. 12). A pick-and-place transfer device, located between these racks, indexes to the appropriate cell, withdraws a projectile, transports it to the exit port, and expels it into the transfer tube. When accessing rounds from the rearward-positioned storage rack, transfer to the exit port will require a 180° rotation. The RSV can store 132 projectiles and 590 charges. It will transfer 10 complete rounds (projectile + 6 charges) per minute to the SPH.

In order to meet the stringent required upload rate to the SPH, an independent pair of active MAC magazines was incorporated (see Fig. 27). These magazines surround the projectile cells. The front magazine passes adjacent to the exit conveyor where it deposits a set of six MACs onto the conveyor while the transfer device retrieves the next round. The rear magazine is similar but passes the charges forward to continuously replenish the front magazine via a transfer conveyor.

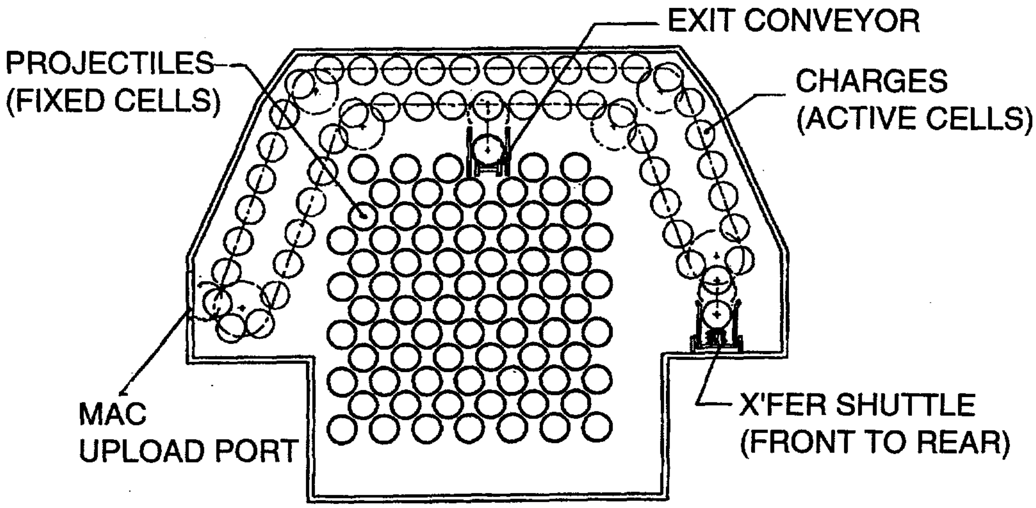

Fig. 27. RSV storage mechanisms.

An upload workstation at the rear of the RSV (see Fig. 28) contains the processing tools for fuzing and weighing the projectiles prior to upload. The fuzed projectile is placed in a drawer-type tray and pushed closed and round information is keyed in. The transfer device then removes it from the other side, stows it in the cell area, and records the information and location. Charges are installed directly into a magazine cell, and the magazine is indexed to the next available cell.

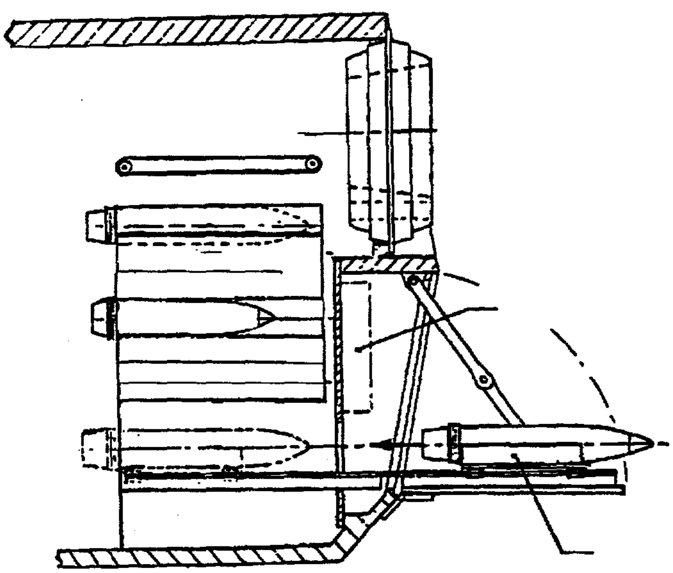

Fig. 28. RSV upload station.

RSV-to-RSV transfer (see Fig. 29) is performed via a rear port identical to that on the SPH. The transfer device, designed to grasp the projectile by the base at the rotating band, normally inserts it into the transfer tube nose first and receives it base first. To upload another RSV therefore requires the projectiles to be sent base first so the second RSV can receive them properly. This is accomplished by placing a secondary pusher directly opposite the exit port of the supplying vehicle. The transfer device positions the projectile base first at the exit port and unlatches it, and the pusher extends into the transfer device to expel the projectile base first out the back of the transfer device into the transfer tube.

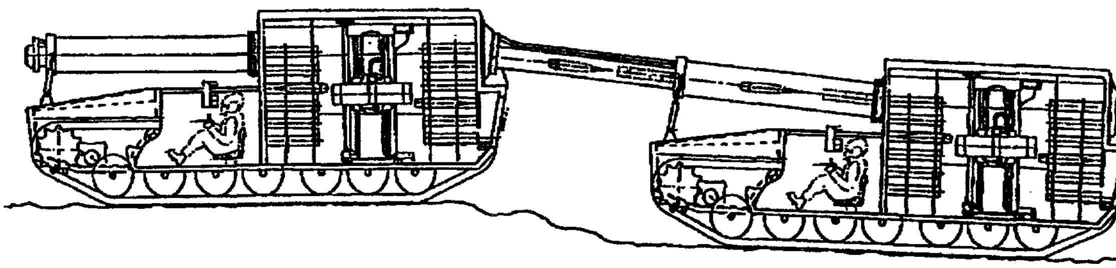

Fig. 29. RSV-to-RSV transfer.

