Payload Interface Guide for The Pegasus Air-Launched Space Booster

by

Marty Mosier* and Gary Harris**
Orbital Sciences Corporation

ABSTRACT

The Pegasus^{tm} Air-Launched Space Booster combines an innovative approach to satellite launch operations with the latest in proven launch vehicle technology. Pegasus provides small satellite users with an exceptionally flexible and cost effective means of placing payloads into a wide variety of orbital altitudes and inclinations. Vehicle ground processing techniques and payload integration methods have been designed to provide small payload users with flexibility in satellite design and integration. This paper describes the Pegasus vehicle, provides information pertinent to payload design and outlines the steps involved in using Pegasus to launch a typical small payload.

Vehicle Overview

Pegasus is a three-stage, solid-propellant, inertially-guided, graphite composite, winged launch vehicle developed as a privately funded joint venture of Orbital Sciences Corporation and Hercules Aerospace Company. The vehicle, shown in Figure 1, is 50 feet long, 50 inches in diameter, and has a gross weight of 42,000 lb. Pegasus is carried aloft by a conventional transport/ bomber-class aircraft to level-flight launch conditions of approximately 44,000 feet altitude and high subsonic velocity. After release from the carrier aircraft and first stage motor ignition the vehicle follows an optimal lifting direct ascent trajectory to orbit.

System Description

As shown in Figure 1, the major components of Pegasus include three graphite composite case solid-propellant rocket motors, a fixed high mounted composite delta wing, an aft skirt assembly with three active composite fins, an avionics section atop the third stage, and a two-piece composite payload fairing.

The three graphite-epoxy composite case solid-propellant rocket motors are were designed specifically for Pegasus. The motors have been developed using a conservative design philosophy

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* Pegasus Deputy Program Manager
** Senior Mechanical Engineer

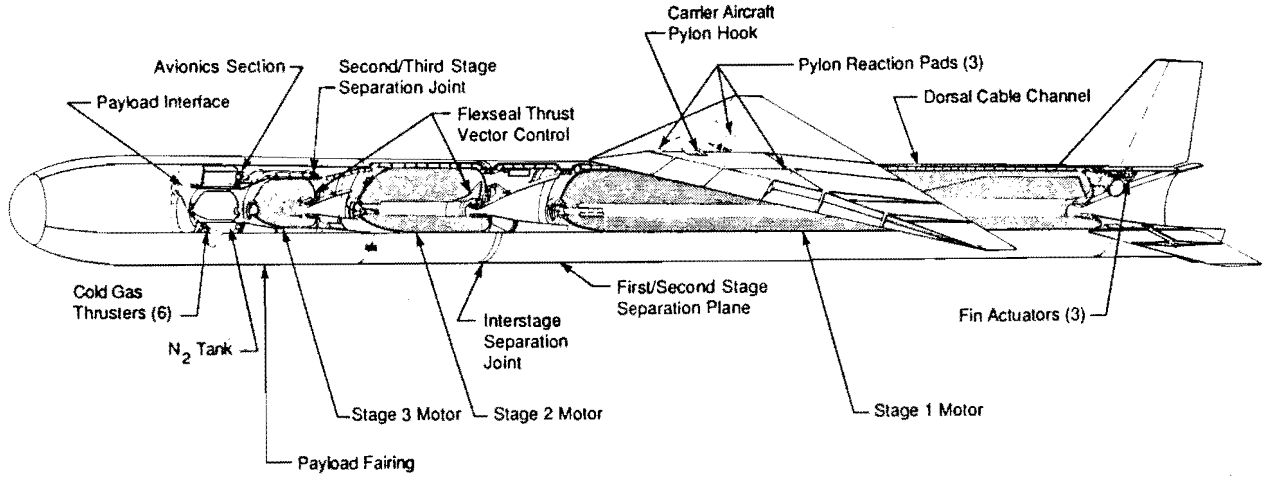

Figure 1. Pegasus Cutaway Drawing

which includes the use of demonstrated component technology, maximum use of common components and tooling among stages, a 1.4 factor of safety for all structural components, and the use of class 1.3 propellant. Motors use IM7 graphite composite cases with aramid filled EPDM rubber internal insulator, cork external insulator and integral skirts. Nozzles have carbon phenolic exit cones with 3-D carbon-carbon integral throat/entry (ITE). Motor performance characteristics are summarized in Table 1. The first stage motor has a fixed nozzle. Second and third stage nozzles have electro-mechanical thrust vector control.

The avionics subsystem is mounted to the third stage motor and serves as a mounting structure for most vehicle avionics. These include an inertial measurement unit (IMU), flight computer, telemetry transmitter, telemetry multiplexer, ordnance and thruster driver units, RCS thrusters, dual flight termination receivers, radar transponder, batteries, various other components and harness. The structure is comprised of a graphite conical and cylindrical sections with an aluminum planar honeycomb deck. The avionics structure also provides a mechanical interface for the payload.

Vehicle avionics have been designed to be as simple and robust as possible. The vehicle functional block diagram is shown in Figure 3. Pegasus is controlled throughout all phases of flight by a 68020 based flight computer which communicates with all vehicle avionics devices using serial digital RS-422 communication lines. Most stage and special function avionics components have integral microprocessors which increase flexibility and reduce main computer processing requirements. Digital communication techniques and reliance on distributed processing capability within stage avionics components significantly reduces vehicle wiring and simplifies ground processing, integration and test.

Motor Characteristics	1st Stage	2nd Stage	3rd Stage
Inert Weight (lb)	2,780	800	277
Propellant Weight (lb)	26,790	6,670	1,725
Burn Time (sec)	72.3	71.4	64.6
Max Pressure (psia)	1,088	1,003	749
Avg Pressure (psia)	797	793	637
Max Vac Thrust (lbf)	131,244	30,912	9,065
Avg Vac Thrust (lbf)	109,419	27,605	7,772
Vac Impulse (lbf-sec)	7,911,000	1,971,000	502,100
I_{sp} Vac (sec)	295.3	295.5	291.1

Table 1. Motor Performance Summary

During flight all critical vehicle performance parameters are transmitted to the ground using a single 56 kbps S-band telemetry channel. A C-band radar transponder is provided to improve the ability of ground stations to track the vehicle during ascent. A fully redundant UHF flight termination system is provided to satisfy range safety requirements. Antenna systems for these three RF links are installed on both the second and third stage motors.

