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1989 (26th) Space - The New Generation

Apr 26th, 3:00 PM

Paper Session II-B - The Pegasus Air-Launched Space Booster

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THE PEGASUS AIR-LAUNCHED SPACE BOOSTER

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ABSTRACT

The Pegasus Air-Launched Space Booster is an innovative new space launch vehicle now under full-scale development in a privately-funded joint venture by OSC and Hercules Aerospace Company. Pegasus is a three-stage, solid-propellant, inertially-guided, all-composite winged vehicle that is launched at an altitude of 40,000 ft from its carrier aircraft. The 41,000 lb vehicle can deliver payloads as massive as 900 lb to low earth orbit.

This status report on the Pegasus development program first details the advantages of the airborne launch concept, then describes the design and performance of the Pegasus vehicle, and concludes with a review of the progress of the program from its conception in April 1987 through January 1989. First launch of Pegasus is scheduled for 31 July 1989 as a launch service under contract to the Defense Advanced Research Projects Agency. The second DARPA flight is scheduled for 15 September 1989.

THE ADVANTAGES OF AIRBORNE LAUNCH

Pegasus was conceived to provide a more flexible and more efficient launch system for small space payloads by taking advantage of the many benefits inherent in the airborne launch approach. As designed, the Pegasus system achieves a substantial improvement in payload performance relative to comparable ground-based launch vehicle designs, while also providing numerous advantages in operational flexibility. The advantages of airborne launch, together with current technologies and production approaches, yields a more cost-effective launch system for small satellites as well.

The performance advantage of the air-launched Pegasus derives from five major contributing factors, each of which has the effect of reducing the required change in velocity or delta-V required to achieve orbit. The first contribution results directly from the potential and kinetic energy imparted to the vehicle by the carrier aircraft at the launch conditions of 40,000 ft. altitude and Mach 0.8. Qualitatively, this might be considered equivalent to using the carrier aircraft as a (reusable) zeroth stage, however quantitatively the contribution is roughly only 2% of the total required orbital velocity.

A second contribution results from improvements in propulsion efficiency. The specific impulse of each stage (most particularly the first stage) benefits from airborne launch in two ways. The lower outside static pressure at 40,000 ft (approximately one quarter of sea-level pressure) yields a higher specific impulse for a given nozzle expansion ratio. In addition, the expansion ratio of the first stage motor (40:1) has been chosen to optimize performance over the altitude range of first stage burn (from 40,000 ft to 200,000 ft). The resulting improvement in specific impulse relative to a ground-launched first stage with a typical 8:1 expansion ratio nozzle is better than 20 sec.

A third factor that contributes to the overall vehicle efficiency is the lower atmospheric pressure. Not only does this result in lower drag losses, but the lower resulting maximum dynamic pressure during ascent results in lower stresses on the vehicle and therefore a lighter weight design than for a ground-launched booster.

The Pegasus vehicle trajectory is designed to take advantage of the lift generated by the delta wing in two ways. Gravity losses are reduced by both the compensating lift and because the horizontally launched vehicle follows a trajectory with a lower average flight path angle. This shallow trajectory, together with the wing lift, also results in reduced thrust direction losses since the turning can be achieved at lower velocities.

All these factors combine to yield a vehicle design that delivers nearly twice the useful payload to low earth orbit of an equivalent gross weight ground-launched system.

The mission flexibility that results from airborne launch of the Pegasus launch vehicle is realized in numerous ways. Launch can occur from virtually any over-water launch point with a clear downrange for re-entry of the expended first and second stages, resulting in an orbit insertion capability that can achieve any desired combination of orbit inclination and ascending node, without the launch window restrictions of shore-based ground-launch facilities. The independence from shore-based facilities and the capability to base the launch system at numerous airfields worldwide also leads to improved survivability and improved robustness.

Without launch pads to refurbish, the surge capability of the Pegasus system is limited only by the manpower available for vehicle integration and the number of carrier aircraft. A single aircraft with multiple launch vehicle integration teams (typically 6 men each) can achieve a surge rate of better than one launch per day. This rapid turn-around is further facilitated by the horizontal launch vehicle and payload integration process and the multiple purpose assembly and integration trailer that is used for both vehicle buildup and mate to the carrier aircraft.