It is apparent at this point that the RSV stores and transfers MACs in groups of six to an SPH which stores them in groups of four. This mismatch is compensated for by the zoning drums acting in reverse whereby the drum receives the full complement of six and, while the loader is retrieving more ammo, distributes them to the charge magazine in groups necessary to successively fill each cell.

6.5 TRANSFER TUBE

The RSV transfer tube (shown in Fig. 12) is a straight telescoping conveyor housed in an enclosure external to the vehicle. It has one universal joint at the vehicle interface and is supported and controlled by two linear actuators arranged in a triangular pattern at the front of the vehicle. The tube can be partially extended and used as a visual alignment guide to position the RSV behind the SPH. The tube is then guided and extended into the self-aligning (swash plate) upload port of the SPH. A limited degree of float allows the tube to self align. If fuel is to be transferred, the tube connector is rotated to align the fuel port, and the fuel connection is completed by the SPH. Both the connection angle and universal joint angle can be minimized by transferring control of vehicle counter-rotation and variable height suspension to the transfer operator.

A short conveyor inside the RSV serves as a transition device for material entering and exiting. It contains sensors and guides to transition the joint, control the ammunition transfer rate, position incoming rounds for the transfer devices, and sort projectiles from charges. The SPH upload port has a similar but simpler device.

7. REAR-ENGINE CONCEPT CONSIDERATIONS

As described in the previous sections, the Solid Propellant Resupply System BTA utilizes front engine configurations for both the RSV and the SPH. These concepts, as well as the other concepts investigated by the team, were not restricted to any particular engine placement or type. Of the four RSV concepts submitted, two were front engine and two were rear. Five of the six SPH concepts were front engine.

In considering an RSV-SPH transfer, most people typically think of transferring ammunition from the front of the RSV to the rear of the SPH. In this scenario, having a rear-engine RSV and a front-engine SPH is advantageous because it allows the access ports to be positioned low on each vehicle. This gives good access when manual upload or download is required. Having a rear-engine SPH requires that ammunition transfer be high in the vehicle or over a sponson in order to get over the engine, thus precluding easy manual loading. This is most likely the reason for the predominance of front-engine SPH concepts.

It is also desirable that both the RSV and SPH be of like configuration to minimize manufacturing and maintenance costs. Engine placement seemed to be more constrained in the SPH because of the reasons described previously. Since front-engine configurations were chosen for both the RSV and the SPH, vehicle commonality is preserved. A front-engine SPH is also traditionally considered to offer a more stable firing platform.

The team noted, however, that the Crusader contractor team has chosen a Perkins diesel engine for use in the Crusader vehicles, which makes a front-engine layout more difficult. System contractor concepts available at this writing utilized rear-engine configurations. The exact space claim required by this engine was not known to the MAC Resupply team, but the team felt that it would be significantly taller than the Advanced Integrated Propulsion System powerpack, which had been under development. The team also felt that utilizing the currently chosen Perkins engine would make a front-engine configuration more difficult.

If the MAC Resupply Team was constrained by the current engine choice, further study would be required. At a minimum, the mobility of the SPH would be affected, and ammunition storage and handling would change drastically from the current concepts.

8. CRITICAL TECHNOLOGIES

Based on the concepts submitted, the team felt that the following technologies were of high risk or critical to the development of a MAC Resupply System. This section describes those technologies and documents their current state of development.

8.1 PROJECTILE/MAC AUTOLOADING AND POSITIONING

The automatic loading of MACs is an area where definite technological challenges remain. FMC, with its Advanced Field Artillery System Technology Demonstrator, and various foreign systems have demonstrated the feasibility of loading artillery projectiles at required firing elevations. However, little work has been done to demonstrate the loading of varying numbers of MACs into a gun chamber. The MAC community is still conducting tests to determine the criticality of the actual positioning of the charges in the chamber. Early testing had shown possible unusual pressure distributions if charges were positioned directly against the rear of the projectile body. Final resolution of this issue could significantly affect the design of the MACs Loader.

The overall artillery concept of separate projectile and propellant systems places a tremendous burden on the loading system if rates of fire on the order of 10 to 12 rounds per minute are to be achieved. Although many operations in the sequence can be completed in parallel, the projectiles and propellant need to be loaded sequentially. This forces the actual operation of loading into the gun chamber to be accomplished in a very short time, requiring high-speed rammers and precise transfer from ramming the projectile to loading the correct number of MACs. Unfortunately the relatively delicate combustible case of the charges, the nearly square length-to-diameter relationship, and the need to position up to six individual charges in the chamber, requires a slower, more controlled ram stroke. Based on preliminary information received on the Japanese automatic loading system, it appears the Japanese system rams charges at less than half the speed that it rams projectiles. In order to achieve the loading rates required, the ramming of MACs into the gun chamber must be optimized wherever possible.

8.2 DOCKING

Giving the user the most flexibility and meeting his basic needs for docking and transferring rounds under the widest practical range of vehicle orientations require the application of critical technologies. Meeting the user requirement of resupplying under armor also makes docking and transferring technologies critical. The degree of docking aids provided to the vehicle driver and the capabilities of the vehicles themselves to adjust their suspension to help establish the required alignments are critical issues.

Additional work is needed in the area of "compliant ports" to assess the feasibility of relatively simple, nonarticulated transfer booms.

