Intrepid - A New Small Satellite Launcher

J.R. French
Rocket Development Company
10821 Bloomfield Street, Unit B2
Los Alamitos, CA 90720
562-596-0111
french@spacelines.com

T. Ingersoll
Universal Space Lines
1501 Quail Street, Suite 102
Newport Beach, CA 92660
714-476-3448
ingersol@spacelines.com

Universal Space Lines (operator) and Rocket Development Company (hardware fabricator) are in the early stages of development of a small, low-cost expandable launch vehicle called "Intrepid". This two-stage vehicle, using the liquid oxygen / liquid hydrogen propellant combination, is targeted for payloads up to about 1,100 lb for eastward launches in its basic form. Construction is primarily composite in the interest of high production and low unit cost. Maximum use is made of existing electronic components in order to minimize development. Software design follows the very successful methods developed on the DC-X / XA programs. The goal of the Intrepid program is to reduce launch costs in this payload range by 50 - 60%. The USL / RDC team was one of the winners of the Bantam Cycle I competition with a design which is a derated version of the basic Intrepid design. First flight is planned for 1999.

Introduction

Rocket Development Company with Universal Space Lines is conducting business planning, concept development and risk reduction testing for a new small launch system called ***Intrepid.*** Our baseline low cost composite LO_2/LH_2 vehicle is sized for a commercial market and is capable of delivering 800 lbs to a 200 nm sun synchronous orbit. Two Intrepid flight tests are scheduled for late 1999 with an initial commercial operating capability in 2000.

Vehicle design is currently underway with PDR scheduled for late November. Risk reduction activities include the following: testing of a new LO_2/LH_2 engine, cryogenic testing of an 85% scale filament wound composite tank and demonstration of a low cost autonomous launch vehicle and satellite tracking system.

Program Summary

Operator:	Universal Space Lines
Developer:	Rocket Development Co.
Major Suppliers:	Thiokol Aerospace Allied Signal Aerospace Scaled Technology Works
Stages:	2
Propellant:	LO_2/LH_2
Height:	110 feet
Diameter:	9 feet
GLOW:	95,000 lbs
Tankage:	Filament wound GrEp
Engines:	Gas Generator
Booster:	One Engine
Thrust (SL):	123,300 lbs
Isp (SL):	325 sec
Nozzle:	4.9:1
Upper Stage:	One Engine
Thrust (Vacuum):	20,000 lbs
Isp (Vacuum):	410 sec
Nozzle:	53:1
Performance:	800 lbs to 200 nm
Launch Sites:	Kodiak, AK Wallops Island, VA
Price (goal):	$5.5M

Figure 1-1. The Intrepid system reduces launch prices by over 60% vs. existing competition.

Our team's vision and experience will make low cost access to space a reality

- USL is a privately funded entrepreneurial company actively investing in the development of commercial space services
- Intrepid performance exceeds NASA Bantam-class requirements at up to a 60% savings vs. existing systems
- RDC is a privately funded company focused upon low cost launch vehicle development
- Concurrent with Cycle 1, our team is investing $2.05M for tank, engine and ground systems demonstrations, providing early risk mitigation for Cycle 2
- Our team consists of key members of the DC-X/XA team- a low operations cost LO_2/LH_2 system- and expertise from Thiokol, Allied Signal, Scaled Tech Works, Conatec, Arizona State, USRA, NASA-MSFC, NASA-LaRC and NASA-WSTF

With the evolving change in the philosophy of space economics comes the demand for new ways of doing business in space. Universal Space Lines (USL), a privately funded entrepreneurial company, was formed to implement the new business paradigm for the commercialization of space. The commercialization of space is our core business. It is our only business.

Founded by former Apollo Astronaut and aircraft executive Charles "Pete" Conrad Jr., the company is owned, controlled, and operated by industry leaders. USL believes while the future of space transportation is in reusable launch vehicles (RLVs), there are also tremendous near term opportunities for low cost expendables. With this in mind, USL committed company funding in July of 1996 to begin business planning for Intrepid launch vehicle (Figure 1-1).

