Rapid Delivery Launch System (RaDLS) Concept Study

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1.0 Abstract

This paper examines a potential application of advanced propulsion, avionics, and structural technologies to provide a viable, low-cost launch system for the United States Navy. The concept, called the Rapid Delivery Launch System or RaDLS provides a tactical user with a highly capable and rapid response launch system to meet anticipated warfighter needs in both peacetime and crisis. RaDLS has a multi-mission capability to serve as a target vehicle, a tactical missile, and a high altitude balloon deployment system. RaDLS can be deployed and launched from either sea or land using a boost propulsion system based on hybrid technology. In its two stage configuration, RaDLS can place a 1,600 kg (3,526 lbs) payload up to 2,000 km (1,080 nmi) downrange. Its second stage is designed to serve as a stand-alone booster with a unique set of capabilities to meet specific mission needs. RaDLS can provide an increased capability for the Navy to meet emerging needs while significantly reducing cost.

2.0 Background

During the 1980's, the Department of Defense (DoD), the National Aeronautics and Space Administration (NASA), and Industry invested heavily in enabling launch vehicle technologies. The focus was primarily on lighter weight, higher performance, and lower cost systems. Key technology breakthroughs were made in the areas of hybrid propulsion systems, advanced composite structures, Inertial Navigation Systems integrated with the Global Positioning System (INS/GPS), and highly capable computer processing architectures. Additional process-related technologies in the areas of rapid-prototyping, non-destructive test and evaluation, low-cost manufacturing, and information-handling technologies have made possible reusable launch systems. Based on these developments, an investigation was undertaken to postulate a launch system that could undertake a variety of missions that included:

- A low-cost, target system to simulate theater ballistic missile (TBM) threats from land and sea. The capability to perform a sea-launch is critical in terms of simulating submarine TBM launches. This same capability also allows multi-azimuth, multi-range launches in existing treaty-approved test ranges.
- A low-cost, highly accurate tactical missile system capable of being launched at sea under rapid deployment conditions.
- A low-cost, boost vehicle capable of being launched at sea under rapid deployment conditions and capable carrying an unmanned aerial reconnaissance system (e.g., a balloon package) to support demanding national security requirements.

Finally, launch systems are constrained by the relevant sections of the Strategic Arms Reduction Treaty (START), the Anti-Ballistic Missile (ABM) treaty, and the treaty on the elimination of Intermediate-Range and Shorter-Range Missiles (INF). A preliminary review of the requirements was incorporated into the designs of the target vehicle and the low-cost boost vehicle for the balloon package.

3.0 Investigation Objectives and Constraints

Existing targets to simulate the TBM threat are expensive and of limited flexibility. Supplies of these vehicles rely heavily on aging surplus weapons designed for other purposes and mandate the need for extensive support resources. To meet the anticipated TBM need, a low-cost target system with multiple capabilities was defined (See Figure 1). Key investigation objectives included the following requirements:

- provide up to 1,600 kg (3,525 lbs) at up to 2,000 km (1,080 nmi) to simulate TBM threats;

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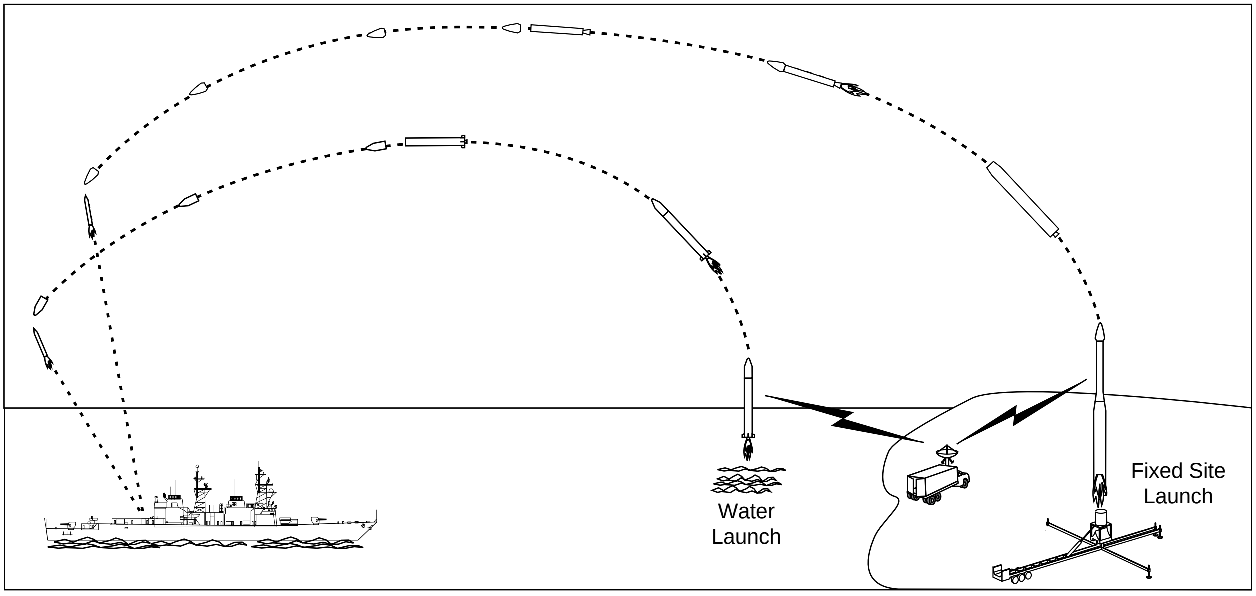


Figure 1. RaDLS Target Vehicle Supports Land or Water Launches

- provide flexible deployment scenarios, including sea or land launch;
- provide the capability for tailoring thrust for varied trajectory profiles and the ability to dope the propellant for plume signature simulation;
- provide the capability to add payload appliques simulating TBM RF emissions;
- provide rapid deployment and launch, coupled with minimal launch support infrastructure, safety and ease of use; and
- utilize a fully autonomous INS/GPS guidance and range safety system.

