NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

OMV Payload Support Concept
for
Pegasus Boosted Payloads

by

Ronald C. Repper

September 1989

Thesis Advisor:	Dr. Dan C. Boger
Co-Advisor:	Dr. Herschel H. Loomis, Jr.

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ecurity Classification of this page

REPORT DOCUMENTATION PAGE

a Report Security Classification Unclassified	1b Restrictive Markings
a Security Classification Authority	3 Distribution Availability of Report
b Declassification/Downgrading Schedule	Approved for public release; distribution is unlimited.
Performing Organization Report Number(s)	5 Monitoring Organization Report Number(s)
a Name of Performing Organization Iaval Postgraduate School / 6b Office Symbol (If Applicable) 39	7a Name of Monitoring Organization Naval Postgraduate School
c Address (city, state, and ZIP code) Ionterey, CA 93943-5000	7b Address (city, state, and ZIP code) Monterey, CA 93943-5000
a Name of Funding/Sponsoring Organization / 8b Office Symbol (If Applicable)	9 Procurement Instrument Identification Number
c Address (city, state, and ZIP code)	10 Source of Funding Numbers Program Element Number / Project No / Task No / Work Unit Accession No

1 Title *(Include Security Classification)* OMV Payload Support Concept for Pegasus Boosted Payloads

2 Personal Author(s) Ronald C. Repper

3a Type of Report	13b Time Covered	14 Date of Report *(year, month,day)*	15 Page Count
Iaster's Thesis	From To	September 1989	85

6 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official olicy or position of the Department of Defense or the U.S. Government.

7 Cosati Codes			18 Subject Terms *(continue on reverse if necessary and identify by block number)*
ield	Group	Subgroup	Launch Vehicles, Pegasus, Orbital Maneuvering Vehicle, Small Satellite Design, Space Systems, Commericial Launch System, Booster

9 Abstract *(continue on reverse if necessary and identify by block number*

This thesis examines a new concept of orbiting and maintaining payloads in low earth orbit. Two existing :chnologies, namely the Pegasus Air-Launched Space Booster and the Orbital Maneuvering Vehicle (OMV), are ierged to create an operational space system. The boosted payload need not be an autonomous satellite, as the)MV will provide all required support to the payload. This allows new satellite design, as the weight and volume f non-productive satellite subsystems can be replaced with more payload. A superior system could then be rbited while maintaining a fixed weight and volume budget. The first four chapters provide background on the roposed concept and the OMV and Pegasus vehicles. Chapter five describes the docking and activation of the egasus payload to the OMV. A comparison of a current NOAA satellite system to the OMV/Pegasus concept is ffered in Chapter six to determine the merits of this strategy. Conclusions and recommendations are then offered oncerning the economic and operational advantages over current space systems with the implementation of this ew concept.

Distribution/Availability of Abstract [X] unclassified/unlimited [ ] same as report [ ] DTIC users	21 Abstract Security Classification Unclassified
a Name of Responsible Individual an C. Boger	22b Telephone *(Include Area code)* (408) 646-2607 / 22c Office Symbol 54Bo

) FORM 1473, 84 MAR 83 APR edition may be used until exhausted security classification of this page

All other editions are obsolete Unclassified

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Pegasus Boosted Payloads

by

Ronald C. Repper
Lieutenant Commander, United States Navy
B.S., University of Missouri, 1977
M.S., Troy State University, 1984

Submitted in partial fulfillment of the
requirements for the degree of

MASTERS OF SCIENCE IN SYSTEMS TECHNOLOGY
(SPACE SYSTEMS OPERATIONS)

from the

NAVAL POSTGRADUATE SCHOOL
SEPTEMBER 1989

ABSTRACT

This thesis examines a new concept of orbiting and maintaining payloads in low earth orbit. Two existing technologies, the Pegasus Air-Launched Space Booster and the Orbital Maneuvering Vehicle (OMV), are merged to create an operational space system. The boosted payload need not be an autonomous satellite, as the OMV will provide all required support to the payload. This allows new satellite design, as the weight and volume of non-productive satellite subsystems can be replaced with more payload. A superior system could then be orbited while maintaining a fixed weight and volume budget. The first four chapters provide background on the proposed concept and the OMV and Pegasus vehicles. Chapter five describes the docking and activation of the Pegasus payload to the OMV. A comparison of a current NOAA satellite system to this OMV\Pegasus concept shows the merits of this strategy. Conclusions and recommendations are then offered concerning the implementation of this new concept.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFB - Air Force Base

DARPA - Defense Advanced Research Projects Agency

DMSP - Defense Meteorological Satellite Program

EVA - Extravehicular Activity

FPS - Feet Per Second

Ga-As - Gallium Arsenide

GCC - Ground Control Console

GFE - Government Furnished Equipment

GN&C - Guidance, Navigation and Control

GPS - Global Positioning System

IMU - Inertial Measurement Unit

KG - Kilogram

KPS - Kilobits Per Second

kW - Kilowatt

LB - Pound

LBF - Pounds Force

NASA - National Aeronautics and Space Administration

Ni-Cd - Nickel-Cadmium

$Ni-H_2$ - Nickel-Hydrogen

NM - Nautical Mile

NOAA - National Oceanic and Atmospheric Administration

OMV - Orbital Maneuvering Vehicle

ORU - Orbital Replacement Unit

OSC - Operations Support Center

OSC - Orbital Sciences Corporation

PM - Propulsion Module

RCS - Reaction control System

Si - Silicon

SRV - Short Range Vehicle

TPDM - Three Point Docking Mechanism

TRS - Teleoperator Retrieval System

VDC - Volts Direct Current

ACKNOWLEDGMENT

I would like to extend my gratitude to Dr. Boger and Dr. Loomis for their assistance during the preparation and writing of this thesis. They provided a positive influence, motivation, and acted as a springboard for my ideas and thoughts. My greatest thanks goes to my lovely wife Sharon. Her continual patience and understanding during the last few months have made this effort much easier.