The aft skirt subsystem consists of an aluminum cylindrical section which supports three electro-mechanical fin actuators and fin actuator control electronics. The three composite fins provide aerodynamic control throughout the first stage burn.

The payload fairing is a two piece carbon composite structure consisting of 60 mil face sheets over 0.5 inch aluminum honeycomb. The fairing maintains the 50 inch outside diameter of the second stage motor and completely encloses the payload, avionics subsystem and smaller diameter third stage motor. Openings are provided for two sets of RCS thruster pods, a payload access door, and pyrotechnic bolt cutters for separation of the forward fairing clamp ring. Honeycomb venting is provided through small holes in the inside face sheet. Bulk venting is provided by two cutouts near the base of the fairing. When on the ground the payload area is cooled and maintained under positive pressurization by the air conditioning cart. During captive flight dry nitrogen is purged through the fairing from tanks inside the carrier aircraft.

Ground Operations

Pegasus was designed to simplify and minimize field integration effort, facilities and equipment. Build up of Pegasus begins with the delivery to the integration site of the solid

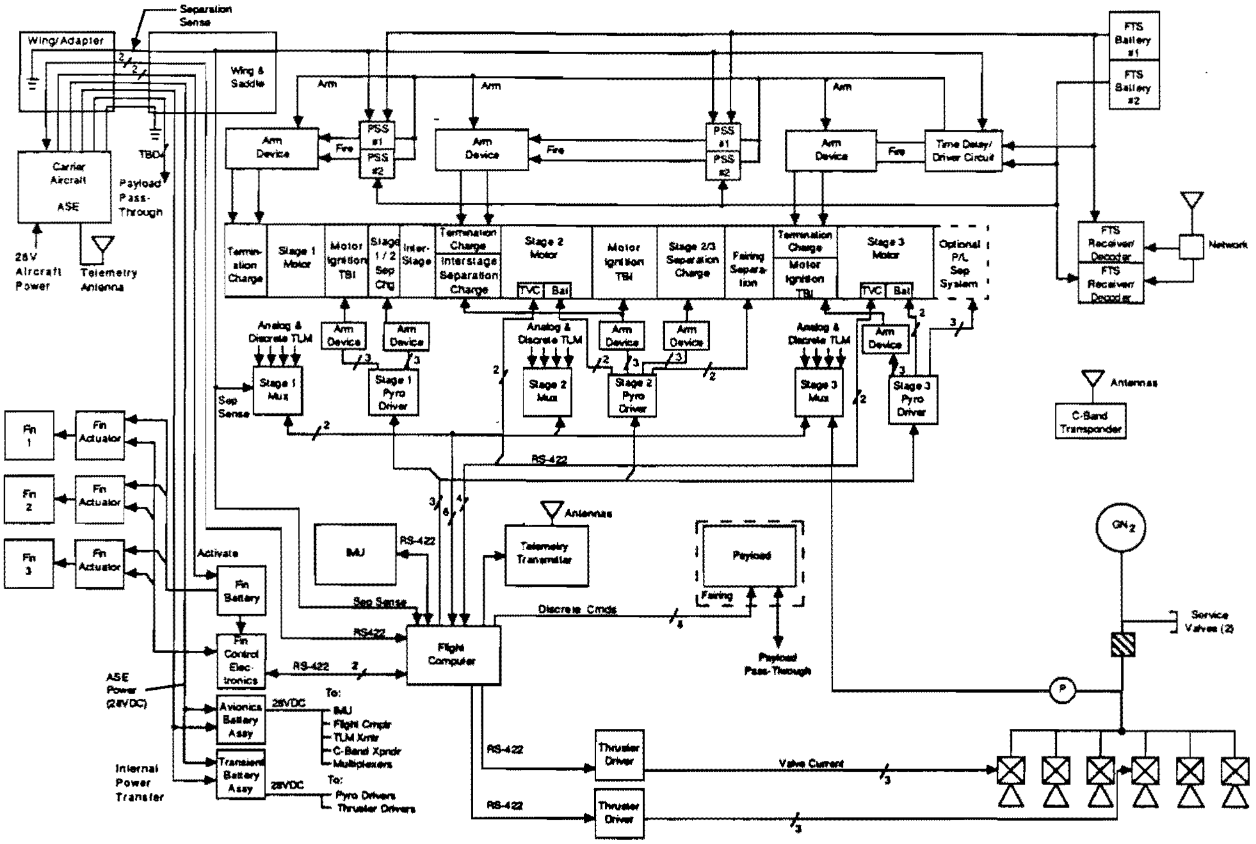

Figure 2. Pegasus Avionics Block Diagram

rocket motor sections. Motors are shipped in standard ordnance transportation vans (TARVANS) on custom designed handling dollies. The motor sections remain on these handling dollies throughout the integration process which eliminates the need for lifting motors in the field. Upon arrival, stages are removed from the TARVANs and placed on a custom designed multifunction Assembly and Integration Trailer (AIT). The AIT has integral lifting jacks which allow it to be elevated to TARVAN bed height and the motor sections off-loaded directly onto the AIT bed. The AIT is then lowered to floor level for vehicle integration. The avionics subsystem is delivered to the field completely integrated, acceptance tested, and ready for integration with the third stage motor. The wing, fins and payload fairing are received with all thermal protection and instrumentation installed. Once the vehicle has been integrated and tested the payload is mated and the fairing installed. The AIT is then used to transport Pegasus to the carrier aircraft, elevate it, and align it for mating. The combined AIT and custom dolly system provides full six-degree of freedom movement capability for the finished vehicle. A portable air conditioning unit provides filtered conditioned air for the payload and avionics while the vehicle is being mated prior to takeoff.