The primary attributes for a low-cost and highly accurate tactical missile system included a goal of a circle of error probable (CEP) of 9.14 m (30 ft), a 680 kg (1,500 lbs) payload capability, and an ultimate range of 3,500 km (1,890 nmi). Additionally, the attributes required for an balloon package [containing a 159 kg (350 lbs) communications and surveillance payload] included the capability to rapidly boost the package to initial altitudes of 69,060 m (200,000 ft) and to deploy the package allowing surveillance of large geographic areas of interest for extended periods of time. Finally, the need to meet treaty obligations mandates that a water-launched target vehicle must maintain a maximum range of ≤500 km (270 nmi). Range capabilities ≥500 km require fixed launchers that are above ground and located at only those launch sites specified within the relevant treaty.

4.0 Enabling Technologies

4.1 Hybrid Propulsion

Recent technology advancements have resulted in the development of a hybrid propulsion system (See Figure 2) that combines the advantages of the hybrid combustion mechanism and the superior safety advantages of a low-cost, non-cryogenic oxidizer (i.e. 90% hydrogen peroxide, H_2O_2).

An added advantage is that the storage, handling, and use of the hybrid propulsion is also environmentally acceptable. The hybrid propulsion system consists of a solid fuel grain, nominally using hydroxol-terminated polybutadiene (HTPB), and a liquid oxidizer. The oxidizer is either pressure or turbopump fed into the fuel chamber through a main oxidizer valve and injector. The fuel chamber is typically of a “wagon-wheel” geometry. The hybrid propulsion enables a robust design that supports the low-cost manufacturing and testing approach needed for the application. The hybrid propulsion system is a zero TNT equivalent offering unmatched safety and eliminating the toxicity considerations of the usual liquid and solid fuels. The system is relatively simple, requiring only one liquid propellant feed system for the oxidizer and the inert solid fuel grain. The combustion products are environmentally acceptable, containing no particulates, HCl, or Al_20_3. The design and manufacture of the hybrid propulsion system does not require any major technology development since the system incorporates conventional materials and existing manufacturing processes for both the non-toxic fuel grain and the oxidizer. During the testing and operational phases, minimal environmental and safety restrictions are anticipated due to the ease of material storage and the low risk of catastrophic failure modes.

4.2 Advanced Composite Structures

Recent advancements in technology and manufacturing technology are enabling the use of low-cost, lightweight, and reusable materials that stress manufac-

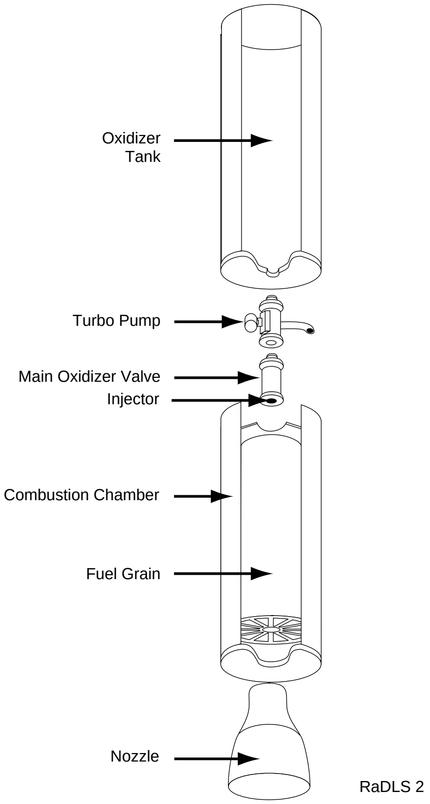


Figure 2. Hybrid Propulsion System

turability and allow in-field refurbishment. As an example, the use of liquid crystal polymers or the use of composite overwrapped tankage offer the potential for ease-of-manufacturing and rapid production. Coupled with these advantages is the overall mass reduction with the consequent increase in vehicle performance.

4.3 Navigation Technologies

Substantial efforts to miniaturize and integrate attitude sensors have taken place during the last few years. As an example, NRL's CLEMENTINE mission demonstrated the use of a small and relatively inexpensive interferometric fiber optic gyroscope (IFOG) inertial measurement unit (IMU) derived from the COMANCHE helicopter program.[1] The IFOG IMU weighs ≤0.65 kg (1.43 lbs) and provides a long-term bias stability of ≤1.0 degree per hour with no moving parts. Similarly, small, very high performance hemispherical resonator gyroscopes (HRG) are now becoming available. These devices, coupled with the use of autonomous GPS positioning, offers the opportunity to obtain integrated INS/GPS systems providing accurate positioning information without reference to external systems. GPS can provide not only highly-accurate time, but also vehicle attitude by use of an interferometric pair of antennas located on the boost vehicle. Existing GPS provides accuracies of ≤100 meters CEP with an inexpensive GPS receiver weighing ≤2 kg (4.4 lbs). A integrated INS/GPS can potentially provide a CEP accuracy of ≤9.1m (30 ft) over ranges of 1852 km (1000 nmi).

4.4 Flight Avionics

Advances in electronics technology, more than any other field, have enabled the most significant decrease in the size of hardware. Dramatic improvements made in the integration and speed of integrated circuits, combined with the associated reliability of these circuits, has allowed a substantial reduction in the mass, volume, and power requirements of launch vehicle systems. A paradigm shift in the design of launch vehicle avionics is possible due to the inclusion of highly capable microprocessor architectures. Specifically, the use of distributed computing architectures, coupled with the use of high level languages, can expedite the mission-critical software development and validation process. Fiber optic data buses (e.g., MIL-STD-1773) are finding their way into a variety of airborne applications and are appropriate for launch vehicles. Optical buses provide higher data rates with additional immunity to electromagnetic interference (EMI) and offer lower weight electrical cabling.