I. INTRODUCTION

A. GENERAL CONCEPT

This thesis proposes a new concept in space operations. It will analyze the utility of boosting a satellite into low earth orbit, where it will rendezvous with an already orbiting platform which will provide on-orbit services such as power and attitude control. The concept is aimed at the small commercial or government user desiring to orbit a satellite with a limited lifetime of approximately one year.

A major criterion for this concept was to use existing systems. To provide a near term capability to the commercial sector, future designs and concepts were not considered. Both the satellite boost system and the orbiting host platform are in final development. Only minor modifications are required to integrate these two autonomous systems into a new payload support concept.

The orbiting platform will be a long life system, ten years or greater, and will sequentially support multiple payloads. The user will launch his satellite to the orbiting platform's position, dock with it, and lease on-orbit services for the length of the mission. Once completed, the OMV will detach from the payload and be available for another customer's payload.

The satellite design for this concept is much simpler than the design which is currently used. It would be built without many of the support systems currently required, as these functions will be provided by the host platform. Only the basic payload need be launched to the host platform. Once on orbit and mated to the platform, attitude control, propulsion, electrical power, and telemetry will be provided. The savings from the elimination of satellite systems such as the attitude, electrical, communications, and telemetry equipment have two major benefits. The first is to offset the cost of on-orbit services provided by the host platform. A fee for use of the host vehicle will be charged to the user based on the time he is mated to the vehicle. This user-cost is partially defrayed as satellite hardware procurement dollars for subsystems no longer required are available to buy on-orbit services. The second and most significant benefit is the weight and volume made available to the satellite designer by eliminating these systems from the satellite. This extra weight and area may now be used to increase the actual number or the size of payload devices onboard the satellite while remaining within a fixed weight budget.

The satellite boost system to be used is the Pegasus air-launched space booster. This system is the newest commercially developed booster, with its first launch scheduled in October 1989, and is designed for small payloads of 600-900 lb size.

The orbiting host platform is the Orbital Maneuvering Vehicle (OMV). Funded by NASA and currently under construction, the first OMV will launch in 1993 to support the Hubble Space Telescope mission.

The basic concept is to launch Pegasus and a payload as close as possible to the OMV's orbit. After orbital insertion, the OMV will be maneuvered to intercept and dock with the payload. Once docked, the OMV will then transfer to the desired orbital altitude and begin the mission.

B. THESIS OBJECTIVE

The intent of this study is to investigate the feasibility of a new payload design and support system for small satellite missions. The current launch system infrastructure is very costly and prohibits many potential customers from orbiting payloads. A more affordable means of employing space for research and development efforts is needed and, if found, would attract many users to space. This concept could be a major breakthrough in the economic barrier for the small payload user.

C. ORGANIZATION OF THE THESIS

The second chapter gives a brief background on the need for small satellites. Generic uses and missions of the satellite and the growing need to orbit small payloads are presented. Modification in the basic design of current satellites is proposed and the benefits discussed. The two subsystems of the space-based payload support concept are introduced.

The third chapter is an indepth look at the OMV. A brief history of the vehicle and the original design mission is stated. The vehicle's physical description and its subsystems are described for the reader's understanding. Modifications to the existing NASA design, required for the space-based host platform, are presented.

The Pegasus booster system is discussed in Chapter IV. The booster's background and development, systems, ground and air support structures, and flight profile are covered. Payload integration and size constraints are also given for the booster.

Chapter V describes the details of a payload launch and mating with the OMV. The rendezvous technique to be used is covered and the specific on-orbit services to be provided the payload are listed. The OMV's maneuvering capability for the payload and deorbit capability after mission completion are presented.

Chapter VII compares the OMV/Pegasus concept to a current NOAA satellite system. The advantages of the space-based OMV providing a platform for a Pegasus boosted payload are summarized. Conclusions and recommendations are then offered regarding implementation of this new concept of payload design and hosting by an on-orbit vehicle.

II. BACKGROUND

The availability of space for use in research and development is limited to a relatively small group. The large expense involved in building a spacecraft and funding a launch to orbit can be managed by only the largest firms and major governments.

A large amount of research can and needs to be done in the space environment. New work in medicine, biotechnology, remote sensing, solar power, and materials processing are examples of increasing needs for a responsive and affordable access to space. Small business, institutions and universities would greatly benefit from an affordable avenue to space, which is currently unavailable.

A. CONCEPT DEFINITION

To allow more access to space for research and development, the cost simply must be reduced. The direct correlation of launch cost to launch weight is fixed for the near future. To reduce launch cost, one is left with the option of reducing launch weight. If satellite design is changed so that more actual payload mass is launched for the same cost, a true savings is realized by launching the equivalent of a larger satellite for the same cost. More payload is available by deleting payload support systems from the satellite.

The main advantage of this concept is an economic one. The cost to boost a satellite to orbit is high and unavoidable. Some variability exists between the cost of specific launch platforms, but once the platform is selected this is basically a fixed cost. The relationship between weight of a satellite to the cost of the launch is currently over $12,000 per lb for a Scout booster. For light-lift vehicles used to boost payloads weights considered here, only the Scout and Minuteman derivatives have been utilized to date. The Pegasus system is a new and more economical booster system, with a launch cost per pound of less than $7,000 [Ref. 1:p. 15].

Another economic advantage is in the design and construction of the satellite itself. Eliminating costly supporting subsystems, from a weight aspect, allows more actual payload to be engineered into the fixed volume and weight budget of the satellite.

B. GROWING SPACE LAUNCH REQUIREMENTS

NASA has historically provided U.S. commercial access to low earth orbit (LEO) by flying payloads onboard the shuttle. On August 15, 1986, President Reagan stated that private industry would be playing an increasingly important role in the American space program. Free enterprise corporations will become highly competitive in this area and will develop methods of launching commercial satellites [Ref. 2:p. 4].

With the increasing commercialization of space, firms will place more demands on the current national launch facilities. Utilized by NASA, the Department of Defense, and other national agencies, these launch pads and tracking services become a 'chokepoint' in the access to space. The slow turnaround times for existing launch pads and space shuttle vehicles have caused a backlog of payloads waiting to be launched into orbit. An increase in launch services, not requiring existing pads, is greatly needed.