Launch Operations

The sequence of events for a typical launch profile is shown in Figure 3. The time, altitude, velocity and flight path angle

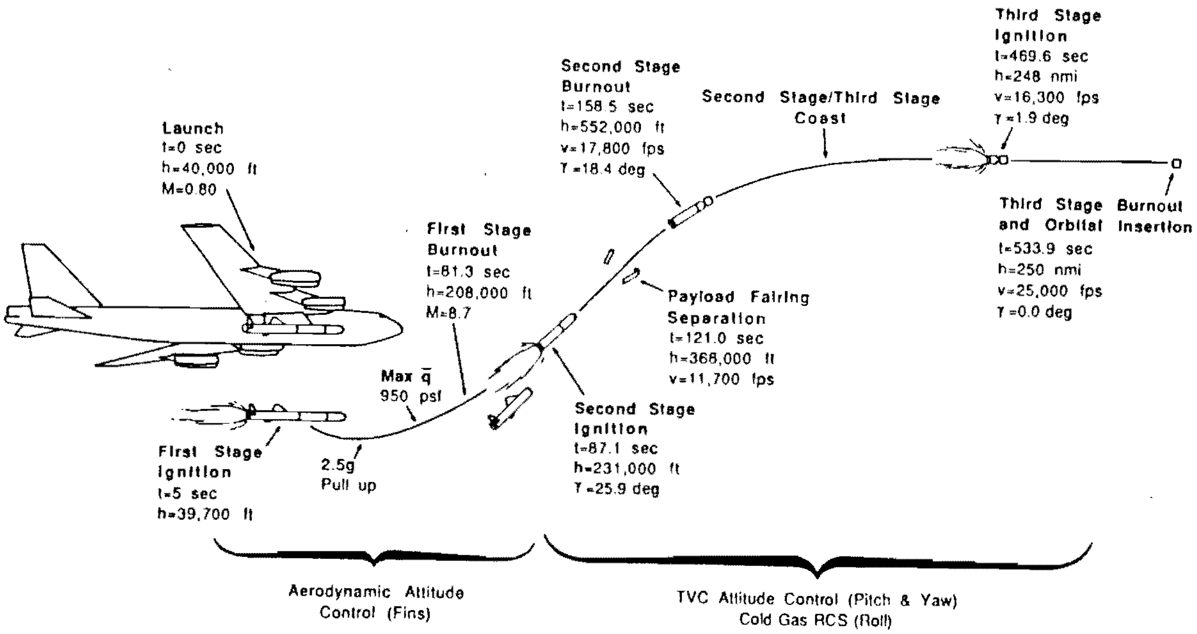

Figure 3. Typical Launch Profile

shown for the motor ignition, separation and burnout events are typical for a trajectory that achieves a 250 n.mi. altitude circular polar (90° inclination) orbit. Launch begins with release Pegasus from the carrier aircraft at 44,000 ft altitude and 0.80 Mach. First stage ignition occurs 5 seconds after release from the carrier aircraft after Pegasus has fallen approximately 300 feet. The vehicle then quickly accelerates to supersonic speed before beginning a pull-up which is nominally limited to 2.5 g transverse acceleration. Maximum dynamic pressure occurs approximately 30 sec after launch. After approximately 35 seconds, the trajectory is depressed and the angle of attack approaches zero.

Second stage ignition occurs shortly after first stage burnout. The payload fairing is separated shortly after second stage ignition, as soon as an altitude sufficient to assure that the payload does not experience excessive pressure or heating has been achieved. 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 n.mi. downrange from the launch point. Attitude control during first stage burn is provided by the aerodynamic control surfaces. Attitude control during both second and third stage powered flight is provided by the thrust vector control (TVC) system (pitch and yaw) and the cold gas nitrogen RCS (roll). The RCS also provides three-axis control during coast phases.

Following orbital insertion, the Pegasus third stage executes a series of pre-specified commands contained in the mission data load to provide the desired initial payload attitude prior to payload separation. Either an inertially-fixed or spin-stabilized

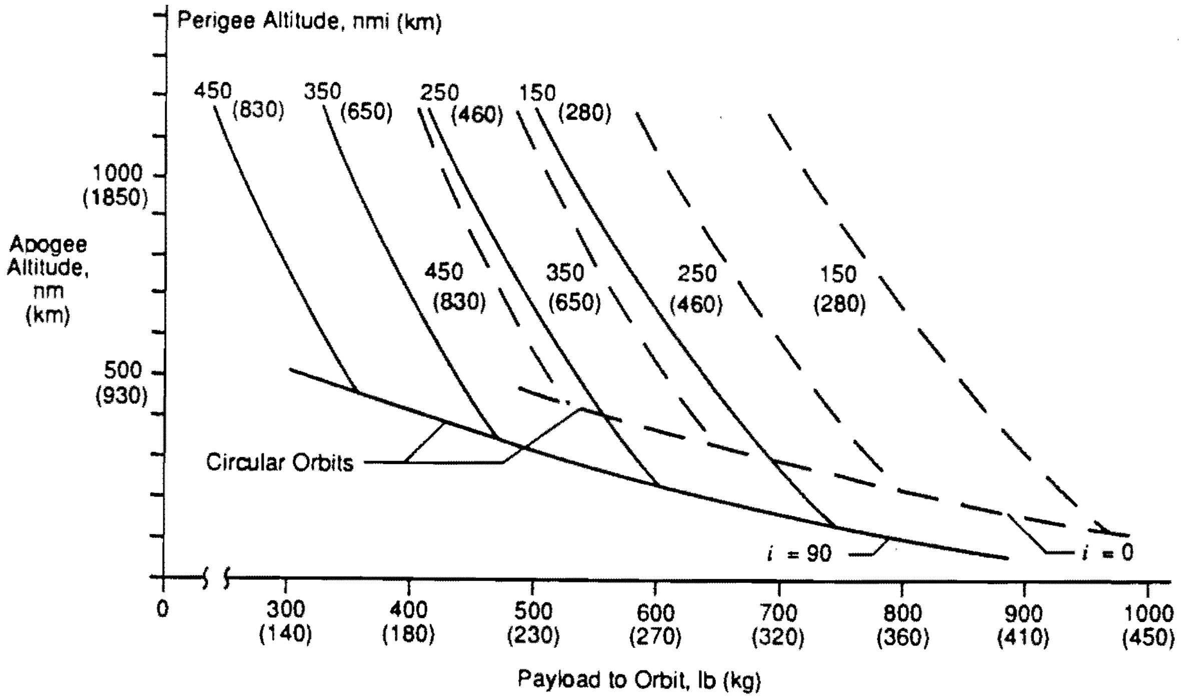

Figure 4. Pegasus Payload Performance

attitude may be specified. For inertial attitudes the payload and third stage can be oriented to ± 2 degrees in angular position in each axis. For a spin-stabilized initial attitude, the maximum spin rate achievable depends on the payload and spent third stage combined spin-axis moment of inertia. RCS can provide up to 1,000 lb-in-sec total impulse for spin-up. Orientation of the payload/third-stage spin axis can be achieved to ± 2 degrees.