8.3 PNEUMATIC LOADING SYSTEM

The pneumatic loading system being developed for FSAC by Vista Controls Corporation has shown potential for use in a MAC resupply system. The pneumatic loader controls the supply of compressed air applied to the rear of a projectile, or MACs, resulting in movement. A velocity sensor is utilized to provide feedback control so that a specific velocity can be achieved. Initial testing with projectiles has demonstrated the ability of the system to ram at all elevations. Issues that need to be addressed include air supply/storage requirements and the ability of the system to adequately load and place one to six MACs. This technology must be evaluated prior to serious future consideration.

8.4 MAC ZONING

Loading of the SPH requires that 1 to 6 charges be selected from a storage system and positioned such that they can be loaded into the gun chamber. This zoning must be done "off-line" so it does not slow the loading rate. The possible variation in length and diameter between the XM231 low zone and the XM232 standard charge will complicate this mechanism. The zoning system should be designed to utilize all charges from each storage location (i.e., it should not leave a group of partially filled cells or bins which would significantly complicate the resupply process).

8.5 MAC AND PROJECTILE IDENTIFICATION

The Crusader requirement to verify projectile type immediately prior to the loading of the gun could have a major effect on the rate of fire that can be achieved. To achieve the desired rates it appears that an identification system must be employed while the projectile is moving to the gun (i.e., a parallel operation). Current efforts at ORNL are working under the assumption that the SPH will utilize two identification systems.The first, used to identify the system data base as the projectile is uploaded, would utilize laser profilometry, color sensing, and/or feature comparison techniques to identify round and fuze types. It would incorporate a vision-based character recognition system to read projectile and fuze lot numbers. The second system would be used as a safety verification before the projectile enters the breech. This system uses a digitized image which can provide enough physical information about the projectile and fuze that their type can be determined without the need for character recognition capabilities (which would read the text on the projectile but would slow down the identification).

MAC identification is still indefinite. Recent user actions indicate that a much longer or different diameter XM231 low zone charge may be required. This will simplify identification but complicate storage and handling. If different colors are to be used on the XM231 and XM232, more effort is needed in the selection of the colors, which have been tentatively selected as green and brown. It would be more cost effective to use a black and white camera for identification, which implies that the colors selected should be reliably identifiable using a gray-scale system.

The most reliable method of MAC identification would likely come from utilizing a data symbology printed directly onto the charges. This symbology could contain all pertinent information about the lot, type, etc. Since MACs are not in current military inventories, the charges could be coded by the manufacturer, where it is the easiest and most cost effective. This would also allow relatively inexpensive scanners to be utilized in the vehicles for identification.

8.6 STORAGE MAGAZINES

In general, storage magazines have been developed in many shapes and sizes. Some unique requirements of this system may present some challenges. The method of loading and unloading the magazine, from the ends or from the side, will require a specific cell design. This must be accomplished at reasonable expense and in a manner that allows the cells to support the projectile body or charges as appropriate.

The MAC magazines have an additional constraint in that the magazine design must ensure that the charges' combustible case material is not damaged by movement through the magazine. Combustible case dust is extremely flammable. Some significant testing will be required at some point to determine if the case material will hold up in the storage system. Also, variation of the charge length and diameters will affect the optimum system design substantially.

8.7 MAC HANDLING

Representatives from the MAC Resupply team have seen the latest design for the XM231 and XM232 containers. The XM232 container holds five charges with separators between charges to prevent propagation. These separators can be removed at once by pulling a strap. This should work well for the initial loading of the RSV. The XM231 container holds three charges with individual cradles that require each charge to be removed from its cradle. This may work fine for manually loading a gun with one or two charges but would seem to be slow and awkward for loading of a quantity of XM231s into the RSV.

8.8 SURVIVABILITY

Detailed survivability measures were not considered by the team at this time. While no study was performed on the types of hits and explosions anticipated, the team considered survivability measures in storage compartmentation and venting, storage fratricide protection, and crew and ammunition location.

8.9 MAC STORAGE

The MAC storage devices discussed in this report are predicated upon the dimensional similarity of both charges to achieve a high density mix which can be varied to suit mission requirements. Recent proposed revisions in MAC design, however, have suggested differences in diameter and/or length between the two types. Such differences may drastically affect the mix capability and storage capacity of both the SPH and the RSV with regard to the interchangeability of storage locations. Of the two, diameter is the most important as it will require dedicated cells for each type of charge, thus fixing the mix by hardware design. An increase in length only, while reducing overall capacity (for a given volume), is not likely to affect the mix variability.

With the increasing trend toward automated battlefield equipment, it is incumbent on the charge developer to consider compatibility with automated handling machinery concepts, as well as the gun, to create more effective weapon systems.

APPENDIX A
SPH SCORING

Table A-1. Benet A SPH Component Scores

Wgt	Criteria	SPH PROJO STORAGE	SPH MAC STORAGE	SPH AUTOLOADER	SPH TO RSV	SPH TO GROUND	MAN UPLOAD SPH	MAN DOWNLOAD SPH	PROJO/MACS VERIF	Weighted Score
		8	8	10	6	6	8	6	9	
10	COMPLEXITY	3.1	3.2	2.8						30.2
8	VOLUME	3.1	3.2	2.6						23.4
6	WEIGHT	2.9	2.9	2.5						16.6
6	ACCESSIBILITY	3.2	3.0	3.1						18.6
10	SELECTABILITY (PROJECTILES, MACS)	3.2	3.5							33.5
6	ZONING (MACS=> 1 THRU 6)			3.4						20.4
5	COMMONALITY	3.4	3.4	3.1						16.4
6	PROJECTILE COMPARTMENTATION	2.9								17.6
6	MAC COMPARTMENTATION		3.4							20.4
8	TECHNICAL RISK (5=low risk)	3.1	3.2	2.9						24.4
9	TRANSFER RATE (DOWNLOAD/UPLOAD)				3.3	2.6	2.9	2.2	3.6	27.0
								Concept Score		248.4