4.5 Parafoil Recovery

Advancements in RAM-Air canopy and autonomous airborne guidance technology make precision recovery of the RaDLS first stage a viable option. Existing and tested parafoil systems have flown more than six times the anticipated RaDLS payload at twice the anticipated RaDLS flight velocity from 50% higher altitudes with approximately half the miss distance of previous attempts. RAM-Air canopies have demonstrated support of payload recoveries of ≥13,154 kg (29,000 lbs). Advanced reefing systems enable the deployment of large, highly loaded canopies, at high altitude. Advancements in navigation technologies (See Section 4.3) allow for autonomous flight of a parafoil system. A range of sensors including GPS, air speed indicators, compasses, and altimeters, used in conjunction with on-board computer and guidance algorithms, can autonomously 'fly' the RAM-air canopy. In flight, the autonomous piloting system can continuously monitor and update for changes in the wind conditions. This system can be developed to 'fly' autonomously or be used in conjunction with a ground station. The ground station may be used to take manual control of the system or as a beacon.

5.0 Vehicle Performance and Flight Profiles

RaDLS offers a complete launch system that includes the launch vehicle [in one of two possible configurations (i.e., fixed site or water launch)], the associated launch facilities, and related services. The launch vehicle is basically a two-stage vehicle using hybrid propellants and an integrated INS/GPS system. Depending upon the required performance (See Table 1) and the composition

Table 1. Comparison of RaDLS Vehicle Configurations

Parameter	2-Stage Launch Configuration	2nd Stage “Stand-Alone” Launch Configuration
Gross Lift-Off Weight (Minus Payload)	18,263 kg (40,263 lbs)	3,071 kg (6,770 lbs)
Stage 1 Thrust	541.8 kN (121.81 klbs)	n/a
Stage 2 Thrust	116.9 kN (26.282 klbs)	116.9 kN (26.282 klbs)
Recovery Weight	1,992 kg (4,391 lbs)	557 kg (1,227 lbs)
Diameter	1.38 m (4.53 ft)	0.78 m (2.56 ft)
Length*	22 m (72.18 ft)	10.4 m (34.12 ft)
Payload Weight	650 kg (1433 lbs)	600 kg (1,323 lbs)
Apogee	847 km (457 nmi)	138 km (74 nmi)
Range	3,282 km (1,772 nmi)	505 km (273 nmi)
Payload Weight	1,600 kg (3500 lbs)	n/a
Apogee	424 km (229 nmi)	—
Range	1,775 km (958 nmi)	—
Parafoil Recovery System	Yes	Yes
Water Launch Capable	No**	Yes
Land Launch Capable	Yes	Yes

* Includes fairing length of 3.7m (12.14 ft)

** RaDLS 2-Stage configuration can be launched from water; existing treaty obligations require launch from existing, approved, land-based test ranges.

of its mission or payload, one of several launch configurations can be selected. The launch configurations are designed with a substantial degree of propulsion system, avionics, and mechanical commonality to lower cost and to improve overall system reliability. To allow maximum flexibility, each stage is equipped with its own controller and guidance system.These configurations are referred to as RaDLS and RaDL2 (See Figure 3). Among the many possible types of missions, the following three categories are described.

- **RaDLS Two Stage Launch Configuration**: The two stage launch configuration supports a variety of fixed site missions that can include a TBM target vehicle mission or a tactical missile mission (See Figure 4). This vehicle can also be used in a water-launched configuration.
- **RaDL2 Balloon Deployment Configuration**: Figure 5 shows a mission scenario for a rapid launch and deployment of a balloon carrying a reconnaissance or communications payload package. The balloon operates at an altitude of 38,100 to 21,336 m (125,000 to 70,000 ft) with an on-station endurance ≥24 hours. The RaDL2 Balloon Deployment Configuration booster can be recovered and reused with a parafoil recovery system.
- **RaDL2 Upper Stage Configuration**: The upper stage launch configuration is designed to be a ≤500 km (270 nmi) range, sea-launch, target vehicle. In this configuration, RaDL2 is anticipated to support test-range requirements for the development and test of TBM defense systems.

6.0 Launch Vehicle Description.

The following sections describe the major subsystems of the RaDLS launch vehicle. To minimize system cost, substantial commonality among these systems is envisioned. A summary table of the vehicle’s electrical characteristics is provided in Table 2.

6.1 Electrical Systems

The subsystems described in the following sections are housed in the equipment bay located at the top of the boost stage.

6.1.1 Guidance, Navigation, and Control

The Guidance, Navigation, and Control (GNC) function computes the vehicle attitude command from the data of the INS/GPS package to optimize vehicle performance and place the payload mass at the required coordinates. It is actively supporting guidance from prior to launch until the cut-off command of the stage. After the cut-off command, the GNC provides guidance inputs to the recovery subsystem. The GNC function is performed in the on-board flight processor contained within the Command and Telemetry System. The flight controller executes the navigation calculations and implements the guidance law. The GNC computes the commands for the nozzle-swivelling actuation of the hybrid motor’s active