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 the Western Test Range, which is currently being used for Pegasus launch operations. Inclinations from 20° to more than 60° can be achieved from overwater launch points within control of the Eastern Test Range. 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, payload performance can be as much as 1500 lb. or more.

Payload Interfaces

Available payload volume and the standard mechanical interface is shown in Figure 5. This represents the maximum dynamic envelope allowed for the payload during captive carry and flight. The location of the combined payload and adaptor center of mass is restricted to satisfy bending and buckling load limits of the avionics structure design. The maximum axial displacement of the combined payload and payload adapter center of mass, relative to the payload interface plane is summarized in Figure 6. The standard payload mechanical interface consists of a bolt hole pattern in the aluminum honeycomb deck, reinforced by doublers on each side. OSC will supply a payload interface drill tool to customers to guarantee proper mating. It is anticipated that for most applications, a customer-supplied payload adaptor will be bolted directly to the deck. In other cases, a payload adaptor can be designed by OSC to specific payload requirements, or if the payload and third stage are to remain attached throughout on-orbit operations, the payload can be mated directly to the bolt hole circle.

Two payload umbilical interfaces are built into the honeycomb deck to provide the payload with electrical power prior to launch and discrete commands for payload events sequencing. Figure 5 shows the location and typical connector designation for the interface. Up to eight (8) discrete sequencing commands, generated by the Pegasus flight computer can be tied directly to the launch vehicle sequence timing. Payload telemetry downlink while attached to the carrier aircraft and/or during launch can be provided using the Pegasus telemetry system by employing an optional payload telemetry multiplexer. Up to 12 kbps of the 56 kbps telemetry stream is available for optional payload telemetry.

Environments

This section summarizes the static, dynamic, thermal, and acoustic environments that will be experienced by the payload in a direct insertion orbital launch mission, and assumes use of the NASA Dryden B-52 research aircraft. Environmental parameters for suborbital and depressed atmospheric flight trajectories, will be somewhat different from the values presented herein and must be developed based on specific mission requirements. Figure 7 summarizes the coordinate and sign conventions for all load cases.

Acceleration - Aircraft landing, flight pull-up, and stage-3 burn-out produce the maximum load cases on the payload. The maximum expected (design limit) steady-state accelerations at the payload interface plane for these three cases are summarized in Table 2. It should be noted that quasi-static accelerations from motor burn vibration must be added to the steady-state accelerations for the stage-3 burn-out case to get an overall limit