Table A-2. Benet A SPH System Scores

Wgt	Criteria	Score	Wgt	Criteria	Score
7	Gun Orientation Awareness	2.8	10	System Reliability	2.7
10	Rate of Fire (SPH Reload Speed)	2.9	7	Accessibility to Mission Equipment	3.1
9	Upload - Automated	3.0	7	Accessibility to Power Pack	3.8
7	Upload - Manual Backup	2.6			
9	Cannon Loader - Automated	2.9	10	Crew Vision	2.5
7	Cannon Loader - Manual Backup	3.0	6	Crew Safety	3.6
			9	Crew Interaction	3.8
8	Crew - Threat to	3.6	10	Crew Firing Dynamics	3.8
6	Projectiles - Threat to	3.0	8	Crew Ingress/Egress	2.6
6	MACs - Threat to	2.7	5	Crew Ride Quality	4.0
6	Projectiles - Venting Feasibility	2.6			
6	Projectile - Crew Distance From	2.3	9	Center of Gravity	4.3
6	MACs - Venting Feasibility	3.9	8	Combat Load	3.5
6	MACs - Crew Distance From	4.5	8	Curb Weight	2.9
6	Crew - Distance from Center of Mass	3.3			
6	Projectiles - Distance from Center of Mass	2.6	9	Integration Technical Risk (5=Low Risk)	2.4
6	MACs - Distance from Center of Mass	3.5	5	Subcomponent Commonality	2.6
			8	Cost	2.7
	Total Score: 721.1				

Table A-3. Benet B SPH Component Scores

Wgt	Criteria	SPH PROJO STORAGE	SPH MAC STORAGE	SPH AUTOLOADER	SPH TO RSV	SPH TO GROUND	MAN UPLOAD SPH	MAN DOWNLOAD SPH	PROJO/MACS VERIF	Weighted Score
		8	8	10	6	6	8	6	9	
10	COMPLEXITY	2.9	3.2	2.6						29.0
8	VOLUME	3.2	3.2	2.6						23.8
6	WEIGHT	3.0	3.0	2.8						17.3
6	ACCESSIBILITY	2.8	3.0	3.2						18.0
10	SELECTABILITY (PROJECTILES, MACS)	3.4	3.4							33.8
6	ZONING (MACS=> 1 THRU 6)			3.4						20.4
5	COMMONALITY	3.4	3.2	3.2						16.1
6	PROJECTILE COMPARTMENTATION	3.1								18.4
6	MAC COMPARTMENTATION		3.4							20.6
8	TECHNICAL RISK (5=low risk)	3.2	3.2	2.7						24.1
9	TRANSFER RATE (DOWNLOAD/UPLOAD)				3.2	2.9	2.9	2.5	3.7	27.6
									Concept Score	**249.1**

Table A-4. Benet B SPH System Scores

Wgt	*Criteria*	*Score*	*Wgt*	*Criteria*	*Score*
7	Gun Orientation Awareness	3.9	10	System Reliability	2.9
10	Rate of Fire (SPH Reload Speed)	3.3	7	Accessibility to Mission Equipment	2.6
9	Upload - Automated	3.4	7	Accessibility to Power Pack	3.1
7	Upload - Manual Backup	2.6			
9	Cannon Loader - Automated	3.4	10	Crew Vision	4.1
7	Cannon Loader - Manual Backup	2.7	6	Crew Safety	3.4
			9	Crew Interaction	3.5
8	Crew - Threat to	3.3	10	Crew Firing Dynamics	2.1
6	Projectiles - Threat to	2.8	8	Crew Ingress/ Egress	4.4
6	MACs - Threat to	2.7	5	Crew Ride Quality	2.5
6	Projectiles - Venting Feasibility	2.2			
6	Projectile - Crew Distance From	1.6	9	Center of Gravity	3.9
6	MACs - Venting Feasibility	3.9	8	Combat Load	3.3
6	MACs - Crew Distance From	4.5	8	Curb Weight	3.0
6	Crew - Distance from Center of Mass	3.6			
6	Projectiles - Distance from Center of Mass	2.8	9	Integration Technical Risk (5=Low Risk)	2.8
6	MACs - Distance from Center of Mass	3.5	5	Subcomponent Commonality	2.8
			8	Cost	2.8
				Total Score: 725.9	

Table A-5. CCAC A SPH Component Scores

Wgt	Criteria	SPH PROJO STORAGE	SPH MAC STORAGE	SPH AUTOLOADER	SPH TO RSV	SPH TO GROUND	MAN UPLOAD SPH	MAN DOWNLOAD SPH	PROJO/MACS VERIF	Weighted Score
		8	8	10	6	6	8	6	9	
10	COMPLEXITY	3.2	3.2	3.1						31.6
8	VOLUME	3.1	2.9	2.9						23.9
6	WEIGHT	3.2	3.2	3.1						18.9
6	ACCESSIBILITY	3.0	2.4	3.3						17.5
10	SELECTABILITY (PROJECTILES, MACS)	3.4	3.4							33.8
6	ZONING (MACS=> 1 THRU 6)			3.6						21.4
5	COMMONALITY	3.1	3.1	3.3						15.9
6	PROJECTILE COMPARTMENTATION	3.2								19.4
6	MAC COMPARTMENTATION		3.2							19.4
8	TECHNICAL RISK (5=low risk)	3.2	3.2	3.1						25.3
9	TRANSFER RATE (DOWNLOAD/UPLOAD)				3.1	2.3	2.5	2.5	2.8	23.8
								Concept	Score	250.9