The Pegasus launch system proposed for this concept does not require a launch pad. This booster and its payload are launched horizontally from under a conventional aircraft. Any existing large runway would serve as a launching facility for the vehicle. Not being tied to a national launch site provides great flexibility in launch location and scheduling. This system is further detailed in Chapter III.

C. SATELLITE DESIGN SIMPLIFICATION

One solution to reducing the overall cost of orbiting a satellite is to change its basic design. For a fixed weight allowance, if more weight could be devoted to strictly the payload section and less to the support structure and systems, the equivalent of a orbiting larger satellite could be realized at a lower launch cost. The proposed satellite to be used in this concept is designed not to be autonomous, or even capable of functioning, until mated with the OMV. The on-orbit OMV is designed to provide the vital support requirements of a satellite such as attitude control, electrical power, communications links, and navigation.

The three-axis stabilized platform utilizes a plug-in device to mate with the payload. Once connected, attitude stability and orbit maintenance is provided using OMV's propulsion system. This allows the elimination of propulsion, reaction control systems, and attitude control devices on the satellite. The final stage of the Pegasus booster will provide attitude control of the payload until docking is achieved with the OMV.

Electrical power and communications with the payload are provided from the OMV's onboard systems specifically designed for this purpose. A small battery is required to furnish minimum power during launch, and no solar arrays are required to be installed on the payload. A transponder would be required only if data during the launch sequence was required. The OMV provides the user communication through a dedicated telemetry channel for the payload. NASA-proven standard connectors will be used for linking the payload to the OMV bus.

These simplifications to the design of the satellite are substantial. Not only does the payload capacity increase for a given satellite, but most of the high risk subsystems are eliminated. This new design no longer requires a propulsion system, steerable communications antennas, or tracking solar arrays, which greatly increases the overall reliability of the system. By using the OMV's host services, a simpler and more capable satellite can be designed and launched.

D. SUBSYSTEMS OF THE SPACE-BASED PAYLOAD SUPPORT CONCEPT

Two major systems comprise the space-based payload support concept, the Pegasus air-launched booster and the OMV payload support platform. Integrating these two systems will be relatively simple. The Pegasus booster system will be utilized for launch as currently designed. Through prior planning, the Pegasus launch will place the payload as close as possible to the OMV to minimize the fuel expended for intercept and docking. After the connections are made, the payload will be energized and transferred to a new orbit if desired, for the mission.

The OMV will require some modifications to the original design for the payload-support mission. The original OMV layout and required changes are addressed in the next chapter.

III. ORBITAL MANEUVERING VEHICLE

This chapter will describe the orbital maneuvering vehicle's history, proposed NASA missions, and the unique design of an on-orbit maintenance capability. All references contained in this chapter, except where noted, are taken from the User's Guide for the Orbital Maneuvering Vehicle [Ref.3].

A. HISTORY

The ideas for the orbital maneuvering vehicle (OMV) grew out of the Skylab era. NASA launched the space station, Skylab, on 14 May, 1973 fully expecting its orbit to last until the 1981-1982 time frame when the space shuttle would replenish Skylab fuels enabling a reboost to proper orbit. Excessive solar activity exerted a cumulative drag on Skylab causing an early deorbit on 11 July, 1979. Many contingencies were explored in the latter days of its orbital life to try to save Skylab. Among these was a vehicle designed to attach itself to Skylab and 'drag' it back to a safe orbit, called the Teleoperator Retrieval System (TRS). A decade after Skylab's deorbit, the OMV space vehicle with far more capabilities than the TRS is in full scale development and scheduled for launch in 1993 in support of the Hubble Space Telescope.

B. MISSION

The OMV is a versatile, reusable, multi-mission spacecraft with a designed lifetime of 10 years over 40 launches/landings. Built by TRW Space & Technology Group for NASA, its main missions include:

1. Rendezvous and dock to space assets for retrieval, reboost or deboost.
2. Service of space assets on orbit, including refueling and hardware replacement.
3. Resupply of the space station, from the shuttle orbit to the higher space station orbit.
4. Serve as a payload support platform.

The current launch system for the OMV is via the space shuttle. The OMV will be loaded vertically in the aft end of the shuttle bay with a payload mated to it. Held in place by four trunion latches and a keel fitting, it will be deployed with the remote manipulator arm. Studies are underway at TRW to integrate the OMV to a Titan-34 launch platform to increase the launch opportunities.

The OMV will be delivered to orbit by the shuttle with a payload attached and remain in space until refurbishment is required. It can operate independently up to 1,250 nm beyond the shuttle's orbit. This free-flying, remotely controlled low earth orbiting vehicle could also carry scientific instruments, pick up space debris, and be refueled on orbit. NASA will use the OMV to complement the shuttle operations. With the shuttle at its optimum parking orbit of 130 nm, the OMV will be used to ferry logistic modules to the space station parked in a 250 nm orbit. The OMV is planned to remotely assemble space station components and retrieve ailing satellites for return to the shuttle for repair and redeployment or return to Earth. The system is designed with a level of reliability such that no single failure could result in loss of the shuttle mission, the OMV, or the OMV's payload or mission. Another unique feature is the ability to power down the OMV into a space-basing mode, enabling it to hibernate on-orbit for up to nine months after completion of a mission. This technology was adapted from the Pioneer vehicle to conserve fuel and electrical power. The space-basing mode will point the OMV towards the sun for maximum solar-cell output and spin-stabilize the vehicle to conserve fuel. When needed, a 'wake-up' signal is transmitted to reactivate the OMV either from the ground or the space station.

The Hubble Telescope is planned to be launched via space shuttle in December 1989. The first OMV, which is NASA-funded, is scheduled to be launched via shuttle in 1993 to reboost the telescope. Future NASA missions include multiple OMVs on-orbit to facilitate space station construction. Other capabilities being explored are front end 'kits' to be installed for debris recovery, remote refueling, servicer kits for repair of specific components, and increased propulsion capability to reach geostationary orbits.