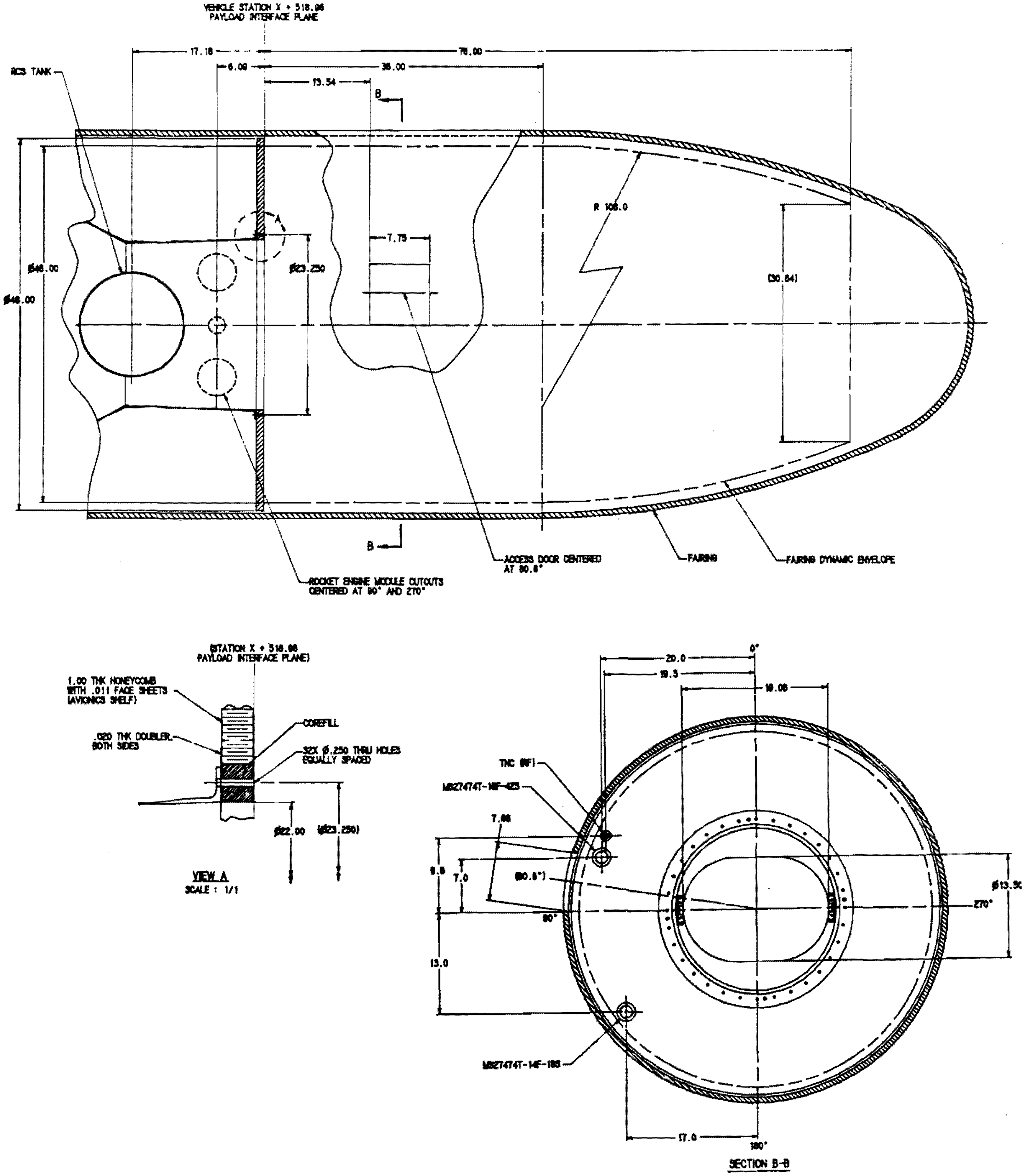

Figure 5. Payload Area and Interfaces

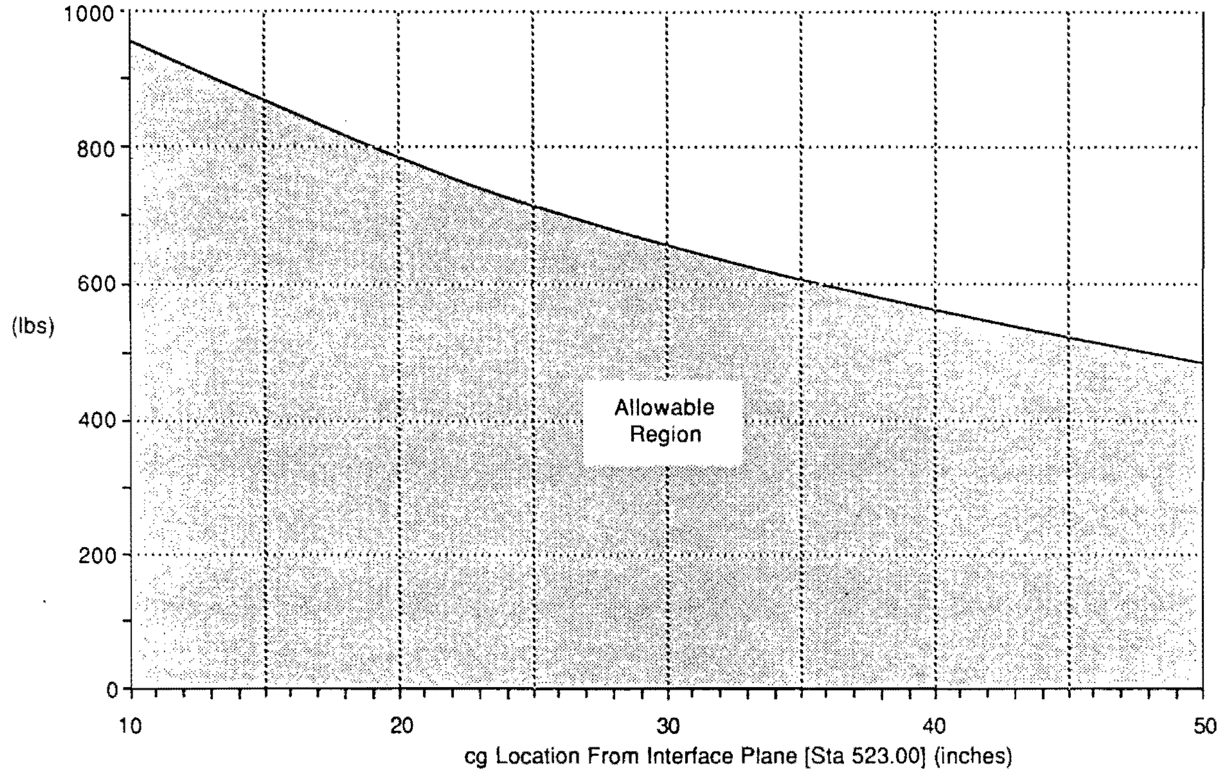

Figure 6. Payload Mass vs. CG Location

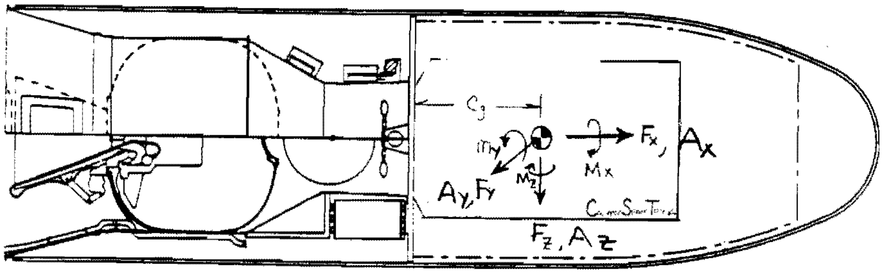

Figure 7. Load Case Coordinate System

load for the payload. The stage-1 motor burn vibration is attenuated by the other two motors and thus there is no need to add stage-1 quasai-static accelerations for the pull-up case.

<u>Vibration</u> <u>Loads</u> - The highest payload random vibration load is that produced by stage-3 motor ignition and burn. Using data from a ground test firing of the motor, a FEM coupled loads analysis was conducted to develop quasi-static loads (Grms). These loads are shown in Figures 9 and 10. Both axial and lateral Grms must be added to steady state acceleration to get a total load for the payload.

	Load Case	Accelerations (g's / Rad/s^2)					
		A_X	A_Y	A_Z*	R_X	R_Y	R_Z
1.	B-52 Landing	+.60 -.60	+.60 -.60	+2.8 -.35	+.50 -.50	+1.4 -1.0	+.40 -.40
2.	Flight Pull-up	+4.0	+.50	+2.8			
3.	ST-3 Burn-out	See Figure 8	+0.2 -0.2	+0.2 -0.2			

* Note: A_Z includes gravity in all cases.