Table A-6. CCAC A SPH System Scores

Wgt	Criteria	Score	Wgt	Criteria	Score
7	Gun Orientation Awareness	3.0	10	System Reliability	3.3
10	Rate of Fire (SPH Reload Speed)	3.1	7	Accessibility to Mission Equipment	3.4
9	Upload - Automated	3.5	7	Accessibility to Power Pack	3.8
7	Upload - Manual Backup	2.8			
9	Cannon Loader - Automated	3.4	10	Crew Vision	2.9
7	Cannon Loader - Manual Backup	3.7	6	Crew Safety	4.0
			9	Crew Interaction	3.8
8	Crew - Threat to	3.7	10	Crew Firing Dynamics	4.0
6	Projectiles - Threat to	3.3	8	Crew Ingress/ Egress	3.0
6	MACs - Threat to	3.4	5	Crew Ride Quality	4.1
6	Projectiles - Venting Feasibility	3.4			
6	Projectile - Crew Distance From	4.2	9	Center of Gravity	3.7
6	MACs - Venting Feasibility	3.8	8	Combat Load	3.7
6	MACs - Crew Distance From	4.1	8	Curb Weight	2.9
6	Crew - Distance from Center of Mass	2.9			
6	Projectiles - Distance from Center of Mass	3.5	9	Integration Technical Risk (5=Low Risk)	2.4
6	MACs - Distance from Center of Mass	3.9	5	Subcomponent Commonality	3.3
			8	Cost	2.8
	Total Score: 783.9				

Table A-7. CCAC B SPH Component Scores

Wgt	Criteria	SPH PROJO STORAGE	SPH MAC STORAGE	SPH AUTOLOADER	SPH TO RSV	SPH TO GROUND	MAN UPLOAD SPH	MAN DOWNLOAD SPH	PROJO/MACS VERIF	Weighted Score
		8	8	10	6	6	8	6	9	
10	COMPLEXITY	3.5	3.5	3.0						33.1
8	VOLUME	3.5	3.0	3.0						25.2
6	WEIGHT	3.5	3.5	3.5						21.0
6	ACCESSIBILITY	3.5	3.0	3.5						20.1
10	SELECTABILITY (PROJECTILES, MACS)	4.0	4.0							40.0
6	ZONING (MACS=> 1 THRU 6)			3.0						18.0
5	COMMONALITY	4.0	4.0	5.0						21.9
6	PROJECTILE COMPARTMENTATION	3.0								18.0
6	MAC COMPARTMENTATION		3.0							18.0
8	TECHNICAL RISK (5=low risk)	3.5	3.5	3.5						28.0
9	TRANSFER RATE (DOWNLOAD/UPLOAD)				3.0	1.5	1.5	1.5	3.0	19.3
									Concept Score	**262.6**

Table A-8. CCAC B SPH System Scores

Wgt	Criteria	Score	Wgt	Criteria	Score
7	Gun Orientation Awareness	4.0	10	System Reliability	3.0
10	Rate of Fire (SPH Reload Speed)	2.0	7	Accessibility to Mission Equipment	3.7
9	Upload - Automated	3.7	7	Accessibility to Power Pack	4.3
7	Upload - Manual Backup	3.3			
9	Cannon Loader - Automated	3.7	10	Crew Vision	3.0
7	Cannon Loader - Manual Backup	4.0	6	Crew Safety	4.7
			9	Crew Interaction	4.0
8	Crew - Threat to	4.0	10	Crew Firing Dynamics	4.5
6	Projectiles - Threat to	4.0	8	Crew Ingress/ Egress	3.0
6	MACs - Threat to	4.0	5	Crew Ride Quality	5.0
6	Projectiles - Venting Feasibility	3.3			
6	Projectile - Crew Distance From	4.7	9	Center of Gravity	4.0
6	MACs - Venting Feasibility	4.0	8	Combat Load	4.3
6	MACs - Crew Distance From	4.3	8	Curb Weight	3.0
6	Crew - Distance from Center of Mass	3.0			
6	Projectiles - Distance from Center of Mass	4.0	9	Integration Technical Risk (5 = Low Risk)	3.0
6	MACs - Distance from Center of Mass	4.7	5	Subcomponent Commonality	4.3
			8	Cost	3.0
	Total Score: 854.7				

Table A-9. FSAC A SPH Component Scores

Wgt	Criteria	SPH PROJO STORAGE	SPH MAC STORAGE	SPH AUTOLOADER	SPH TO RSV	SPH TO GROUND	MAN UPLOAD SPH	MAN DOWNLOAD SPH	PROJO/MACS VERIF	Weighted Score
		8	8	10	6	6	8	6	9	
10	COMPLEXITY	2.3	2.3	3.6						28.2
8	VOLUME	3.1	3.1	2.9						24.5
6	WEIGHT	2.7	2.7	2.9						16.7
6	ACCESSIBILITY	2.0	1.8	3.0						13.9
10	SELECTABILITY (PROJECTILES, MACS)	3.4	3.4							33.7
6	ZONING (MACS=> 1 THRU 6)			3.4						20.2
5	COMMONALITY	3.6	3.6	3.4						17.5
6	PROJECTILE COMPARTMENTATION	3.2								19.0
6	MAC COMPARTMENTATION		3.2							19.0
8	TECHNICAL RISK (5=low risk)	2.5	2.5	3.5						22.8
9	TRANSFER RATE (DOWNLOAD/UPLOAD)				2.8	2.8	2.5	2.0	2.8	23.4
								Concept	**Score**	**238.7**