C. PHYSICAL CHARACTERISTICS

The OMV is 15 feet in diameter and 56 inches wide and sized to require minimum volume in the shuttle bay. Using proven technology, the OMV was engineered with a modular concept, enabling on-orbit replenishment of expendable fuels as well as easy repair or upgrade of components. These orbital replacement units (ORUs) utilize a single-bolt attachment and will allow replacement by telerobotics via another OMV, the shuttle, or by an astronaut during an extravehicular activity (EVA) event. This design not only allows maintenance when required, but enables future capability upgrades to meet unforeseen requirements.

A fully loaded OMV weighs 19,900 lbs including 9,300 lbs of usable bipropellant (monomethyl hydrazine/nitrogen tetroxide) for the variable-thrust orbit-adjustment engines, 1200 lbs of usable monopropellant (hydrazine) for the reaction control system (RCS) and 192 lbs of usable nitrogen for the cold gas RCS system. The cold gas can be used for close proximity operations to reduce payload contamination during final docking maneuvers. The spacecraft is composed of two separable modules, the short-range vehicle (SRV) including the RCS and avionics systems and the bipropellant propulsion module (PM) (see Figure III.1).

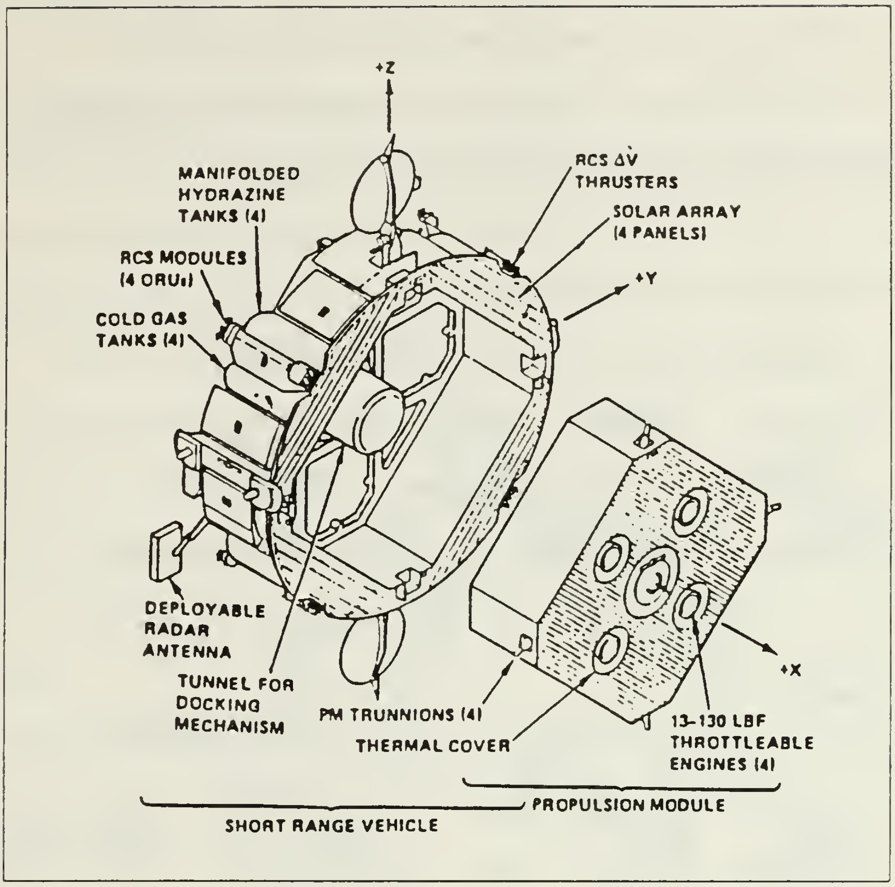

Figure III.1 OMV Configuration
Propulsion Module Side
[Ref. 4:p. 10]

1. SHORT-RANGE VEHICLE

The SRV is designed so it can function autonomously, performing close-in shuttle support missions or space station work using its integral monopropellants. The SRV's propulsion system is independent of the propulsion module, utilizing hydrazine and nitrogen (cold gas). Four reaction control modules, consisting of 28 hydrazine thrusters rated at 12 lb each and 24 non-contaminating cold gas thrusters, are equally spaced around the vehicle. Solar cells as well as two battery ORU's are located on the SRV.

All avionics subsystem ORU's are accessibly placed on the periphery of the SRV (see Figure III.2).