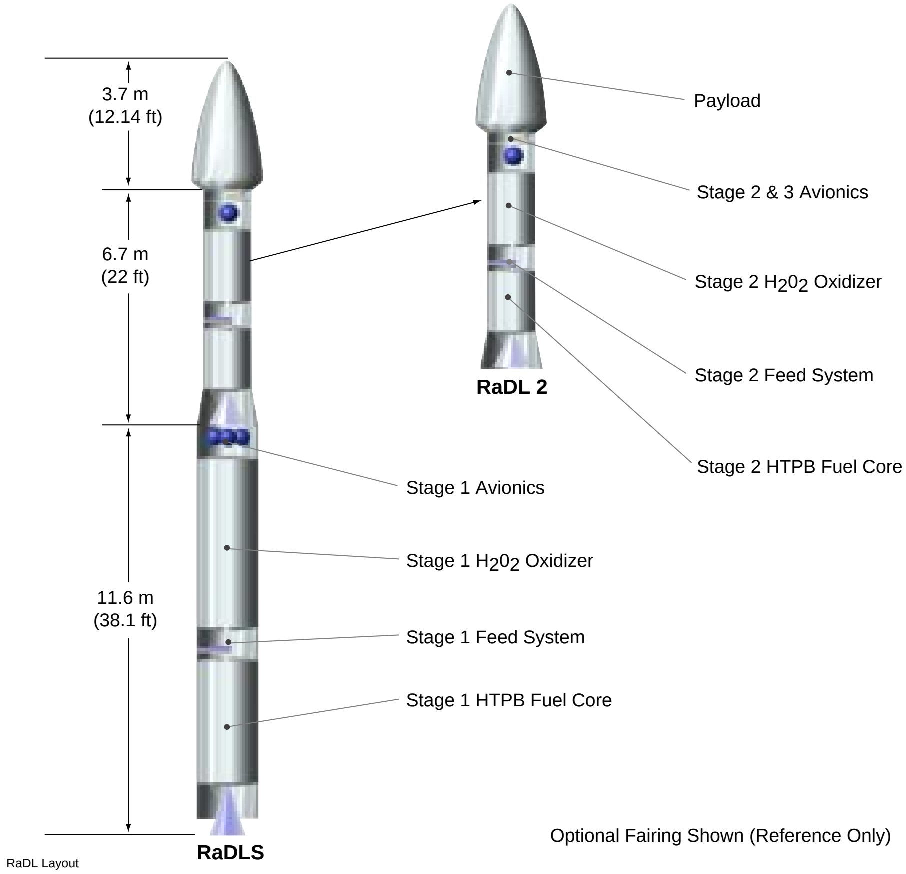
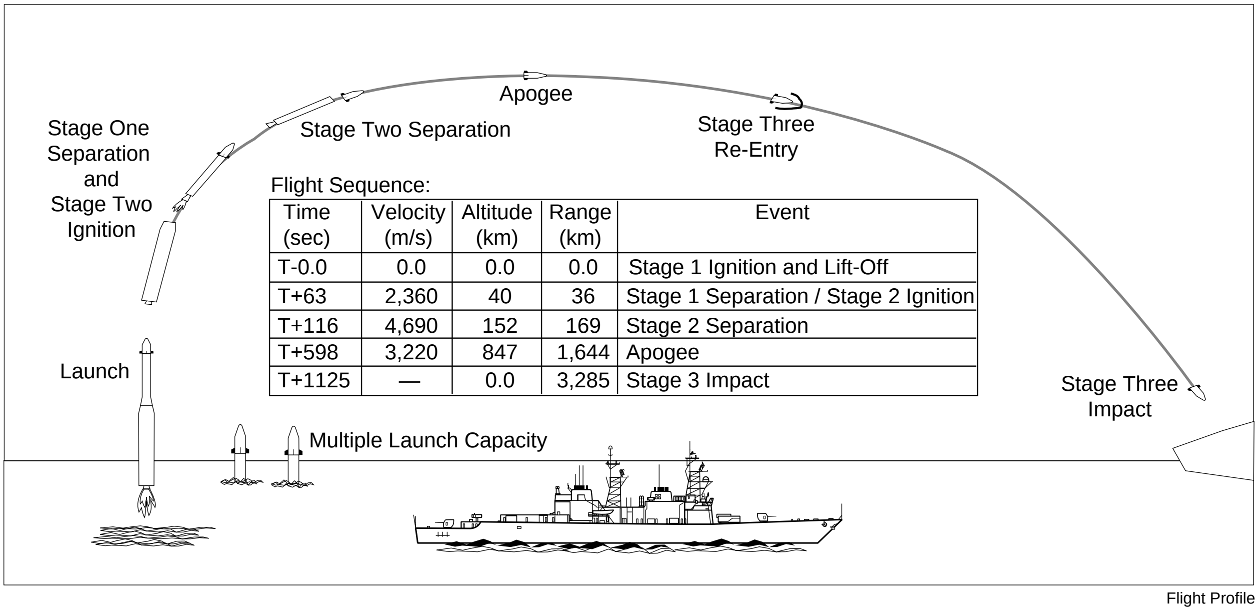


Figure 3. RaDLS Launch Vehicle Comparison



Flight Sequence:

Time (sec)	Velocity (m/s)	Altitude (km)	Range (km)	Event
T-0.0	0.0	0.0	0.0	Stage 1 Ignition and Lift-Off
T+63	2,360	40	36	Stage 1 Separation / Stage 2 Ignition
T+116	4,690	152	169	Stage 2 Separation
T+598	3,220	847	1,644	Apogee
T+1125	—	0.0	3,285	Stage 3 Impact