Table A-10. FSAC A SPH System Scores

Wgt	*Criteria*	*Score*	*Wgt*	*Criteria*	*Score*
7	Gun Orientation Awareness	3.1	10	System Reliability	2.7
10	Rate of Fire (SPH Reload Speed)	4.3	7	Accessibility to Mission Equipment	2.0
9	Upload - Automated	2.9	7	Accessibility to Power Pack	2.7
7	Upload - Manual Backup	2.7			
9	Cannon Loader - Automated	4.1	10	Crew Vision	2.7
7	Cannon Loader - Manual Backup	2.6	6	Crew Safety	3.2
			9	Crew Interaction	3.1
8	Crew - Threat to	3.0	10	Crew Firing Dynamics	2.8
6	Projectiles - Threat to	2.7	8	Crew Ingress/ Egress	2.6
6	MACs - Threat to	2.7	5	Crew Ride Quality	2.7
6	Projectiles - Venting Feasibility	3.1			
6	Projectile - Crew Distance From	4.1	9	Center of Gravity	1.3
6	MACs - Venting Feasibility	3.4	8	Combat Load	2.1
6	MACs - Crew Distance From	4.0	8	Curb Weight	2.8
6	Crew - Distance from Center of Mass	2.5			
6	Projectiles - Distance from Center of Mass	3.0	9	Integration Technical Risk (5=Low Risk)	1.8
6	MACs - Distance from Center of Mass	3.2	5	Subcomponent Commonality	3.4
			8	Cost	2.2
		Total Score: 657.3			

Table A-11. FSAC B SPH Component Scores

Wgt	Criteria	SPH PROJO STORAGE	SPH MAC STORAGE	SPH AUTOLOADER	SPH TO RSV	SPH TO GROUND	MAN UPLOAD SPH	MAN DOWNLOAD SPH	PROJO/MACS VERIF	Weighted Score
		8	8	10	6	6	8	6	9	
10	COMPLEXITY	2.3	2.3	4.0						29.7
8	VOLUME	3.0	2.7	3.0						23.2
6	WEIGHT	2.7	2.7	3.0						16.8
6	ACCESSIBILITY	2.0	1.7	3.0						13.7
10	SELECTABILITY (PROJECTILES, MACS)	3.7	3.7							36.7
6	ZONING (MACS=> 1 THRU 6)			3.7						22.0
5	COMMONALITY	4.0	4.0	4.0						20.0
6	PROJECTILE COMPARTMENTATION	3.0								18.0
6	MAC COMPARTMENTATION		3.0							18.0
8	TECHNICAL RISK (5=low risk)	2.7	2.7	4.0						25.4
9	TRANSFER RATE (DOWNLOAD/UPLOAD)				3.0	3.0	2.7	2.0	3.0	24.8
									Concept Score	**248.3**

Table A-12. FSAC B SPH System Scores

Wgt	*Criteria*	*Score*	*Wgt*	*Criteria*	*Score*
7	Gun Orientation Awareness	3.3	10	System Reliability	2.8
10	Rate of Fire (SPH Reload Speed)	4.5	7	Accessibility to Mission Equipment	2.0
9	Upload - Automated	3.3	7	Accessibility to Power Pack	3.0
7	Upload - Manual Backup	3.0			
9	Cannon Loader - Automated	4.5	10	Crew Vision	3.0
7	Cannon Loader - Manual Backup	2.5	6	Crew Safety	3.5
			9	Crew Interaction	3.5
8	Crew - Threat to	3.0	10	Crew Firing Dynamics	3.0
6	Projectiles - Threat to	2.8	8	Crew Ingress/ Egress	3.0
6	MACs - Threat to	2.8	5	Crew Ride Quality	3.0
6	Projectiles - Venting Feasibility	2.8			
6	Projectile - Crew Distance From	4.5	9	Center of Gravity	1.0
6	MACs - Venting Feasibility	3.3	8	Combat Load	2.0
6	MACs - Crew Distance From	4.5	8	Curb Weight	3.0
6	Crew - Distance from Center of Mass	2.5			
6	Projectiles - Distance from Center of Mass	3.3	9	Integration Technical Risk (5=Low Risk)	1.8
6	MACs - Distance from Center of Mass	3.5	5	Subcomponent Commonality	3.5
			8	Cost	2.0
		Total Score: 691.3			

APPENDIX B
RSV SCORING

Table B-1. Benet A RSV Component Scores

Wgt	Criteria	Uploading	RSV Projo Storage	RSV MAC Storage	RSV Handler	Docking Mech	Transfer Mech	Weighted Score
	Subsystem Weights	6	7	7	8	10	8	
10	Complexity	3.0	3.0	3.2	3.4	2.3	3.4	30.3
	Volume	3.3	3.8	3.8	3.4	3.1	3.3	27.2
	Weight	3.3	3.2	3.2	3.2	3.3	3.1	19.2
	Accessibility	3.3	2.8	3.0	2.9	3.3	3.3	18.5
10	Selectability (Projectiles, MACs)		3.4	3.6	3.7			35.8
	Manual Backup	3.1	2.2	2.6	2.4		2.7	15.5
	Component Commonality	3.5	3.7	3.7				18.3
	Projectile Compartmentation		3.3		3.1			19.3
	MAC Compartmentation			3.3				20.0
8	Technical Risk (5=Low Risk)	3.4	3.2	3.0	3.0	2.3	3.6	24.3
	Subsystem Weights	10	4	4	8	5		
		RSV to SPH	RSV to RSV	RSV to Ground	Man Upload	Man Download		
9	Transfer Rate (Download/Upload)	3.8	3.8	3.3	2.4	2.7		28.6
							Concept Score	**257.0**