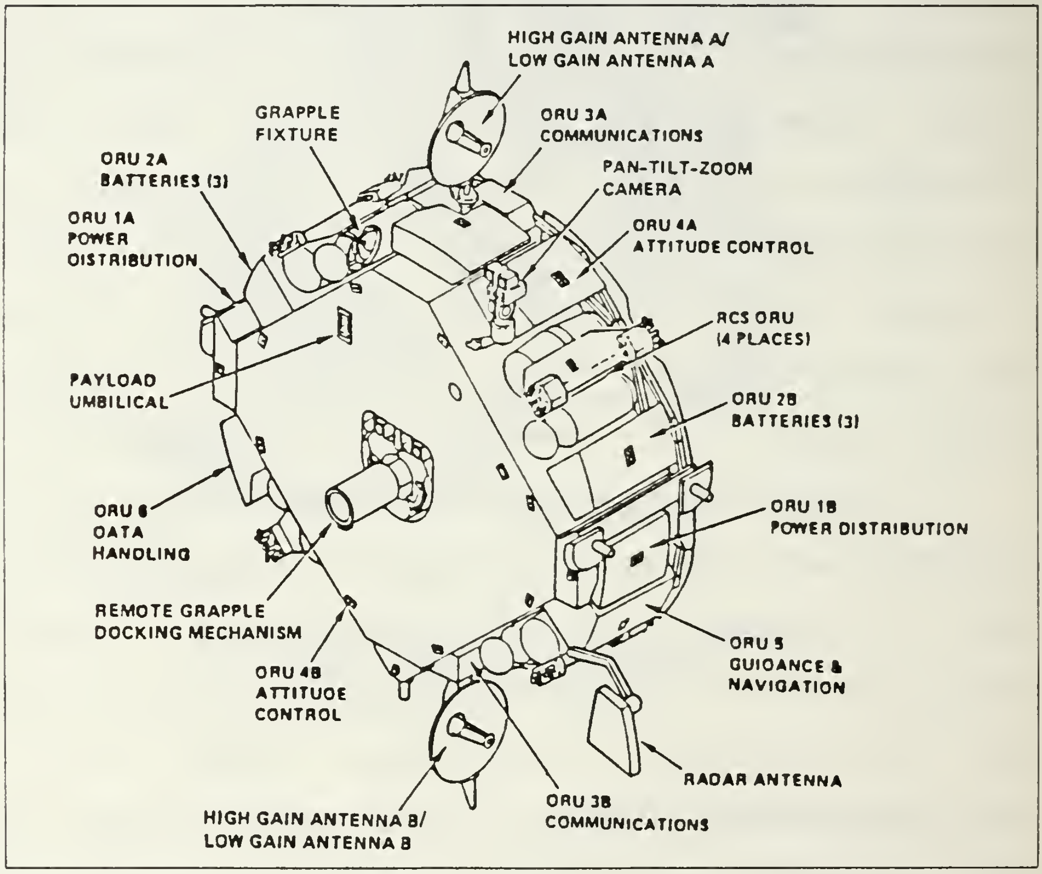

Figure III.2 OMV Configuration
Payload Side
[Ref. 4:p. 9]

These include guidance, navigation, data management, communications, attitude control, electrical distribution, and video subsystems. There are fourteen ORUs in the SRV, ten avionics and four reaction control systems. The SRV vehicle is designed to be left on orbit.

2. PROPULSION MODULE

The four main engines and bipropellant are contained in the replaceable propulsion module (PM). An innovative design of the OMV was to place the PM in the center of the vehicle. The removable PM utilizes the ORU concept with no fluid interconnections and with plug-in fittings for electrical power, commands, and data. This greatly enhances safety by eliminating dangerous fluid transfer on-orbit. The expended PM will be returned to earth via the shuttle for refueling.

The replacement of a fully loaded PM on-orbit has been successfully simulated using the shuttle's remote manipulator arm and a full scale 9000-lb mockup. The extravehicular activity ORU and PM removal and replacement have been demonstrated at the Marshall Space Flight Center's 'neutral buoyancy' simulator. This test proved that two astronauts could easily remove and replace the 9000-lb PM on-orbit.

The PM consists of four throttleable bipropellant engines based on the lunar excursion module design of the Apollo missions. Thrust for the four engines is adjustable over a range from 13 to 130 lbf for each engine. This selectability ensures delicate payloads can be moved at less than 0.002g with no damage. On-orbit satellites with solar arrays deployed or having other fragile appendages may be gently transported with no need to store them. The PM is required for large orbit or plane changes, providing 90 percent of the total impulse capability of the OMV, and allows fuel reserves for multiple missions. The OMV has the capability for specific plane and altitude changes of up to 6.5 degrees and/or 1000 nm (see Figure III.3).

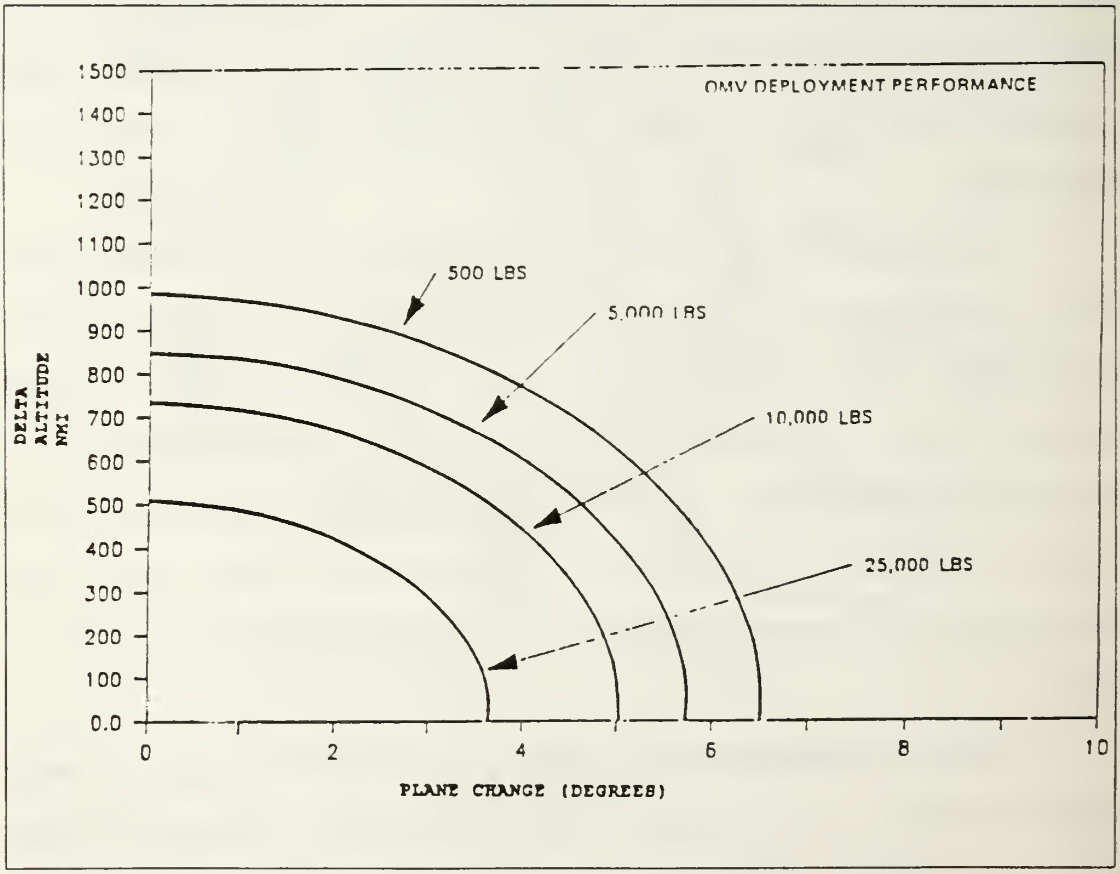

Figure III.3
OMV Deployment Performance
Altitude and Plane Change
[Ref. 4:p. 16]

OMV altitude change performance is directly dependent on the payload weight. Some specific capability examples with the PM include [Ref. 5:p. 7]:

> The OMV is capable of retrieving a 25,000 lb observatory from 130 nm above the base for service at the base and returning it to the same altitude.
>
> The OMV is capable of delivering a 3500 lb payload to an altitude of 340 nm above the base [120 nm orbit], and returning to the base.
>
> The OMV is capable of departing the base, rendezvousing and docking with a 11,000 lb payload at an altitude of 220 nm above the base, and returning it to the base.
>
> The OMV is capable of transferring a module weighing 50,000 lbs to one base and returning with another module weighing 50,000 lbs to the original base.
>
> The OMV is capable of departing the base, rendezvousing with and/or circumnavigation of a payload at an altitude of 840 nm above the base, and providing video and/or Government Furnished Equipment high resolution still photographic viewing of the payload.