Figure 4. RaDLS Tactical Missile Mission Profile

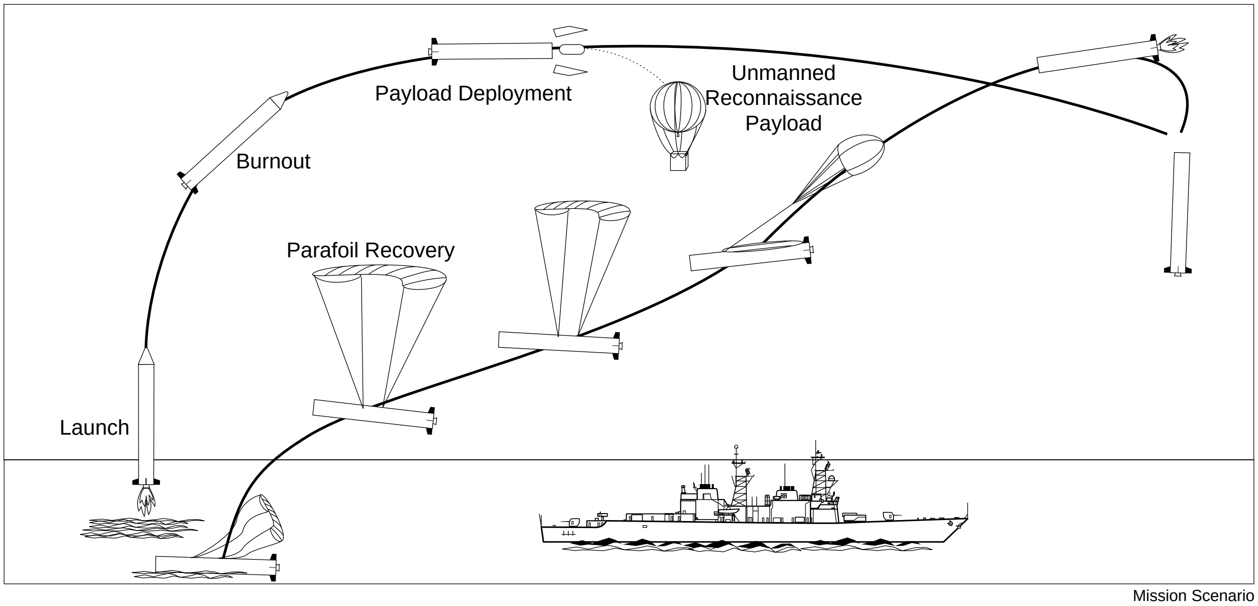


Figure 5. RaDLS Rapid Deployment of Balloon and Recovery By Parafoil Concept

Table 2. RaDLS LV Characteristics

Subsystem	Characteristics
Avionics	Central Processor Via High-Throughput RISC (R4600) Computer Flight Software In High-Level Language Optical Bus-Oriented Architecture Uses MIL-STD-1773 Laser Initiated Ordnance
Communications	S-Band Telemetry Transmitter (Downlink)
Electrical Power	Lithium Polymer Batteries Chemical-Thermal Energy-Storage Systems
Guidance, Navigation, and Control	Integrated INS/GPS System Attitude Control Jets (Pitch, Roll, and Yaw) for Stage 1 and Stage 2 Active TVC for Hybrid Motor (Pitch and Yaw) Control Surfaces for Stage 3 Reentry Vehicle Control (Pitch and Yaw)
Flight Termination	Ultra-High Frequency (UHF) Command Destruct Receiver On-Board GPS-Aided Autonomous Flight Termination System
Structures	Advanced Alloy (Primary Structures) Advanced Composites (Secondary Structures) Composite Overwrap Oxidizer Tankage Option for Liquid Crystal Polymers on Oxidizer Tankage
Propulsion	Hybrid Motors (TVC) Use HTPB Fuel (UTF-29901) Non-Cryogenic Oxidizer (90% H_2O_2)

thrust-vector control (TVC) system (pitch and yaw control). It also computes the commands for the attitude control jets that provide pitch, roll, and yaw for the first and second stages. The control function is performed with the aid of an integrated inertial platform sensor that is equipped with a GPS receiver.

6.1.2 Electrical Power Subsystem (EPS)

The unique needs of a launch vehicle for high power density, long storage life (i.e., years), coupled with short-term, high-energy operational needs (e.g., TVC acutators) implies strict requirements for energy storage systems. The long storage life needs can potentially be met using lithium-polymer batteries with a greater than three year shelf-life. Chemical-thermal energy-storage systems (i.e, exothermic chemical reactions and thermionic diodes similar to those used on tactical missiles) provide the short-term, high-energy needs.

6.1.3 Telemetry Subsystem

High performance processors meet the on-board processing needs of autonomous flight and support the projected needs of recovery systems. RaDLS uses a distributed processing approach with “smart” peripheral components (i.e., the parafoil recovery system and the flight termination system contain their own microprocessors) along with a highly-capable, RISC-based flight processor and adequate memory to support autonomous GNC and multiple launch trajectories.

6.1.4 Flight Termination System

The Flight Termination System (FTS), normally used only on the target vehicles, enables the vehicle to be destroyed in the event of abnormal behavior creating either a safety or environmental concern. A destruct signal is generated onboard if a premature stage separation occurs or if the vehicle’s on-board GNC system detects an abnormal deviation from the vehicle’s planned trajectory path. A destruct signal may also be commanded from the ground if an operational decision to abort the mission occurs. The FTS is fully redundant, comprised of two radar transponders and two UHF command receivers.

6.1.5 Ordnance Control Subsystem

The RaDLS’ ordnance control subsystem (OCS) provides safing, arming, and firing control of the electro-explosive devices (EEDs) used in the vehicle separation systems. It uses a Laser Diode Initiated Ordnance System (LDIOS) similar to that used on NRL’s Advanced Release Techniques System (ARTS) program.[2] The system consists of a Laser Diode Firing Unit (LDFU), a fiber optic Energy Transfer System (ETS), and Laser Initiated Squibs (LIS). The LDFU contains high power laser diode sources and uses electronic safe and arm circuitry to provide necessary control and monitoring functions. The ETS uses silica fiber to transmit laser energy from the LDFU to the LIS. The LIS is similar to NASA’s standard initiator in form, fit, function.