Table B-2. Benet A RSV System Scores

Wgt	*Criteria*	*Score*	*Wgt*	*Criteria*	*Score*
10	DOCKING - RSV TO SPH	2.8	10	SYSTEM RELIABILITY	2.9
7	DOCKING - RSV TO RSV	2.8	7	ACCESSIBILITY TO MISSION EQUIPMENT	3.3
10	TRANSFER - RSV TO SPH	3.2	7	ACCESSIBILITY TO POWERPACK	3.8
7	TRANSFER - RSV TO RSV	3.2			
5	TRANSFER - RSV TO GROUND	2.8	10	CREW VISION	4.4
			6	CREW SAFETY	3.3
8	CREW - THREAT TO	3.0	8	CREW INTERACTION	3.9
6	CREW - DIST FROM CENTER OF MASS	3.3	8	INGRESS/ EGRESS	3.8
6	PROJECTILES - THREAT TO	3.2	5	CREW RIDE QUALITY	3.4
6	PROJECTILES - VENTING FEASIBILITY	3.9			
6	PROJECTILES - CREW DISTANCE FROM	3.9	8	CENTER OF GRAVITY	3.4
6	PROJECTILES - DIST FROM CENTER OF MASS	2.9	8	COMBAT LOAD	3.5
6	MACS - THREAT TO	3.1	8	CURB WEIGHT	3.5
6	MACS - VENTING FEASIBILITY	3.6			
6	MACS - CREW DISTANCE FROM	2.4	8	INTEGRATION TECHNICAL RISK	3.0
6	MACS - DIST FROM CENTER OF MASS	2.9	5	SUBCOMPONENT COMMONALITY	3.3
			8	COST	3.2
	Total Score: 686.2				

Table B-3. Benet B RSV Component Scores

Wgt	Criteria	Uploading	RSV Projo Storage	RSV MAC Storage	RSV Handler	Docking Mech	Transfer Mech	Weighted Score
	Subsystem Weights	6	7	7	8	10	8	
10	Complexity	3.0	3.0	3.2	3.5	2.3	3.2	30.1
	Volume	3.4	3.8	3.8	3.4	3.2	3.3	27.6
	Weight	3.3	3.1	3.1	3.2	3.3	3.1	19.2
	Accessibility	3.1	2.8	3.0	3.0	3.3	3.3	18.5
10	Selectability (Projectiles, MACs)		3.5	3.7	3.8			36.5
	Manual Backup	3.1	2.2	2.7	2.3		2.5	15.2
	Component Commonality	3.5	3.7	3.7				18.3
	Projectile Compartmentation		3.2		3.2			19.2
	MAC Compartmentation			3.2				18.9
8	Technical Risk (5=Low Risk)	3.4	3.2	3.0	3.0	2.3	3.3	23.9
	Subsystem Weights	10	4	4	8	5		
		RSV to SPH	RSV to RSV	RSV to Ground	Man Upload	Man Download		
9	Transfer Rate (Download/Upload)	3.8	3.8	3.3	2.4	2.7		28.6
							Concept Score	**256.0**

Table B-4. Benet B RSV System Scores

Wgt	*Criteria*	*Score*	*Wgt*	*Criteria*	*Score*
10	DOCKING - RSV TO SPH	2.8	10	SYSTEM RELIABILITY	2.9
7	DOCKING - RSV TO RSV	2.8	7	ACCESSIBILITY TO MISSION EQUIPMENT	3.1
10	TRANSFER - RSV TO SPH	3.2	7	ACCESSIBILITY TO POWERPACK	2.7
7	TRANSFER - RSV TO RSV	3.2			
5	TRANSFER - RSV TO GROUND	2.9	10	CREW VISION	4.1
			6	CREW SAFETY	3.5
8	CREW - THREAT TO	3.2	8	CREW INTERACTION	3.8
6	CREW - DIST FROM CENTER OF MASS	3.8	8	INGRESS/ EGRESS	3.8
6	PROJECTILES - THREAT TO	2.9	5	CREW RIDE QUALITY	2.7
6	PROJECTILES - VENTING FEASIBILITY	3.7			
6	PROJECTILES - CREW DISTANCE FROM	4.0	8	CENTER OF GRAVITY	3.4
6	PROJECTILES - DIST FROM CENTER OF MASS	2.9	8	COMBAT LOAD	2.9
6	MACS - THREAT TO	3.0	8	CURB WEIGHT	3.3
6	MACS - VENTING FEASIBILITY	3.6			
6	MACS - CREW DISTANCE FROM	2.3	8	INTEGRATION TECHNICAL RISK	3.0
6	MACS - DIST FROM CENTER OF MASS	3.0	5	SUBCOMPONENT COMMONALITY	3.3
			8	COST	3.2
	Total Score: 666.4				