To effect development of the Intrepid system, RDC and USL are shattering existing paradigms for launch vehicle development by modeling the aircraft industry. In much the same way as airlines purchase planes from airframe manufactures, USL will buy and operate the Intrepid vehicle from its development partner, the Rocket Development Company (RDC). RDC will design and assemble the Intrepid vehicle which is built to meet market driven requirements established by USL.

USL and RDC are new companies with many years of experience working together. Their core teams consist of key personnel who were part of the successful development of space access beginning in the early days of the Gemini program and continuing to current operational and experimental systems. Much of the staff from both companies held leadership positions on the successful Delta Clipper Experimental (DC-X and DC-XA) programs. Combining knowledge with know how, this team demonstrated strength through their role in building and operating the complex DC-X system for a fraction of what traditional aerospace development estimators predicted it would cost. RDC and USL are also joined by strong aerospace development capability from Thiokol Aerospace, Allied Signal Aerospace, Conatec, Scaled Technology Works and NASA centers including MSFC, LaRC and WSTF.

Intrepid is a two stage, all composite LO_2/LH_2 vehicle with a payload capacity of 800 lbs to a 200 nm sun synchronous orbit. The Intrepid is designed for high rate production, a small launch crew and a short 3 to 6 day launch operation using standards established in the aircraft industry and proven successful on the DC-X/XA programs.

Providing low cost orbital insertion, low cost payload operations and routine launch operations (Figure 1-2), our Intrepid system offers the potential to achieve significant reductions in the current cost of launch services. Intrepid also provides price reductions necessary to enable market elasticity, thereby greatly increasing the number of potential launch customers for future reusable launch systems. The application of commercial practices to the development and procurement of the propulsion system components enables the production of Intrepid and subsequent RLVs at a cost significantly below traditional LO_2/LH_2 systems.

Vehicle Description

The Intrepid is a two-stage configuration. The baseline system has an 800 lb. payload capacity to sun-synchronous orbit, a gross liftoff weight (GLOW) of 95,000 lb., is 9 feet in diameter and has an overall length of 110 feet. The Intrepid uses highly simplified low pressure engines which burn environmentally friendly LO_2/LH_2 propellants fed by stage-mounted turbopumps. In the interest of lighter weight and lower cost, the airframe will be manufactured almost entirely from composite materials using highly automated processes. The overall vehicle has been designed with low manufacturing and operations costs in mind, while ensuring the necessary payload and reliability requirements are met.

Objective	Intrepid Approach
Low Cost Propulsion	Foil bearing, film / ablative cooled, low Pc engine
Commercial Manufacturing Practices	Outsourcing of major assemblies (commercial aircraft model)
Utilization of COTS Hardware	Commercial production & quality standards for propulsion components
Low Cost Structures	Filament-wound GrEp tanks, use of bonding to reduce parts count
Low Cost Av-ionics and SW	Data-base driven OFP- first release by PDR
Low Cost Integration	Integration testing performed at system level using operational HW and SW
Low Cost Launch Processing	Off-line payload processing
Low Cost Operations	DC-X/XA approach- minimal ground and flight crew

Figure 1-2. The Intrepid program addresses NASA Bantam objectives to reduce the cost of small earth-to-orbit transportation systems.

Vehicle Design to Cost

The design requirements are used as fundamental elements in creating our design to cost allocations. Based on marginal cost targets, these allocations are business plan-driven. We have allocated these requirements down to the subsystem level, attacking traditionally high rocket system costs in the areas of propulsion, structures and operations Figure 1-3.

Our development philosophy incorporates cost considerations from the beginning of concept development. This process allows the project costs to be included as a driving constraint in the design and development phases, thereby ensuring the producibility and marketability of the system before any fabrication begins. This 'design to cost' philosophy merges technology development concerns with profitability concerns. Design to cost is fundamental to the way our team designs, builds and operates launch vehicles.