Payload weight versus altitude change capabilities are shown in Figure III.4.

D. THERMAL CONTROL

Thermal control of the OMV utilizes a totally passive design. Insulation between the SRV and the PM is provided by multi-layer insulation blankets on the forward and edge surfaces of the PM and on the four bipropellant tanks. Thermostatic heaters are used for under-temperature protection. All of the avionics ORUs use variable conductance heat pipes coupled to radiator surfaces. The

ORUs are thermally independent to facilitate on-orbit replacement [Ref. 5:p. 20].

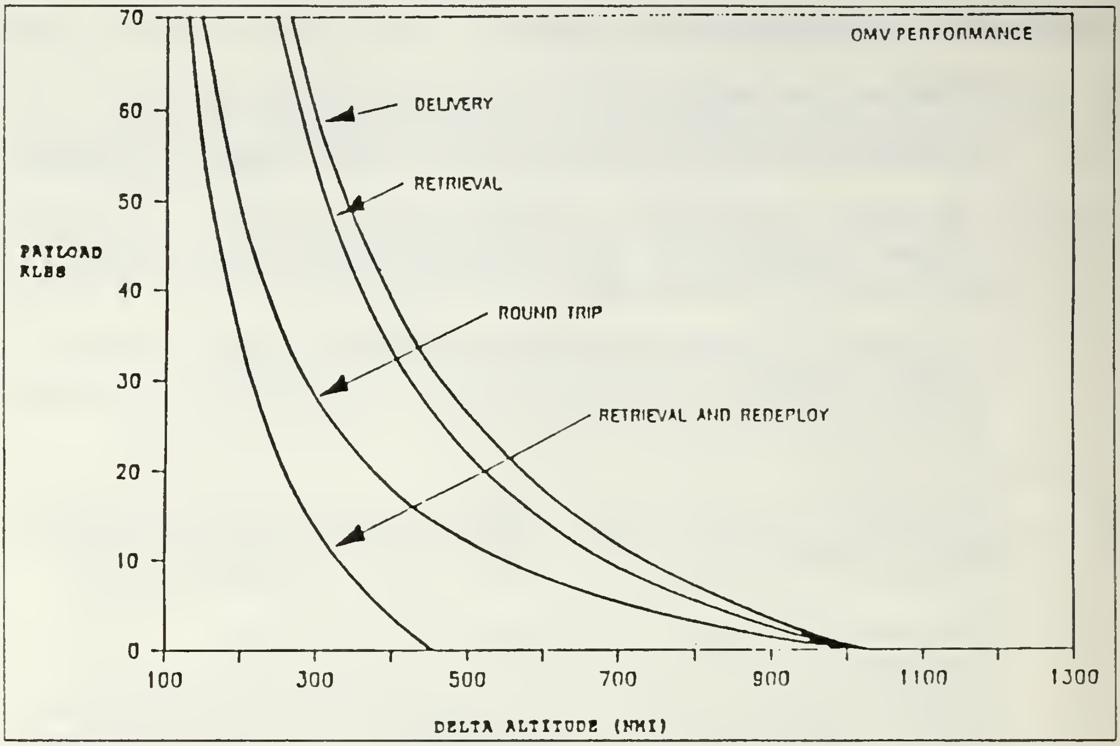

Figure III.4 OMV Delta Altitude, NM
[Ref. 4:p. 17]

E. POWER

Electrical power for the OMV is provided primarily by batteries with solar cells as a secondary and charging source. Batteries are utilized as the mission requires large power outputs over a short amount of time. While the OMV is maneuvering, it can't continuously point towards the sun and must be able to provide the payload power in any attitude. The current OMV will utilize six silver-zinc batteries with an output of 220-ampere-hours. These will provide power for a maximum seven day mission, after which the OMV must reorient the solar array towards the sun to enable recharging. The solar array on the SRV provides battery charging and has a designed end-of-life output capacity of 500 watts.

F. GROUND CONTROL SYSTEM

Primary control of the OMV is from a ground station via a two-way link through the Tracking and Data Relay Satellite System (TDRSS). If the vehicle was based at the space station, it could be controlled by astronauts from there. Other than for the final rendezvous and docking operations which require TV-assisted man-in-the-loop, the OMV is capable of automatic flight. Communications are via S-band frequencies and video data is digitized at approximately 1.0 megabits per second.

Payloads are attached to the OMV using the grapple docking system. This is a three-point system utilizing standard space shuttle fixture design. An integral video camera and light system allow a pilot on the ground to dock with the payload. A retractable docking fixture mechanism is centrally located on the payload side of the OMV. Once attached to a payload, the mechanism retracts flush with the OMV body, latching the payload to provide structural support. Electrical interface is provided using two 56-pin umbilical connectors.

A ground control console (GCC) is required to control the OMV. The GCC provides for real-time pilot control during the final docking phase and routine spacecraft monitoring and control. Two ground control consoles are arranged for close pilot-copilot interaction, much like the cockpit of an airplane. The console receives and formats OMV telemetry data for display to the pilot as well as uplinking pilot generated commands to the OMV. The GCC workstation provides video, text and graphic displays of telemetry data. During final rendezvous and docking operations, the pilot manipulates hand controllers and switches, which are similar to those in airliner cockpits, for manual control of OMV maneuvers. A three second time delay for a signal exists, via land and satellite links, for the round trip from the ground. Extensive use of computer software and simulation of the OMV flight dynamics have been used to prove that docking to a payload was feasible with this time delay and for training of the pilots. The pilots are currently planned to be NASA astronauts and mission specialists. For the NASA missions, the GCC will be located at the Johnson Space Center in the operations support center.