6.2 Propulsion Systems

The scalable nature of the hybrid propulsion system allows a common design approach. The basic configuration, feed system, and TVC system are the same for the Stage 1 and Stage 2 propulsion systems. The boosters use a multi-port HTPB fuel core (UTF-29901 fuel) provided with its oxidizer (90% H_2O_2) through a low-cost, turbopump feed system. The oxidizer tank initial ullage pressure is 5.5×10^5 Pascals [80 pounds per square inch atmospheric (psia)]. The turbopump supplies pressurized oxidizer to a main catalyst bed where it is decomposed. The decomposed H_2O_2 is then fed into the fuel core through a “showerhead” injector. The turbopump is driven by decomposed H_2O_2 from an auxiliary catalyst bed. An electric motor actuated (EMA) main oxidizer valve is used to regulate the flow of oxidizer to the main catalyst bed and provide the capability of throttling the motor.

Ongoing trade studies for the optimal ignition mechanism are in-process, however, at the 90% H_2O_2 concentration level, auto-ignition is feasible. The propulsion system exhausts through a silica-phenolic nozzle. The gimbaled, submerged flex bearing nozzle is capable of being canted 6° from the central fuel core axis.

6.2.1 Stage 1 Booster

The Stage 1 RaDLS booster is 1.38m (4.53 ft) in diameter with a length of 11.6 m (38.1 ft). The nine-port hybrid motor system’s characteristics include an I_{sp} (Vacuum) of 260 seconds with a mean engine operating pressure (MEOP) of 6.2×10^6 Pascals (900 psia). The average vacuum thrust is 541.8 kN (121.8 klb_f). The velocity increment imparted to the vehicle by the first stage is ≈2,360 m/sec (7,743 ft/sec). The system mass is 15,192 kg (33,492 lbs) at lift-off with a propellant mass of 13,155 kg (29,001 lbs).

6.2.2 Stage 2 Booster

The Stage 2 RaDLS booster is 0.78m (2.6 ft) in diameter with a length of 6.7 m (22 ft). The eight-port hybrid motor system’s characteristics include an I_{sp} (Vacuum) of 264.5 sec with a MEOP of 6.2×10^6 Pascals (900 psia). The average vacuum thrust is 116.9 kN (26.3 klb_f). The velocity increment imparted to the vehicle by the first stage is ≈2,330 m/sec (7,644 ft/sec). The system mass is 3,026 kg (6,671 lbs) at lift-off with a propellant mass of 2,388 kg (5,265 lbs).

6.3 Structural Systems

The fuel core is contained within a cylindrical structure [3.5m (11.5 ft) long] that is fabricated from high-strength steel. The fuel core structure is linked to the vehicle by rear and forward mounting systems, located on the rear and on forward skirts. The oxidizer tankage, consisting of a lightweight alloy with a composite fiber overwrap, forms a cylinder [6.4m (21 ft) long] with a 3:1 elliptical bulkhead. Advanced materials (e.g., liquid crystal polymers) are under consideration for the oxidizer tankage. To meet the water-submersion need, sealed-bulkheads and section-mating interfaces are used.

6.4 Separation Systems

RaDLS operation requires the jettisoning of the Stage 1 and Stage 2 hybrid boosters and the fairing in the case of the balloon deployment configuration. Stage 1 is separated by a mechanical disconnection from Stage 2 using pyrotechnic fittings. The Stage 1 booster is forced away from Stage 2 by four high-energy spring systems. On the RaDLS Balloon Deployment system, the Stage 2 “clamshell” fairing and the payload are jettisoned late in Stage 2 flight.

6.5 RaDLS Recovery

The RaDLS Stage 1 (2-stage configuration) or the 2nd stage in the balloon deployment configuration is recoverable with an autonomously guided parafoil recovery system (See Figure 5). After shutdown of the hybrid propulsion system and stage separation, attitude control thrusters are fired to reorient the stage. The hybrid engine is then refired (5 to 7 seconds) to damp out the forward velocity. At an altitude of about 7,620 km (25,000 ft), a drogue parachute is deployed to reduce downward acceleration and extract the parafoil from the vehicle. Once the parafoil is fully deployed, the parafoil’s internal guidance system autonomously controls automated flight to a predetermined landing site. The stage can either be landed in the sea (splashdown) or on an impact attenuation landing platform located on land or shipboard. To determine if recovery, refurbishment, and reuse of RaDLS is economically desirable, further investigation is required.

7.0 Launch Operations Command and Control

RaDLS launch command and control is based on the reuse of an existing NRL Launch Control Center (LCC) developed for another launch vehicle program. The LCC, which played a key role during NRL’s CLEMENTINE Program, is a fully self-contained, low-cost, transportable shelter containing all consoles and their supporting communications, computers, command and control equipment, and interface functions required to support a launch vehicle. (See Figure 6). It is housed in an International Standards Organization (ISO) transport container and is capable of being shipped by truck, air, or ship. It can be setup and operational in a matter of hours and provides all launch site requirements for command and control.

8.0 Launch Support Systems

The launch support system is designed using a core of components based on a common integration and a horizontal assembly and support structure. This assembly and support structure is used for both assembly and transport. This same basic system meets water and fixed-site launch needs. During the automated launch sequence, the launch support system’s vehicle checkout system verifies the correct operation of the vehicle, provides the signal for ignition of the first stage, and monitors the booster’s behavior. If all parameters are within limits, a command opening the vehicle release mechanism (i.e., a Marman clamp) is provided after ignition. If an anomaly occurs, the release mechanism is kept closed and the booster is shut down.

Figure 6. LCC, Exterior View

8.1 Fixed Site Launch Support System

The RaDLS fixed site launch support systems share substantial commonality with the water launch support systems. A standard transportable structure for assembly, transportation, erection, and launch of RaDLS is envisioned. For the RaDLS fixed site launch support system, additional mechanisms (i.e., stabilizing arms, hydraulic system, and flame deflectors) are added to the standard structure. This results in a simple launch system requiring minimal refurbishment before reuse (See Figure 7).