The cost of ground equipment and launch operations have always been high. Our team has experience in creating low-cost, low-maintenance ground support equipment and launch operations systems which will be an enabling capability for the Intrepid System.

Structures and Mechanisms Design

Vehicle Geometry. The Intrepid vehicle consists of two stages, as well as a payload module consisting of a payload adapter and a bi-sector fairing. The vehicle is 9 feet in diameter for both stages. The common diameter significantly lowers the cost of manufacturing the primary structure and provides increased vehicle stiffness. The LO_2 tank is located forward of the LH_2 tank on both stages to enhance control stability. A single external tunnel along the length of the vehicle will be used for the LO_2 fill/feed lines, autogenous pressurization lines, and electrical wiring.

Intrepid Cost Reductions vs. Existing Systems

- Filament wound tanks allow automated manufacturing under high rate production
- Composite structure results in low parts count- bonding is used for structural attachment to reduce fastener counts
- Moderate rate gimbal actuation eliminates the need for a costly high rate system
- Single string avionics meets reliability goal
- Modular, database driven software allows OFP to be quickly generated and verified
- Commercial practices for propulsion system component procurement reduces costly tracking paperwork
- Out-sourcing major assemblies enables high rate production at lower cost
- Minimum crew size and austere infrastructure reduce operations costs
- Low cost engine / foil bearing turbopumps (no purge system is reqd for the engine bearings, and turbopumps are chilled by propellant as tanks are being filled)
- Two-position valves in pressure reg. system are controlled by the flt computer to eliminate costly regulators
- RDC's integ. and assembly at Las Cruces, NM, takes advantage of low cost of living and favorable labor rates

Figure 1-3 Our System incorporates cost considerations into all technical considerations

The primary goal of the NASA Bantam System Technology Project is to contribute to lower recurring costs for access to space. Our Intrepid structural concept is based on three major themes to achieve this goal: structural commonality, part cost reduction and performance margin.

Structural commonality is directly driven by selection of the stage diameter. Therefore, our team has chosen to make the booster and upper stage a common diameter. Reduction in cost will be achieved throughout the entire life cycle. Development costs, production tooling and handling fixtures will all realize savings due to the common diameter of the stages.

Many studies have shown production costs are directly proportional to part count. Structural assemblies with fewer parts are more easily achieved with fiber reinforced composites. Lightweight large structures are possible using sandwich construction. Major vehicle components are joined with shear type joints which eliminate the costly interface rings found in tension type joints.

Moving into the design and development phases with a vehicle concept that has adequate performance margin is arguably the most important element in maintaining cost goals. Doing this allows the detailed structural designs and sub-system components to be simple and therefore of a lower cost. The strategic addition of dry weight to a vehicle could result in a robust and reliable design.

Structural Concept. The primary structure has been divided into pressurized and unpressurized elements. The pressurized elements consist of the LO_2 and LH_2 tanks and the unpressurized elements make up the remainder of the primary structural elements.

We will use unlined filament wound carbon/epoxy composite tanks for both stages. The tank design, material and manufacturing process were all selected to achieve the best balance between weight and cost. The tank laminate is optimized, within manufacturing and cost constraints, for simultaneous internal pressure and external flight loads and propellant containment (limiting strain levels to avoid microcracking and the subsequent need for a liner). The laminate is composed of helical layers wound at 10 degrees and 30 degrees to the tank axis, with hoop layers wound circumferentially. The baseline carbon epoxy material is the Fortafil 50C/UF3339 prepreg developed by our teammate, Thiokol Aerospace. The specially formulated UF3339 resin system is currently being used in structural applications at cryogenic temperatures. The tanks will exhibit "leak before burst" characteristics in addition to a theoretical burst factor of safety greater than 2.0 (based on the maximum expected operating pressure).

The composite tank construction allows control over the hoop and longitudinal strength of the material. We have exploited this unique capability by using internal pressure to provide structural stability during maximum flight loading scenarios. The booster propellant tanks will operate at 100 psi and the upper stage at 45 psi. The weight and cost impact of using higher pressure is offset by through the use of an autogenous pressurization system.