Pegasus is launched from over-water launch points to improve the range safety and reduce the risk to populated areas, beyond that achievable by land-based launch systems. The ability to select alternate launch points for a given mission can significantly reduce the effects of weather on launch delays.

The horizontal launch, lifting ascent and shallow trajectory together yield a vehicle that is uniquely suited to the hypersonic testbed mission. Rather than following a ground-launched trajectory that achieves hypersonic speeds only after exiting the sensible atmosphere, Pegasus can follow a trajectory that falls within the range of velocities and altitudes (the flight corridor) that is important for the testing of hypersonic technology.

In one respect, Pegasus is a small launch vehicle that achieves a cost/performance advantage as a result of the airborne launch concept. However, for a wide range of new missions that require either surge capability, survivability and robustness, orbit insertion flexibility or hypersonic flight profiles, Pegasus is an enabling technology without which these new missions could not be pursued.

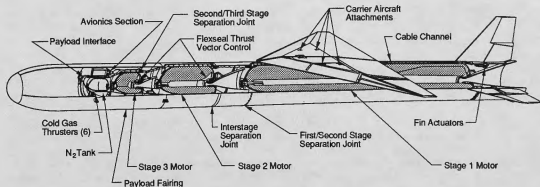


Figure 1. Pegasus Cutaway Drawing

THE PEGASUS DESIGN

Pegasus is designed to provide low cost transportation of small satellites (up to 900 lb) to low-earth orbit or larger payloads (up to 2000 lb) on suborbital ballistic or depressed trajectories. The design uses current state-of-the-art technology throughout and a single-string design philosophy that achieves reliability at low cost through quality of components rather than by arbitrary application of a requirement for full redundancy of systems. This philosophy also dictated that components would be chosen on the basis of cost, reliability and heritage, and to assure that both schedule and cost goals are met, no new technology development would be pursued in the course of the baseline program.

The Pegasus system consists of four major elements other than the satellite or mission payload. These elements are the flight vehicle, the carrier aircraft, the airborne support equipment, and the ground support equipment.

The flight vehicle, shown in Figure 1, consists of three solid-propellant rocket motors, a fixed high-mounted composite delta wing, an aft skirt assembly including three composite fins, an avionics section atop the third stage, and a two-piece composite payload fairing.

Pegasus main propulsion uses graphite-epoxy composite case rocket motors that are being developed by Hercules Aerospace Company. The motors are being developed using a conservative design philosophy that includes the use of demonstrated component technology throughout, maximum use of common components and tooling among the stages, and a conservative 1.4 factor of safety. All three motors use IM7 graphite composite cases with aramid-filled EPDM rubber insulator and integral composite skirts. Each nozzle consists of a carbon phenolic exit cone with a 3-D carbon-carbon integral throat/entry (ITE). The propellant grains employ class 1.3 propellants and are designed for low burn rates. The motors are manufactured using the most recent improvements in propellant preparation, case and nozzle fabrication, and insulator application.

The first stage motor has a core-burning grain design. The design includes a fixed nozzle, an aluminum wing saddle, and an extended forward skirt. The wing saddle is wound-in to the motor case during case fabrication. The forward skirt, which also serves as an interstage adapter, incorporates a linear shaped charge just forward of the forward dome for stage separation. A

second separation device at the first-to-second stage field joint is used to separate the interstage just prior to second stage ignition. The second stage motor is also a core burning design and uses a silicon elastomer flexseal nozzle and electromechanical thrust vector actuator (TVA) for thrust vector control. The third stage motor has a head-end grain design to maximize propellant density. This motor also uses a flexseal nozzle and electromechanical TVA and employs an aft-mounted toroidal igniter.

The Pegasus flight termination system is designed to satisfy both range safety and carrier aircraft safety requirements. When initiated, the termination charge locally ruptures the motor case on the aft dome, relieving motor case pressure and rendering the motor non-propulsive without fragmenting the motor itself. The flight termination system is mechanically disabled until after release from the carrier aircraft, and is armed prior to first-stage ignition. This approach assures that the flight termination system cannot be activated prior to release (as required for aircraft safety), and that it is electrically enabled (as required by the range) prior to first stage ignition.