8.2 Water Launch Support System.

The RaDLS water launch support system is based on the use of a fully recoverable and reusable ballast system. An engineering concept of the ballast system, its high-pressure tankage, and the launch system interfaces is shown in Figure 8. The ballast system provides full launch vehicle services while in the water and requires only minimal refurbishment for subsequent launch operations. It is designed for use in operational environments up to Sea State 4. The system is capable of being deployed in the water for at least three weeks. The system can be retrieved from the water if a launch is aborted. Refurbishment after launch requires the replacement of the blow-out panels, ablative materials, and high-pressure air systems, along with general cleaning, corrosion-maintenance, and routine test and checkout actions. Figure 9 shows an overview of the combined RaDLS ballast and launch system immediately after deployment from ship, along with the ballast deployment, launch, and post-launch functions.

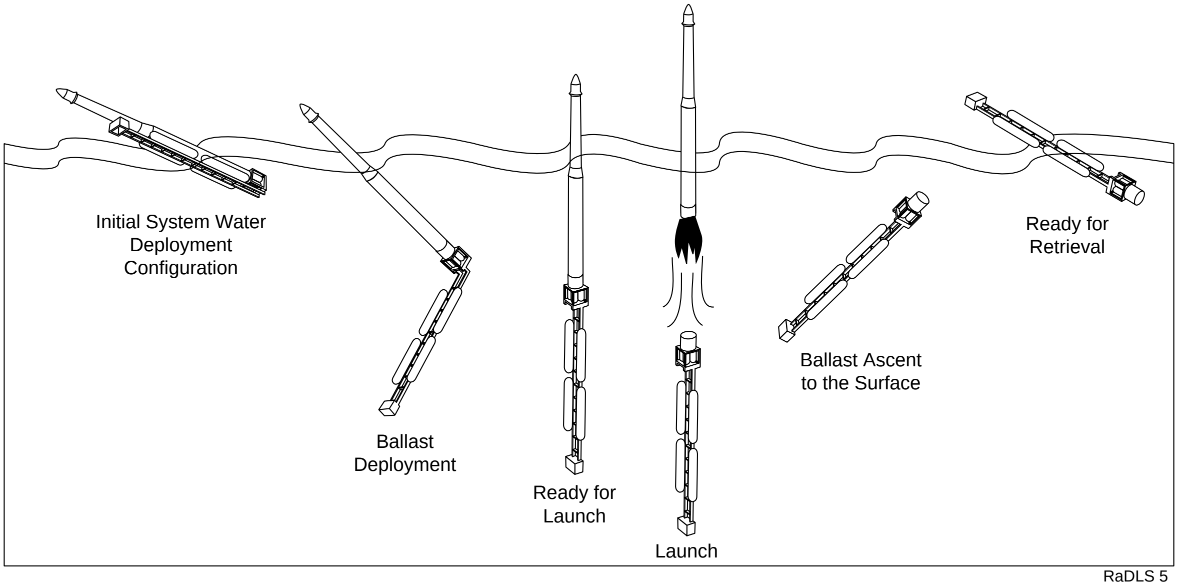


Figure 9. Water-Launched Ballast Deployment, Launch, and Post-Launch Operations

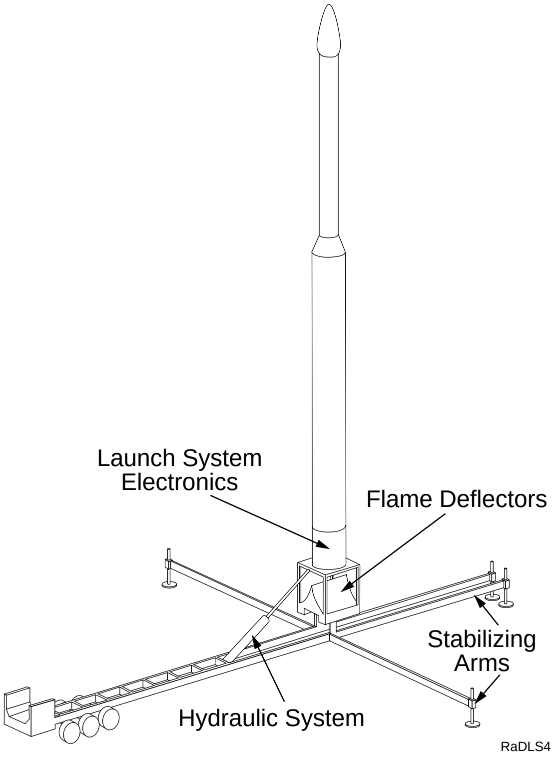


Figure 7. Fixed-Site Launch System

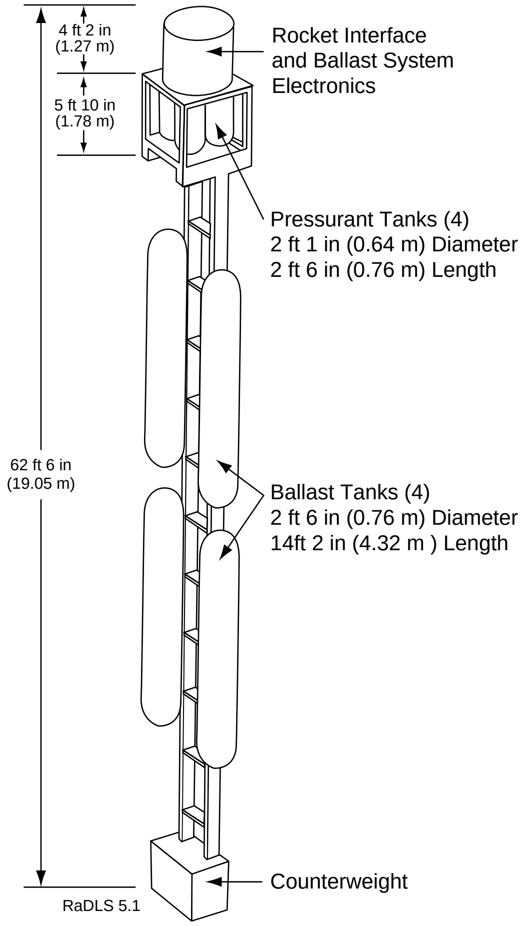


Figure 8. Water-Launched Ballast System

9.0 Development Processes

The relatively low costs envisioned for the RaDLS program development are based on previous experience with the CLEMENTINE program, i.e., the use of an Integrated Product Development Team (IPDT) consisting of a Government Laboratory and an Industry team. The Government Laboratory serves as the principle systems authority. The approach requires direct technical involvement by senior members of the responsibility chain. Participating IPDT member organizations are characterized by minimal overhead management structures. The developmental process is implemented through a relatively small “hands-on” team. Single-point responsibility is required at each level of the project. Responsibility and accountability is vested in the design team. A key tenant of this approach is the use of *objective* or “function-oriented” requirements versus the more common *prescriptive* or “process-oriented” approach. Systems are constrained by their performance expectations rather than performance implementation. This approach allows an efficient design and procurement approach, effective verification and validation, and fewer contractual disputes than the more common requirements-driven project frameworks. The schedule and costing provided in Figure 10 is based on the use of this approach.