To protect the composite structure from electrostatic buildup or lightning strike, we will review the industry accepted techniques and incorporate the concept which provides the minimum impact to our system. Examples of potential solutions include aluminum filaments woven into the structure and wire mesh adhered to the composite surfaces.

During our initial design phase, we will continue monitoring the cost trade between two structural concepts: metallic and composite. The metallic design will be based on a monocoque construction for the pressure vessels and skin stringer for the unpressurized structures. However, to date no suitable vendor has been found for low cost metal propellant tanks.

The unpressurized structural elements will be made from T300 bi-directional cloth. We will use a wet hand lay-up process for early fabrication and transition to a proprietary automated process, created by Scaled Technology Works for high quantity production.

The payload fairing has an ogive shape which is structurally efficient and has good aerodynamics, as well as low transonic noise characteristics. The use of composite structures allows us to design the fairing with only two sectors, thereby reducing the number of separation mechanisms (with associated risks) and fairing weight.

Given the large diameter of the upper stage, the available payload volume will be more than adequate for Bantam-sized payloads. External insulation on the fairing will be sized to reduce structure temperatures due to ascent heating and provide protection from in-flight rain erosion. We will provide acoustic treatment on the inside of the fairing as required to meet the needs of the market.

Mechanisms and Separation Systems. Major propulsion system hardware such as shutoff and vent/relief valves will be actuated pneumatically through solenoid valves. Gimbal actuators on the main engines will be pneumatically-driven screw jacks.

Stage separation will be accomplished using a circumferential linear shaped charge cutting through the composite interstage structure. Fairing separation will be enabled by redundant explosive bolts releasing a mechanical latch. Balanced, constant force coil springs will provide the required separation velocity between the payload fairing halves and the upper stage.

Propulsion System Design

Propulsion System Overview. Our propulsion system consists of one 123,300 lbf (sea level) booster engine and one 20,000 lbf (vacuum) upper stage engine (Figure 1-4). The system has separate gas generator/turbine-driven pumps for each propellant. The tank sumps contain anti-vortex baffles. The autogenous propellant tank pressurization system is fed by