Table B-5. CCAC RSV Component Scores

Wgt	Criteria	Subsystem Weights						Weighted Score
		6	7	7	8	10	8	
		Uploading	RSV Projo Storage	RSV MAC Storage	RSV Handler	Docking Mech	Transfer Mech	
10	Complexity	3.9	4.1	3.4	3.2	3.4	3.1	34.9
	Volume	3.4	3.2	3.2	2.5	2.5	2.4	22.6
	Weight	3.4	3.8	3.8	3.6	2.8	2.7	19.8
	Accessibility	3.5	4.1	4.1	4.1	3.6	3.1	22.4
10	Selectability (Projectiles, MACs)		3.7	3.7	3.8			37.6
	Manual Backup	3.7	4.0	3.8	3.8		3.3	22.1
	Component Commonality	3.5	3.4	3.4				17.0
	Projectile Compartmentation		3.3		3.1			19.1
	MAC Compartmentation			3.5				21.0
8	Technical Risk (5=Low Risk)	3.8	4.0	3.6	3.6	2.8	3.1	27.3
		Subsystem Weights						
		10	4	4	8	5		
		RSV to SPH	RSV to RSV	RSV to Ground	Man Upload	Man Download		
9	Transfer Rate (Download/Upload)	2.8	3.2	3.1	3.1	3.0		26.9
						Concept Score		**270.7**

Table B-6. CCAC RSV System Scores

Wgt	Criteria	Score	Wgt	Criteria	Score
10	DOCKING - RSV TO SPH	3.6	10	SYSTEM RELIABILITY	3.7
7	DOCKING - RSV TO RSV	3.6	7	ACCESSIBILITY TO MISSION EQUIPMENT	4.1
10	TRANSFER - RSV TO SPH	3.0	7	ACCESSIBILITY TO POWERPACK	3.3
7	TRANSFER - RSV TO RSV	2.9			
5	TRANSFER - RSV TO GROUND	2.9	10	CREW VISION	2.5
			6	CREW SAFETY	3.6
8	CREW - THREAT TO	3.8	8	CREW INTERACTION	3.6
6	CREW - DIST FROM CENTER OF MASS	3.4	8	INGRESS/EGRESS	2.5
6	PROJECTILES - THREAT TO	3.2	5	CREW RIDE QUALITY	4.2
6	PROJECTILES - VENTING FEASIBILITY	4.0			
6	PROJECTILES - CREW DISTANCE FROM	2.5	8	CENTER OF GRAVITY	3.9
6	PROJECTILES - DIST FROM CENTER OF MASS	2.6	8	COMBAT LOAD	3.9
6	MACS - THREAT TO	3.2	8	CURB WEIGHT	3.3
6	MACS - VENTING FEASIBILITY	4.0			
6	MACS - CREW DISTANCE FROM	3.3	8	INTEGRATION TECHNICAL RISK	3.4
6	MACS - DIST FROM CENTER OF MASS	3.3	5	SUBCOMPONENT COMMONALITY	3.1
			8	COST	3.5
	Total Score: 699.4				

Table B-7. ORNL RSV Component Scores

Wgt	Criteria	Uploading	RSV Projo Storage	RSV MAC Storage	RSV Handler	Docking Mech	Transfer Mech	Weighted Score
	Subsystem Weights	6	7	7	8	10	8	
10	Complexity	3.3	3.8	2.7	2.8	2.9	3.3	31.2
	Volume	3.3	3.6	4.0	2.7	3.1	3.3	26.3
	Weight	3.4	4.0	3.8	3.3	3.1	3.4	20.8
	Accessibility	3.3	3.9	2.9	3.1	3.5	3.3	20.2
10	Selectability (Projectiles, MACs)		3.8	3.3	3.9			36.8
	Manual Backup	3.0	3.9	2.1	3.1		2.5	17.4
	Component Commonality	3.4	2.7	2.7				14.7
•	Projectile Compartmentation		3.0		2.3			16.0
	MAC Compartmentation			2.7				16.2
8	Technical Risk (5=Low Risk)	3.7	3.6	2.8	2.8	3.0	3.4	25.5
		RSV to SPH	RSV to RSV	RSV to Ground	Man Upload	Man Download		
	Subsystem Weights	10	4	4	8	5		
9	Transfer Rate (Download/Upload)	3.7	3.7	3.6	3.4	3.3		31.7
							Concept Score	256.7

Table B-8. ORNL RSV System Scores

Wgt	Criteria	Score	Wgt	Criteria	Score
10	DOCKING - RSV TO SPH	3.4	10	SYSTEM RELIABILITY	3.6
7	DOCKING - RSV TO RSV	3.5	7	ACCESSIBILITY TO MISSION EQUIPMENT	3.4
10	TRANSFER - RSV TO SPH	3.7	7	ACCESSIBILITY TO POWERPACK	2.7
7	TRANSFER - RSV TO RSV	3.7			
5	TRANSFER - RSV TO GROUND	3.3	10	CREW VISION	4.5
			6	CREW SAFETY	3.5
8	CREW - THREAT TO	3.2	8	CREW INTERACTION	3.6
6	CREW - DIST FROM CENTER OF MASS	3.5	8	INGRESS/ EGRESS	3.7
6	PROJECTILES - THREAT TO	2.7	5	CREW RIDE QUALITY	2.9
6	PROJECTILES - VENTING FEASIBILITY	3.4			
6	PROJECTILES - CREW DISTANCE FROM	4.0	8	CENTER OF GRAVITY	3.2
6	PROJECTILES - DIST FROM CENTER OF MASS	3.4	8	COMBAT LOAD	3.0
6	MACS - THREAT TO	2.9	8	CURB WEIGHT	3.4
6	MACS - VENTING FEASIBILITY	3.4			
6	MACS - CREW DISTANCE FROM	2.2	8	INTEGRATION TECHNICAL RISK	2.7
6	MACS - DIST FROM CENTER OF MASS	2.6	5	SUBCOMPONENT COMMONALITY	2.0
			8	COST	3.6
	Total Score: 684.6				

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