10.0 Planning and Procurement Considerations.

Serious consideration should be given to launch vehicle alternatives. Before selection and implementation of any launch vehicle approach, the advantages and disadvantages of alternative solutions should be addressed. This implies that there should be a preparatory or advanced development phase prior to the start of procurement. The product of this effort would be recommendation of a systems concept, and the development of a project execution plan for the implementation of a RaDLS-type of vehicle. The required steps to meet this goal are suggested in Section 11 (Recommendations).

11.0 Summary and Conclusions

Many of the currently assumed models for implementing target launch vehicles are based on the reuse of surplus missiles and vehicles. This study has explored the applicability of hybrid launch vehicle technologies to meet not only target vehicle requirements, but also to meet DoD needs for tactical missiles and small booster vehicles. An added feature of these technologies is the ability to launch from either ground-based or ocean launch sites.

In summary, this concept study concluded that a launch vehicle based on hybrid propulsion in one of three basic configurations can be responsive to Navy objectives for a multi-purpose, rapid deployment vehicle capable of being launched from either a fixed ground site or via a shipboard assisted water launch site. Furthermore, cost savings may result from the extensive hardware commonality across a fleet of hybrid launch vehicles. The options presented merit further study.

12.0 Recommendations

The following recommendations are based on the results of this study:

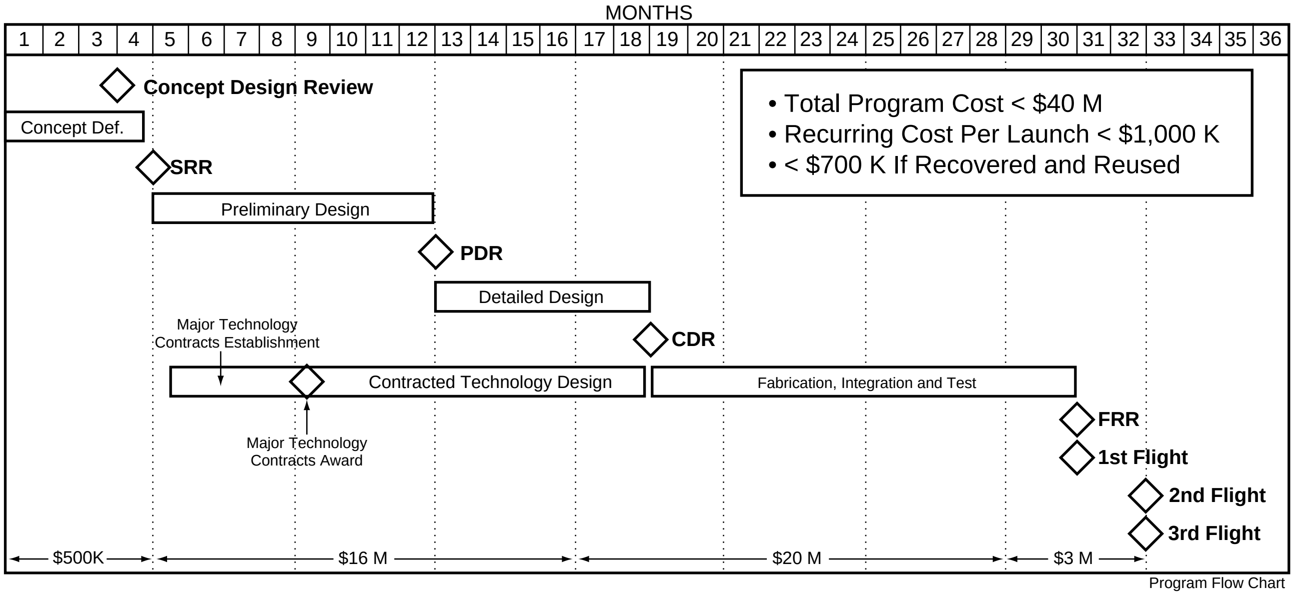


Figure 10. RaDLS Developmental Program Schedule and Budgetary Costing

- Additional concept exploration and definition studies for RaDLS program development should take place and these studies should include an in-depth analyses of the technical trade-offs, risks, and mission benefits of a RaDLS hybrid propulsion launch vehicle.
- Those studies should include launch vehicle and ground segment trade-offs, potential oxidizer and oxidizer storage comparisons, payload design and accommodation, and management and procurement planning.
- The implementation costs for the development of the RaDLS launch vehicle should be viewed over a typical launch vehicle life-cycle.

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