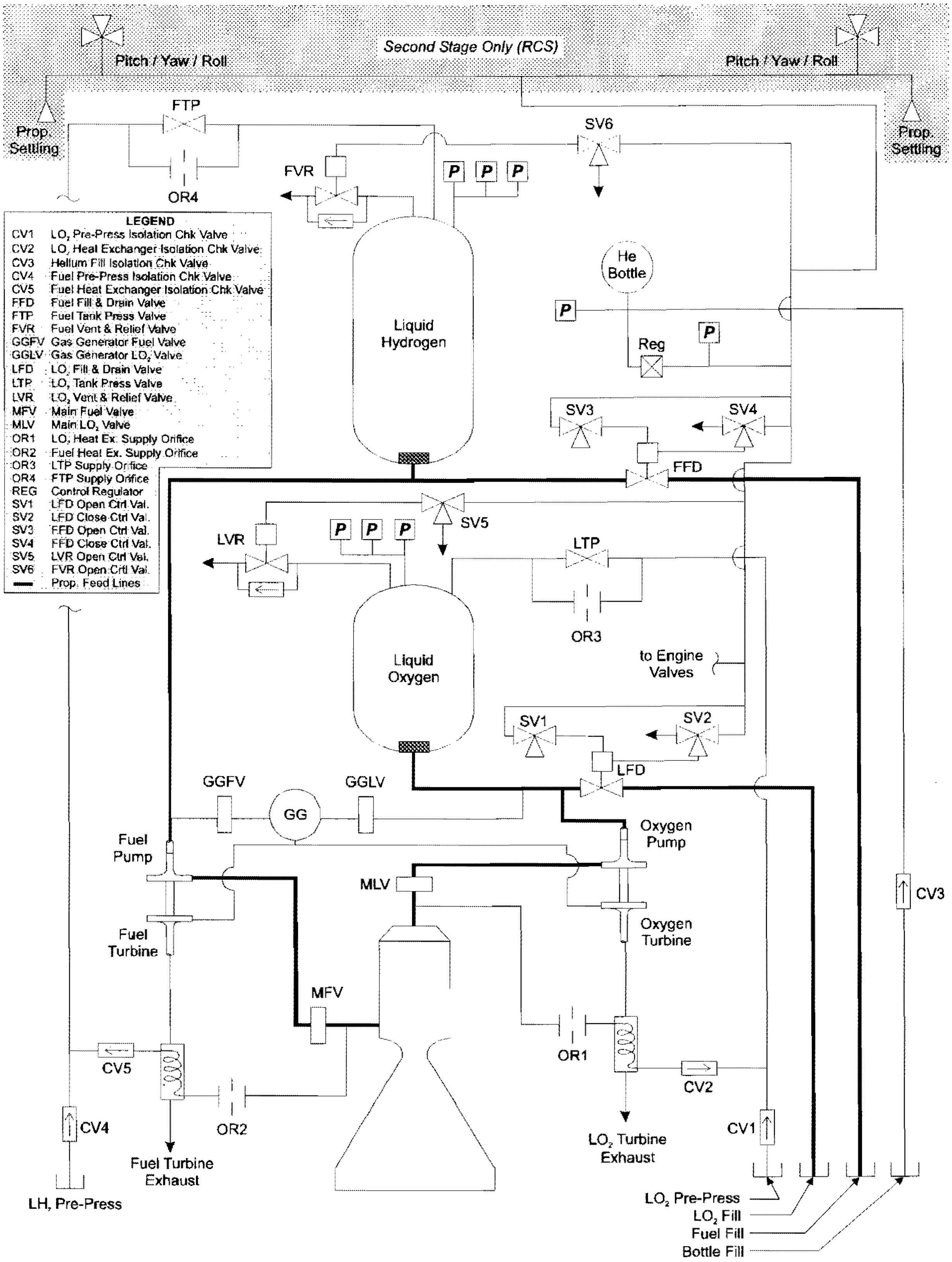


Figure 1-4. Our propulsion system combines simplicity and reliability into a low-cost package

heat exchangers using the gas generator turbine exhaust. The autogenous system gasifies LH_2 and LO_2 using a simple heat exchanger driven off the turbine section of the respective system. The autogenous pressurization design provides a significant contribution to developing a low cost propulsion system.

Common foam-insulated LO_2 fill/engine feed lines keep the LO_2 feed lines chilled, thus avoiding the need for anti-geysering techniques. The system uses computer-controlled pressure regulating valves with fly-away quick disconnect fittings, fill and drain valves, relief valves, lines and fittings similar to those successfully used on the DC-X/XA programs.

The stage-mounted LH_2 and LO_2 pumps are both exposed to liquid propellant throughout the tanking process. This results in a thorough chilldown and eliminating the need for special propellant bleeds prior to engine start. The LH_2 tanks will have one inch external thermal insulation, while the LO_2 tanks will not be insulated.

Since the engines and propellant pump seals do not require purges and tanks are pressurized autogenously, on-board gas storage will be used mostly for the pneumatic screw jack gimbal actuators and the cold gas reaction control system. The RCS estimated requirements are 5 cubic feet at 3,000 psi. The amount required for the pneumatic screw jacks will be determined during preliminary design when calculating the gimbal activity over the range of flight trajectories.

Reaction Control System. A reaction control system used for propellant settling and attitude stability between engine shutoff and payload separation, is located on the upper stage. It consists of two, 4-nozzle cold gas clusters fed by residual control gas.

Avionics and Software

Stability and Control Assessment. Our baseline primary flight control approach uses thrust vector control by gimbaling the engines. Roll control for both stages is made simple by the symmetric nature of the vehicle. Roll is controlled by vectoring the engine turbine exhaust (this approach is also available for upper stage flight). A cold gas RCS system can control the second stage during unpowered flight if needed.