The wing is a truncated delta planform with a 45° sweepback leading edge and a 264 inch wing span. The airfoil is a 10% double wedge with a 1 in. radius leading edge. The wing thickness is truncated to 8 in., with upper and lower parallel surfaces facilitating attachment to the ASE pylon adapter and motor case wing saddle respectively. The wing and fins are fabricated of lightweight graphite composite material and are foam filled.

A two-piece aluminum aft structure support three active fins, associated fin actuators and control electronics. The avionics structure is an graphite composite built-up assembly that includes a conical section, a cylindrical section and a planar aluminum honeycomb deck. The assembly serves as the mounting structure for most vehicle avionics, including an inertial measurement unit (IMU), flight computer, telemetry transmitter, telemetry multiplexer, ordnance and thruster driver units, dual flight termination receivers, radar transponder, and batteries. The structure also provides a mechanical interface for the payload. The payload fairing is a pyrotechnically actuated two-piece graphite composite structure that has the same 50 inch outside diameter as the motor and encloses the payload, avionics assembly and third stage motor. The design provides openings for the two pods of RCS thrusters so that reaction control is available about all three axes prior to payload fairing separation.

Pegasus has an advanced avionics architecture that takes advantage of progress in microelectronics technology during the past 15 years. The vehicle functional block diagram is shown in Figure 2. The vehicle autopilot, which runs on the vehicle's 68020-based flight computer, combines guidance, navigation and control (GN&C) functions, as well as a mission event sequencer, to guide the vehicle to its final orbit. The autopilot is driven by a mission data load which is developed for each mission and loaded into flight computer non-volatile memory (EEPROM) on the ground or once airborne prior to vehicle release. The autopilot processor obtains inertial position and attitude from the Inertial Measurement Unit (IMU) and commands the various vehicle control actuators via standard RS-422 serial lines. GN&C performance is monitored by the autopilot processor and real time performance data is downlinked via the flight telemetry system.

The vehicle is heavily instrumented to provide real time telemetry for all mission critical events, stress levels and temperatures. Remote telemetry

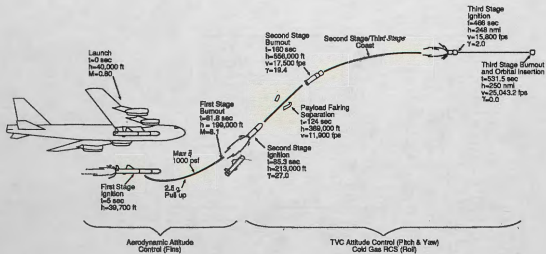


Figure 3. Pegasus Baseline Mission Profile

operational launches and custom mounting adapters will be developed to support new carrier aircraft when required.

GROUND SUPPORT EQUIPMENT

Ground support equipment includes a multifunction Assembly and Integration Trailer (AIT), custom shipping & build-up dollies, small protable cranes, assembly fixtures, electronic test equipment, and a portable clean room for payload environmental control. Final vehicle integration occurs in the horizontal position on the AIT. Once the vehicle has been integrated and tested, the AIT is used to transport the vehicle to the carrier aircraft, elevate it, and align it for mating with the carrier aircraft. The AIT is also used for de-mating, safing and disassembly, if required. The AIT provides full six-degree of freedom movement capability and is pulled by a standard aircraft towing tug. The AIT has a diesel electric generator and air conditioning unit which supplies power for ramp operations and filtered conditioned air for the payload.

LAUNCH OPERATIONS

The sequence of events for a typical orbital launch profile are summarized in Figure 3. The time, altitude, velocity and flight path angle for the motor ignition, separation and burnout events are typical for a trajectory that achieves a 250 nmi. altitude circular polar (90° inclination) orbit.