Table 2. Steady State Acceleration Summary

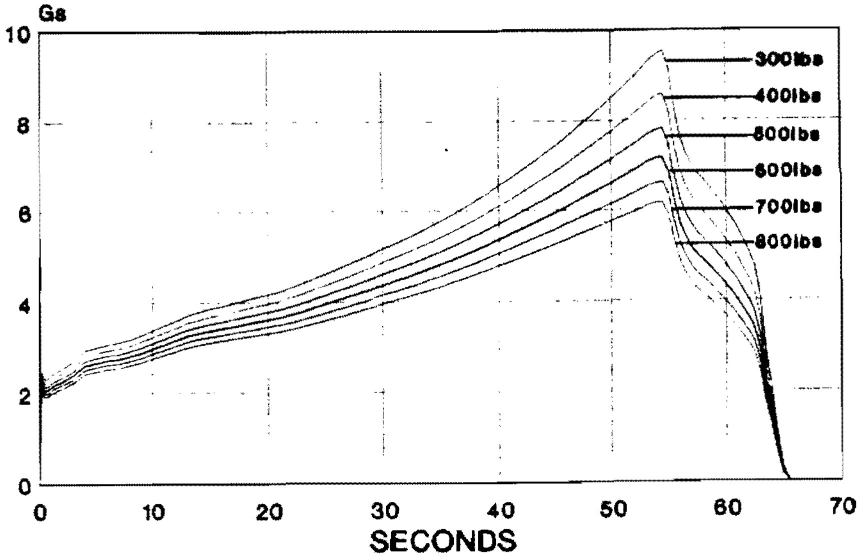

Figure 8. Third Stage Axial Acceleration vs. Payload Weight

Vibration Test Levels - Suggested payload qualification and acceptance random vibration test levels are shown in figure 11. These levels are based on motor test firing data and are independent of direction. The payload should be subjected to these vibration levels in all three directions during testing.

Shock - The pyrotechnic shock environment experienced by the payload is dominated by third stage separation, with the other separation shocks being subordinate. The pyrotechnic shock levels shown in Figure 12 have been developed from stage separation tests and depict the expected payload interface (avionics side) shock levels. Qualification levels for units should be 6dB higher.

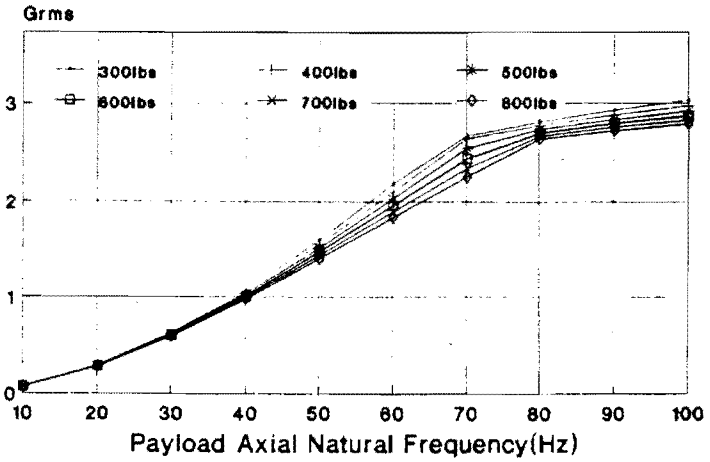

Figure 9. Payload Axial Grms From Random Vibration

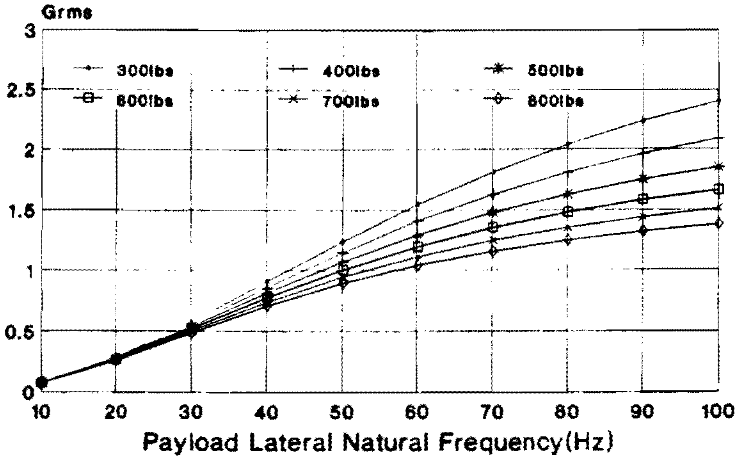

Figure 10. Payload Lateral Grms from Random Vibration

<u>Thermal</u> - Mating the payload to Pegasus and all close-out procedures are carried out in a temperature-controlled working area at 70°F ± 5°F and 40% ± 10% RH. If required, payload mate and close-out can be performed in a clean tent (class 100,000 or better) environment. During ground operations, following closure of the payload fairing, the payload thermal environment is temperature and humidity controlled to 70°F ± 30°F and 40% ± 20% RH, until just prior to carrier aircraft taxi and takeoff.

At launch altitude the ambient air temperature is approximately -70°F. Depending on the launch location requirement of the specific mission, sufficient time may be spent aloft to

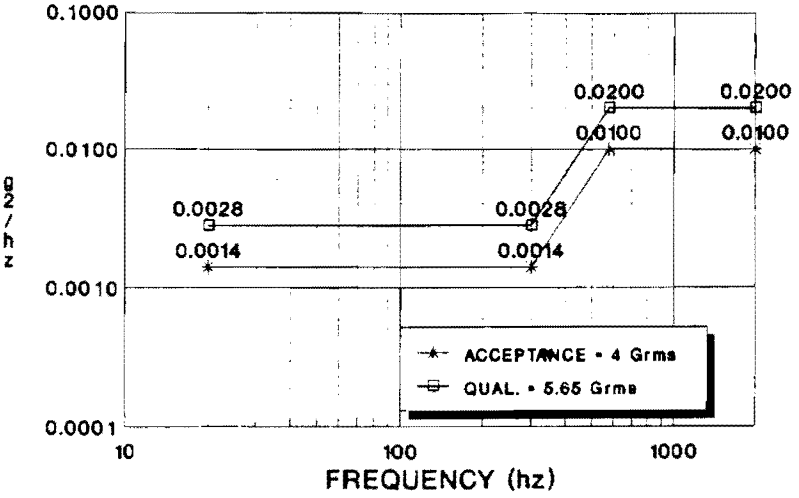

Figure 11. Suggested Payload Vibration Test Levels

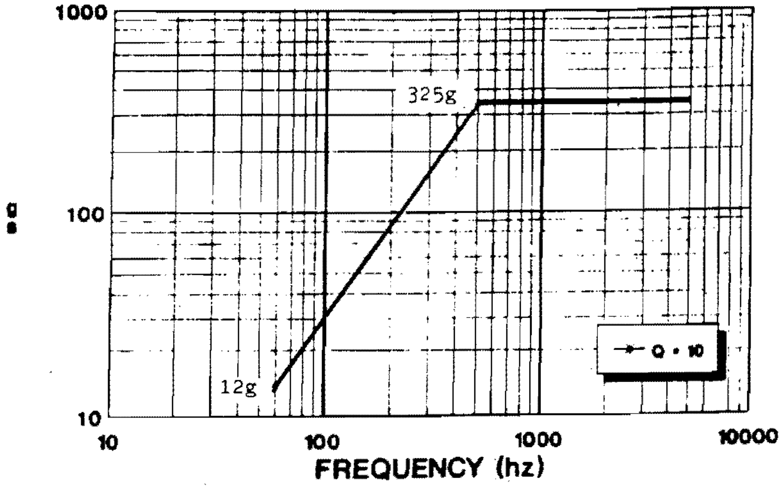

Figure 12. Pyrotechnic Shock at Payload Interface

produce low steady-state payload temperature. For payloads that require heaters to maintain temperature limits on sensitive components, up to 140 watts of 28 VDC power is available during captive carry.