To reduce hardware and operations costs, the gimbal actuators will use a design based on a screw-jack mechanism driven by compressed gas. This actuator design has an upper performance limit (defined as maximum gimbal slew rate) which is lower than comparable hydraulic designs. This can affect system operability since the control system may not have the rapid response necessary to stabilize the rocket through the wind shears and gusts present in the lower atmosphere. We are currently analyzing appropriate features (e.g., fins) to optimize the rocket's static stability through a coordinated interdisciplinary trade study of the complete system to be completed during our current effort. This trade study will enable us to find the optimum performance/cost point, including day-of-flight operations, flexibility and flight robustness. Other options including a traditional hydraulic blow-down system will be assessed should Intrepid require higher response rates.

Vehicle Management System. The VMS (Figure 1-5) will be mounted in the intertank area of the upper stage. It consists of the VMSC computer which hosts the Operational Flight Program (OFP) software and the inertial navigation system. The VMS commands and controls the vehicle, including subsystems and communications, as well as components necessary for payload and ground system

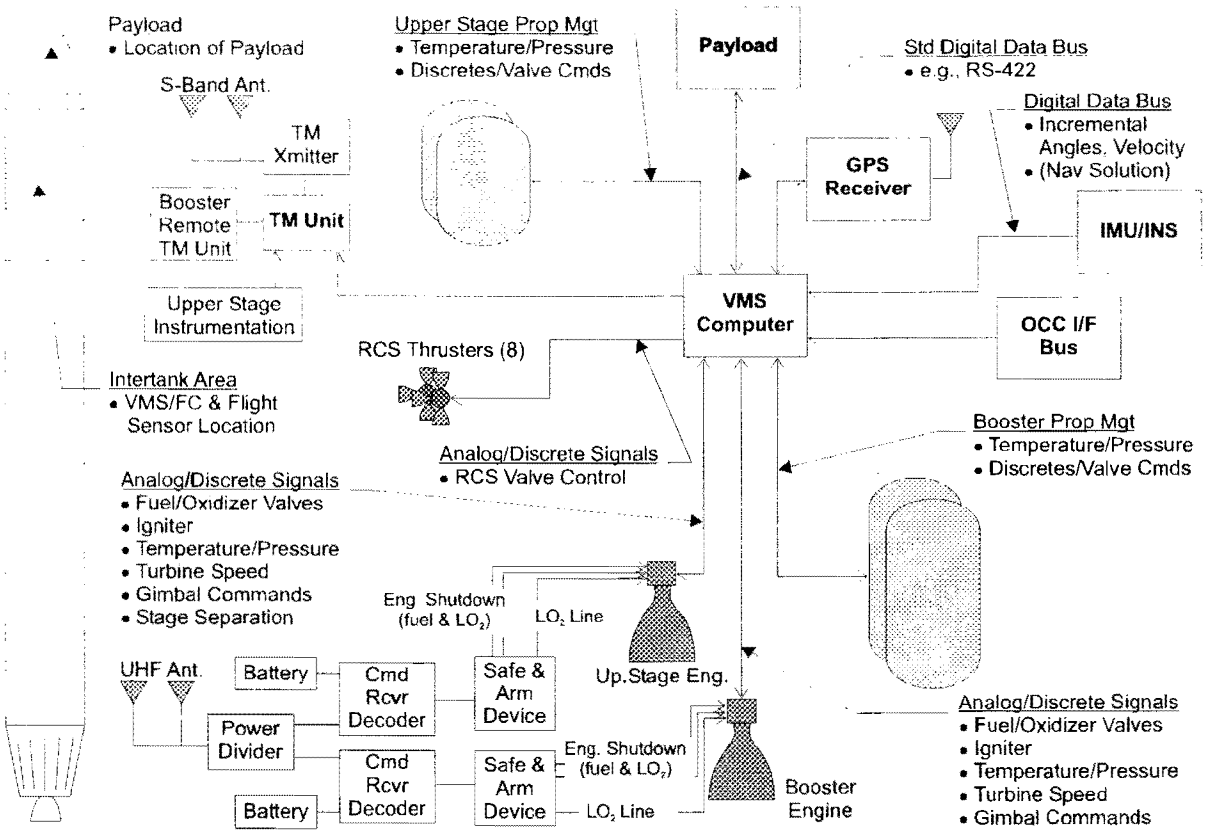


Figure 1-5. Our Vehicle Management System leverages state-of-the-art tools for low-cost development with complete vehicle systems control and monitoring