The launch sequence begins with release of the Pegasus launch vehicle from the carrier aircraft at 40,000 ft altitude and 0.80 Mach. After clearing the aircraft, first stage ignition occurs approximately 300 ft below aircraft altitude. The vehicle quickly accelerates to supersonic speed before beginning a pull-up which is nominally limited to 2.5g transverse acceleration. Maximum dynamic pressure occurs at approximately 30 sec after launch. At approximately 35 sec, a maneuver is initiated to depress the trajectory, and the vehicle angle of attack quickly approaches zero. Attitude control during first stage burn is provided by the three active aerodynamic fins.

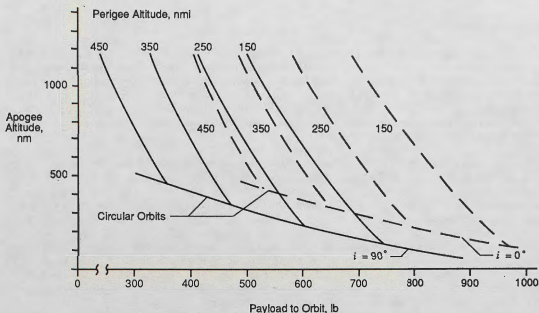


Figure 4. Pegasus Payload Performance

Second stage ignition occurs shortly after first stage burnout and the payload fairing is separated during second stage burn at an altitude sufficient to assure that the payload does not experience excessive pressure or heating rate. Second stage burnout is followed by a long coast during which the satellite and third stage nearly achieve orbital altitude. The third stage motor provides the necessary impulse to circularize the orbit. Third stage burnout typically occurs 10 minutes after launch and approximately 1200 nmi. downrange from the launch point. Attitude control during second and third stage powered flight is provided by the thrust vector control system (pitch and yaw) and the cold gas nitrogen Reaction Control System (RCS) (roll). The RCS provides three-axis control during coast phases.

PAYLOAD PERFORMANCE

Payload performance capability for Pegasus is summarized in Figure 4. The polar performance (solid lines) assumes the baseline launch latitude of 36° , and the equatorial performance (dashed lines) assumes an equatorial launch latitude (0°). Pegasus can achieve a complete range of circular and elliptical orbits, both prograde and retrograde through a suitable choice of launch point and launch azimuth. Orbital inclinations from 55° through 110° or better can be obtained from launch points within control of WSMC, inclinations from 20° to 60° or better can be achieved from overwater launch points within control of ESMC. Special arrangements can be made to launch into very low inclinations (0° to 20°) from overwater launch points at low latitudes. Pegasus can also place non-satellite payloads (attached or deployed) into a wide range of ballistic and depressed suborbital trajectories. For such missions, payloads can be as much as 1500 lb. or more.

RECENT PROGRESS

Since the conception of the Pegasus Air-Launched Space Booster in April 1987, OSC, together with Hercules Aerospace Company, Space Data Corporation and the Pegasus subcontractor team, has embarked on an aggressive development program focused on fielding an initial launch capability in the shortest time possible without sacrificing any critical safety or reliability objectives. This section summarizes some of the recent achievements of the Pegasus development program as of January 1989.

The preliminary design of the Pegasus vehicle was completed in December 1987, at which time Hercules joined OSC as a full joint-venture partner in the privately funded full-scale development. Tooling for major components (motor cases, wing, and fins) was undertaken shortly thereafter, and the full system design was completed in June 1988.

Currently, all three new motor case designs have successfully completed hydroproof tests, and the first set of motor cases is being prepared for propellant casting and curing. This first set of motors will be used for static firing tests in the spring of 1989 to fully qualify the motor designs prior to assembly of the first set of flight motors.

Tooling for the wing and fin structures is now complete at Scaled Composites, Inc. in Mohave, CA, with the first set of wing and fins to be delivered to the OSC integration facility at Dryden Flight Research Facility in late spring. These will support the pathfinder process using a flight-equivalent Pegasus vehicle assembled around inert stage motors. This inert vehicle will be used both for ground handling procedures development and for several captive carry flights with the NASA B-52 carrier aircraft to qualify Pegasus as a captive vehicle, and to verify range connectivity to the telemetry and flight termination systems.

Following successful captive carry flights, the first flight vehicle will be integrated with the DARPA and NASA first payloads for launch on 31 July 1989.