G. NAVIGATION AND DOCKING

Navigation and spacecraft attitude information are provided to the OMV by the global positioning system (GPS) receivers, a rendezvous radar set, an inertial measurement unit, and a set of Sun and Earth sensors. These systems allow the guidance, navigation, and control (GN&C) subsystem to perform autonomous GN&C for the OMV via the on-board computer. Two modes of guidance are provided, orbit change and auto-rendezvous. All information is displayed at the GCC.

H. MODIFICATIONS FOR A PAYLOAD-SUPPORT PLATFORM

Modifications to the current NASA OMV design under development are required to fulfill the mission of a 10 year on-orbit 'payload support platform' for Pegasus-launched payloads. Specific subsystems requiring modification are the electrical power, including the solar array and batteries; thermal control; and radiation protection.

1. POWER

The electrical power system currently uses silver-zinc batteries which meet NASA's requirements of lightweight and high energy density but have the drawback of only a twelve month battery life, after which the battery ORUs must be replaced. By changing the batteries to a nickel-cadmium (Ni-Cd) or nickel-hydrogen (Ni-H_2) type, a ten year life of the battery system can be achieved for extended station keeping.

The Ni-H_2 battery is lighter and more reliable than a Ni-Cd battery and can operate to a higher depth of discharge than the Ni-Cd battery. The Ni-H_2 battery offers a high specific-energy (over 70Whr/kg) and more than twice the power available of the Ni-Cd. They can sustain high rates of overcharging or overdischarging without short or long term degradation, such as the 'memory effect' common to Ni-Cd systems, and the depth of discharge is greater than the silver-zinc or Ni-Cd battery systems [Ref. 6:p. 1]. The battery is a pressure vessel and can be physically sized to fit current OMV battery ORUs. Already used in some commercial communication satellites, Ni-H_2 batteries are planned for use on the space station. Although this is leading edge technology, the Ni-H_2 battery is the preferable system for the 10 year extended station keeping OMV design.

The current OMV solar array design on the SRV is 57 sq ft in area. Every fifth to sixth day the mission must halt while the array is oriented toward the sun for recharge of the silver-zinc batteries. The extended station-keeping OMV design requires an increase in array area to 200 square feet for greater power generation while providing uninterrupted station-keeping service to the payload. The additional solar array area would be achieved with external sun-tracking solar 'wings' which would eliminate the routine interruption for battery recharging of the current design. The total solar area end-of-life requirement is 200 kilowatts [Ref. 16:p. T-140].

NASA has not decided on the solar cell type, silicon (Si) versus gallium-arsenide (Ga-As), for the array on the

OMV. Although not space proven using an entire array, Ga-As cells provide higher efficiency, higher radiation resistance and less temperature dependence than Si cells. These factors support the choice of a 167 square foot Ga-As solar array for use on the extended version of the OMV.

2. THERMAL

Thermal insulation currently will use Teflon tape around critical electronic components for heat transfer. A major drawback of this design is that the tape thermal-conductivity characteristics reduce with time on-orbit. After approximately three years, the properties will degrade to a point where excessive internal temperatures will cause component failure. To avoid this problem, second-surface mirroring will be employed.

3. RADIATION PROTECTION

Increased radiation shielding requirements for an extended version of the OMV is largely dependent on orbital altitude. The Pegasus/OMV concept is currently envisioned for low earth orbits (LEO) payloads. These orbits will be below the earth's radiation belts, but the 10 year orbit life will be subject to cosmic and solar radiation. The current OMV lifetime is designed for forty 6-10 day missions at 160-300 nm. The vehicle is shielded for a total dosage of 10,000 rads. While the Pegasus/OMV missions will operate at similar altitudes, any polar orbits will be subject to much higher dosage levels, and the total dosage of a 10 year continuous orbit requires increased shielding. Greater protection will be built in by using higher radiation tolerant piece parts in the construction of the extended station-keeping version of the OMV.

4. PROPULSION

No modifications are required in the propulsion system for the payload support platform design. With skillful planning, the payload could be launched into an orbit which minimizes the separation from the OMV, thereby requiring minimum fuel for a rendezvous. Once mated with the payload, minimum fuel for station keeping is required. A fully loaded OMV would have the fuel required for a 10 year orbit.

5. MAINTENANCE

Any maintenance or upgrades required during the 10 year life of the OMV will use the ORU modular concept as planned for the NASA version. The required ORUs would be launched with the payload via Pegasus to be retrieved and installed on the orbiting OMV.

IV. THE PEGASUS AIR-LAUNCHED SPACE BOOSTER

The following chapter will describe the Pegasus booster system including its design, components, and the launch platform. The flight profile is discussed along with payload weights and orbit injection capabilities. All the technical information presented in this chapter originates from the Pegasus Payload Users Guide [Ref. 8], except where noted.

A. BACKGROUND

The Pegasus air-launched space booster is a vehicle which has its roots in the X-15 era of thirty years ago. The basic concept is to lift the booster/payload package, by aircraft, as high as possible to reduce atmospheric drag effects on the space vehicle during launch to orbit. A NASA B-52 aircraft will function as the carrier aircraft for the first few launches, after which a commercial four-engine transport is to be utilized. State-of-the-art technology, using graphite and composites, have gone into the design of Pegasus. This has allowed the payload weight-to-orbit to be large enough to enable Pegasus to be commercially feasible.