interfacing, built-in health monitoring tests, preflight checkout, launch and flight. Our baseline navigation system provides adequate accuracy to meet most payload orbit insertion requirements. The VMS architecture accommodates a modularized GPS receiver which will provide added navigation accuracy for payload missions requiring it.

Commands and valve actuation initiated by the VMS will be protected against inadvertent or indeterminate states as a result of component failure or power transients. Fail safe system design will be used to address common mode failures most frequently seen in launch vehicle electrical systems.

Our current design is based upon a single string reliability for the VMS. The primary hardware elements of the VMS are shown in (Figure 1-6) , along with the piece part reliability estimates. Based on a flight time of approximately 560 sec (0.16 hr), the VMS reliability is 0.9999. Even doubling the flight time to 1,120 sec (0.31 hr) only drives the reliability down to 0.9997. Therefore, single string avionics provide more than sufficient system reliability without the additional cost.

The OFP which can be loaded during all stages of vehicle assembly, integration and test (including on the pad), will be designed to be

Item	MTBF (hr)	Failure Rate (per hr)
Batteries	312,500	3.2×10^{-6}
INS/IMU	5,333	1.9×10^{-4}
Flight Computer	4,000	2.5×10^{-4}
Misc. Electrical Components	8,000	1.25×10^{-4}
Telemetry	4,000	2.5×10^{-4}
Avionics System Level		8.18×10^{-4}

Figure 1-6. Our avionics has an inherently high reliability permitting use of a single string design

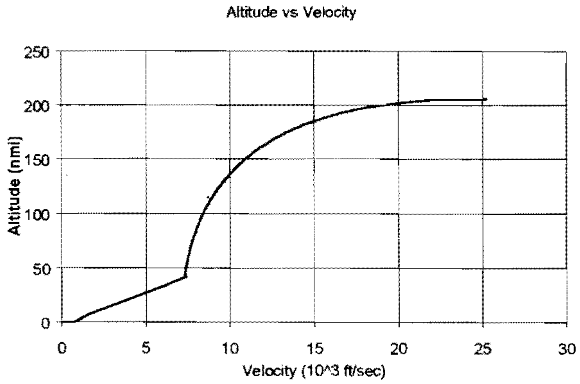
database driven for individual mission loads to be uplinked without having to reload or re-compile software. OFP development will take advantage of the spiral software development methodology effectively demonstrated on the DC-X/XA programs using state of the art design, analysis and autocoding tools. This effort resulted in reliable flight software with enhanced functional capability developed for the program at a fraction of the estimated cost.

Electrical Power. Electrical power for both stages will be supplied by silver-zinc batteries. The upper stage hosts the avionics suite and will have two power busses, one for the avionics "clean power" and a separate system for pulsed demand "dirty power," such as pyrotechnics for separation, valve actuators, etc.. The booster will have a single power system.

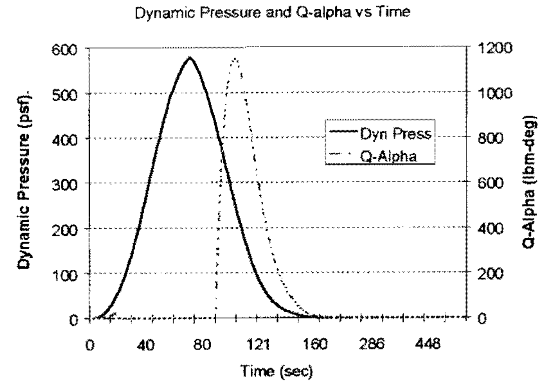
Flight Termination System. The vehicle will have redundant flight termination and inadvertent stage separation detection capabilities. Range safety equipment, including power, will be independent of other vehicle systems.