Acoustic - Acoustic noise is much lower than pad reflected noise on a ground launched vehicle. The actual acoustic noise environment inside the payload fairing will be experimentally characterized during the first several flights.

Design Guidelines

The recommended design margins of safety for payloads using Pegasus™ are listed below:

For man-rated events (load case 1 : B-52 landing),
Design Yield = Limit * 1.25
Design Ultimate = Limit *1.50

Margin of safety over ultimate:
If qualification tested to Design Ultimate - M.S. ≥ 0
If Protoflight tested to Design Yield - M.S. ≥ 0.25

For non-man-rated events (load cases 2 & 3),
Design Yield = Limit * 1.10
Design Ultimate = Limit * 1.25

Margin of safety over ultimate or yield - M.S. ≥ 0

Design Load Calculation Example

Given a 500 lb payload with a center of gravity 30" forward of the interface and a natural frequency of 50 Hz, we will calculate 3 design limit load cases. Design yield and ultimate loads are then calculated and summarized. Coordinate conventions are as presented in Figure 7.

Payload Properties (assumed)

$M = 500$ lbs
$Cg_X = 30$ in
$Cg_Y = Cg_Z = 0$ in
$f_n = 50$ Hz

$I_{xx} = 10.4$ slug-ft^2
$I_{yy} = 15.0$ slug-ft^2
$I_{zz} = 15.0$ slug-ft^2

Bulk Payload Limit Loads:

Load case 1: Aircraft (B-52) landing -

X Direction:
$F_X = M\ (A_X)$
$F_X = 500(.6) = 300.0$ lbs

$M_X = R_X(I_{XX})$
$M_X = .5(10.4) = 5.2$ ft-lbs

Y Direction:
$F_Y = M\ (A_Y + R_Z(Cg/386.4))$
$F_Y = 500(.6 + .4(30/386.4)) = 315.5$ lbs

$M_Y = R_Y(I_{YY})$
$M_Y = .4(15.0) = 6.0$ ft-lbs

Z Direction:
$F_Z = M\ (A_Z - R_Y(Cg/386.4))$
$F_Z = 500(2.8 - (-1.0)(30/386.4)) = 1438.8$ lbs

$M_Z = R_Z(I_{ZZ})$
$M_Z = -1.(15.0) = -15.$ ft-lbs

Note: In all cases, the contribution of the angular accelerations to the total load is small and can usually be neglected.

Load case 2: Flight Pull-up at time of maximum g's -

X Direction: $F_X = M\ (A_X)$
$F_X = 500(4.0) = 2000.0$ lbs

Y Direction: $F_Y = M\ (A_Y)$
$F_Y = 500(.5) = 250.0$ lbs

Z Direction: $F_Z = M\ (A_Z)$
$F_Z = 500(2.8) = 1400.0$ lbs

Load case 3: Stage-3 Burn-out -

X Direction: $F_X = M\ (A_X + V_A)$
$F_X = 500(7.8+1.5) = 4650.0$ lbs

Y Direction: $F_Y = M\ (A_Y + V_L)$
$F_Y = 500(.2+1.25) = 725.0$ lbs

Z Direction: $F_Z = M\ (A_Z + V_L)$
$F_Z = 500(.2+1.25) = 725.0$ lbs

General Notes:

A_X is axial acceleration taken from Figure 8.

V_A is a quasi-static axial acceleration due to motor random vibration from Figure 9.

V_L is a quasi-static lateral acceleration due to motor random vibration from Figure 10.

Summary of results:

	Load Case	Level	F_X	F_Y	F_Z
1.	B-52 Landing	Limit	300	316	1439
		Yield	375	395	1799
		Ultimate	450	474	2159
2.	Flight Pull-up	Limit	2000	250	1400
		Yield	2200	275	1540
		Ultimate	2500	313	1750
3.	Stg-3 Burn-out	Limit	4650	725	725
		Yield	5115	798	798
		Ultimate	5813	907	907

Payload Integration Support

One of the principal objectives of the Pegasus program is to make it as simple and straight forward as possible to launch a payload using the vehicle. To achieve this end, a streamlined methodology is suggested to aid in quickly and easily identifying and resolve interface issues. This process is shown pictorially in Figure 13. The process begins with the recognition of an experiment, proof of concept, or commercial opportunity which requires a space born resource. Once the need has been developed, a preliminary design concept, along with associated orbital parameters can be established. This trade-off effort endeavors to find an acceptable combination of orbital parameters and spacecraft performance requirements to most cost effectively achieve the desired objectives. Performance curves and information provided in this paper can be used to facilitate trade off considerations relative to Pegasus launch vehicle capability. Current information relative to Pegasus vehicle capabilities of an accuracy sufficient for conceptual design studies can also be found in the Pegasus Payload Users Guide.

Once the decision has been made to use Pegasus to launch a particular payload, OSC should be contacted to begin the process leading up to launch. Consistent with the program's goal of making Pegasus as "user Friendly" and flexible as possible the customer interface has been simplified and streamlined. Two individuals at OSC are responsible for all aspects of a specific launch: the payload integration manager and the vehicle engineer.

The payload integration manager is responsible for all customer interface and generation of a specific Interface Control Document (ICD). The ICD specifies clearly and plainly every aspect of the Pegasus to payload interface. Items specified in the ICD include a description of the payload, definition of all mechanical and electrical interfaces, payload ground handling considerations, safety considerations, captive flight and launch services to be provided, orbital parameter requirements (altitude, inclination and accuracy), launch window constraints, and post insertion maneuvers. ICD's are custom documents which are generated for each mission. All requirements are stated clearly and specifically. The vehicle engineer uses the ICD to configure Pegasus hardware and software for a specific launch. The vehicle engineer is responsible for delivering to the integration site, integrating and launching a Pegasus vehicle which meets the performance requirements specified in the ICD.