Flight Performance

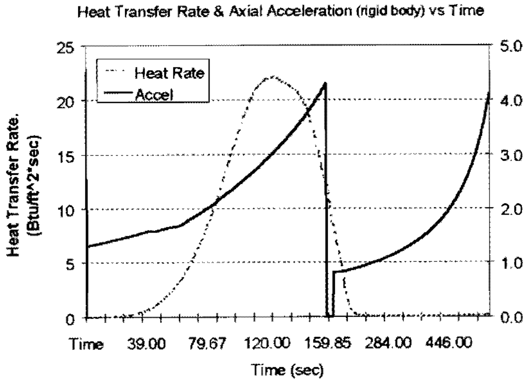
In support of our business plan we have performed optimization of ascent flight profiles. To perform this analysis we used the DAB Ascent 3 degree of freedom trajectory analysis tool using aerodynamic data generated from Missile Datcom. We have also implemented a guidance scheme in our rapid software development environment that minimizes angle of attack during peak dynamic pressure and then uses the Iterative Guidance Mode (IGM) algorithm for near optimal exo-atmospheric steering. This code is currently executing our six degree of freedom simulation and gave results that were less than 1% off of the DAB Ascent optimal trajectory. This represents a significant milestone in early flight software maturation.



Our typical ascent profile provides for direct insertion of the baseline payloads



Dynamic Pressure and Q-Alpha Profiles



Heat Transfer Rate and Axial Acceleration Profiles

Vehicle and Payload Environments

Environment	Peak Load
Acoustic	128 db @ 315 Hz
Heat Rate	22.1 Btu/ft^2-sec @ 126 sec
Axial Acceleration	5g (dynamic)
Lateral Acceleration	2g (dynamic)

Our peak environments are well below the design requirements

The peak flight environments for the vehicle and payload are provided in the Table. Structural vibration and base heating have also been evaluated for the Intrepid and were not found to be design limiting cases due to the vehicle aspect ratio and base geometry.

For the current level of design maturity, we are focusing on the vehicle loads with the assumption the payload environments will be less severe due to such factors as structural dampening. During the early design phase, we will evolve our vehicle environments and develop a detailed analysis of the payload environments.

Preliminary load estimates have been developed using an approximate method of estimating axial and lateral load accelerations that have been factored to include aerodynamic loads and body flexibility effects. Given the vehicle mass distribution and the center of gravity the bending, axial and shear loads are estimated along the length of the vehicle. The maximum case which has been used to size the booster structure include 65,000 lb axial, 48,000 lb shear and 2.83x10^7 in-lb bending moment loads.

Payload Capability

Our team has placed special emphasis on combining the needs of the commercial user community as well as those of the government. In developing our business plan, we performed optimized trajectories for a wide range of payload missions and settled on the payload capability. This allows us the maximum number of payload missions within our design to cost requirements. Our optimized payload envelope has the Intrepid capable of carrying 800 lbm of payload into a 200 nmi sun synchronous orbit. When compared to the 330 lb Bantam requirement, this offers a 240% payload margin. Additional payload capabilities, such as 1,100 lb to 200 nmi from Wallops Island, VA.

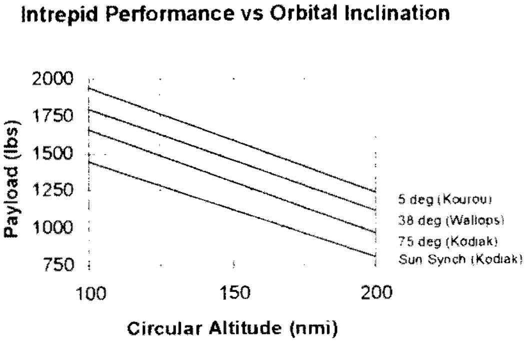


Figure 1-17. The Intrepid Vehicle can provide LEO services for a wide range of PL sizes and orbits