During the process of building the payload the Payload Integration manager and the vehicle engineer work with the customer to resolve problems and answer questions. Changes are documented in the ICD, which is updated as often as required. Pegasus is intended to be a flexible launch vehicle and specific requests for

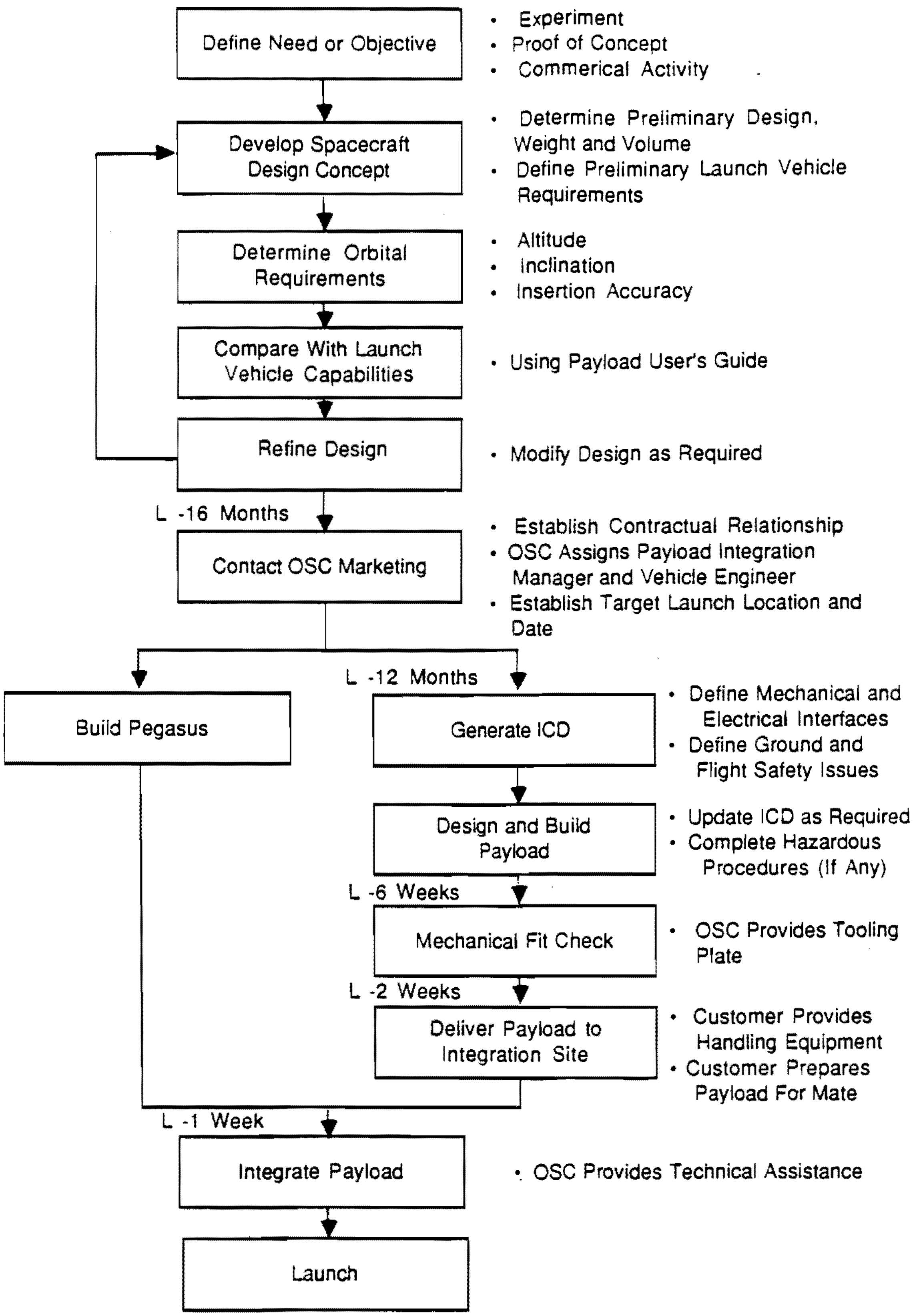

Figure 13. Typical Launch Processing Flow

services and support will be evaluated and accommodated as much as possible.

To facilitate final trajectory optimization and completion of the mission data load payload weight and center of gravity documentation must be provided as soon as it is available. Payload spin balancing and mass moment of inertia information is not required unless the payload requires spin up after orbital insertion. If desired, a coupled loads analysis to produce more detailed load estimates can be performed. Hazardous materials and ordnance devices in the payload must be identified as early as possible so that safety requirements can be met.

At the field integration facility customers have available for their use, an office area complete with desks, chairs, a conference table, and telephones. In the Vehicle Assembly Building payloads can be received and processed in down flow modules which support a minimum of a class 100,000 clean room environment if desired. Final integration and mating of the payload to Pegasus is normally done by the customer with OSC field personnel support. Normal ground handling equipment is available for customer use, however payload suppliers must provide any special handling equipment and fixtures.

Summary

Pegasus is a new launch vehicle which has been designed to provide easy to use, low cost, and flexible launch opportunities for satellites in the half-ton class. The vehicle's low cost and unique launch technique provides small payload user with an opportunity to place payloads in that orbit best suited to the mission, on a fast paced schedule, free from the restrictions and uncertainties normally encountered when flying as a secondary payload. Orbits of virtually any inclination can easily be obtained by flying the carrier aircraft to the proper over ocean launch point. Testing performed during the development program has confirmed that the static and dynamic loads imposed on a payload during launch are equal to or less than conventional ground launched vehicles. With Pegasus, payload preparation and integration is done in a relatively unrestricted airport hanger environment which can be complimented by clean room conditions if required. Ground air conditioning and in-flight nitrogen purge capability assures payload cleanliness. Establishment of a single point of contact Payload Integration Manager and Vehicle Engineer for each launch simplifies and expedites the resolution of integration and launch issues.