The aircraft-launched concept of Pegasus has numerous advantages over a vertical ground-launched system. The forward velocity of the aircraft provides a 1-2% performance increase compared to a ground launch. Probably the most significant advantage results from launching at 40,000 feet, greatly reducing drag, allowing the first stage rocket motor nozzle to be designed much more efficiently. Vehicle dynamic pressure, structural, and thermal stresses are much lower and enable the use of much lighter materials. These advantages add up to a 10-15% reduction in total delta-V required to orbit a given payload. [Ref. 1:p. 16]

B. DEVELOPMENT

The Pegasus vehicle was privately developed and funded in equal shares by the Orbital Sciences Corporation (OSC) and the Hercules Aerospace company. Utilizing existing X-15 test data for early designs, the Pegasus is similar in size, weight, and method of deployment-dropping from a large aircraft. The booster is designed for a horizontal launch, utilizing a conventional wing to provide lift. Mounted on the first of three stages, the wing reduces the amount of specific impulse, or thrust, required to achieve orbit. The three solid rocket motors are newly developed and are constructed of a lightweight graphite composite. The Pegasus is the first high-performance booster to be developed using computational fluid dynamics data instead of wind tunnel testing [Ref. 1:p. 16]. The first vehicle scheduled for launch is an operational Defense Advanced Research Projects Agency (DARPA) payload in October 1989 [Ref. 17].

The revolutionary design of Pegasus incorporates a three-stage, solid-propellant, inertially-guided, all-composite, winged vehicle. The Pegasus weighs 40,000 lbs (minus payload), is 49.2 feet long, has a 22 foot wing span, and is a constant 50 inches in diameter (see Figure IV.1).

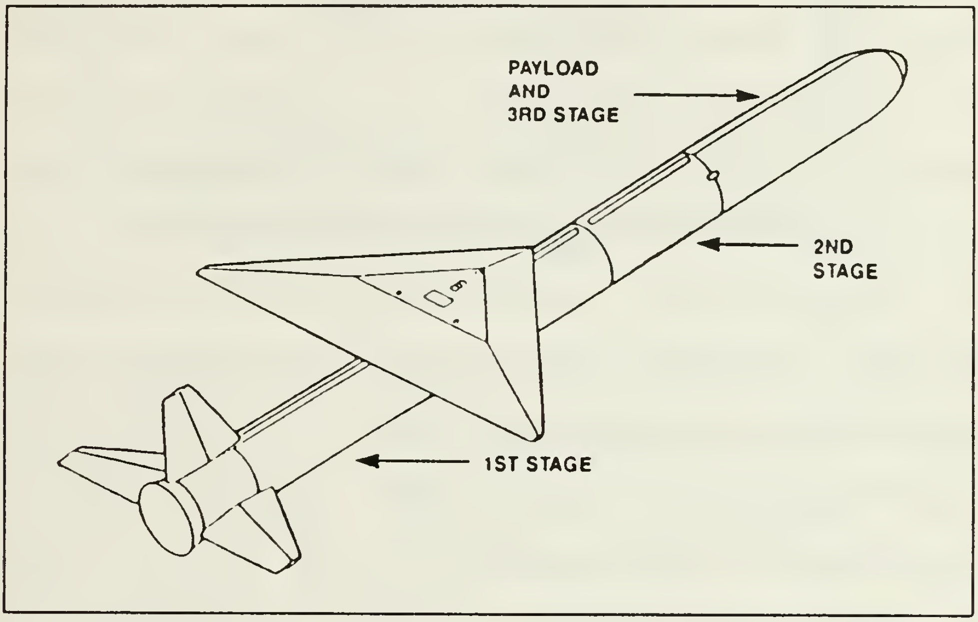

Figure IV.1 Pegasus Vehicle
[Ref. 1:p. 15]

Designed to be carried under the right wing root of a B-52, similar to the X-15 concept (see Figure IV.2), Pegasus is to be launched from an altitude of 40,000 feet at an airspeed of Mach 0.82. This altitude is above approximately 75% of the earth's atmosphere [Ref. 1:p. 16].

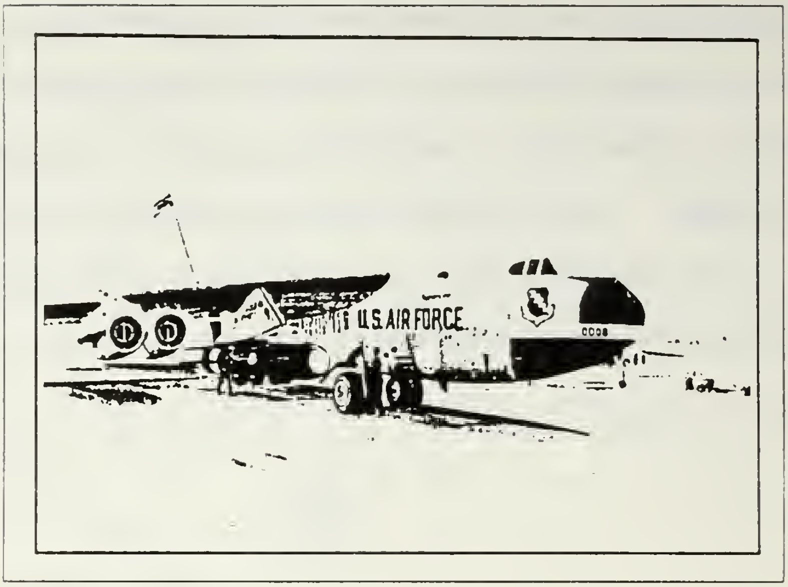

Figure IV.2 Pegasus Mated to B-52
[Ref. 7:p. 19]

The entire vehicle was designed for minimum prelaunch handling, ideally using a crew of six or seven technicians for final assembly at the airfield over a 14 day period. On-site mating of the payload and launch, in this short time frame, allows extreme flexibility and on-demand availability to orbit.

C. SYSTEMS

The various systems of Pegasus will be described separately. These include the vehicle, carrier aircraft, airborne support equipment, and ground support equipment.

1. PEGASUS FLIGHT VEHICLE

The booster incorporates three solid-propellant rocket motors, a fixed delta composite wing, an aft skirt section including three control fins, an avionics section, and a payload faring.

a. MOTORS

The motors are manufactured by Hercules using graphite-epoxy composite casings. The Stage 1 motor uses a fixed nozzle and has a core-burning grain design with 26,790 lbs of solid propellant. The designed burn time is 72.3 seconds and develops a maximum thrust of over 131,000 pounds force (lbf). The Stage 2 motor is similar in design to the Stage 1 motor but incorporates thrust vector control (TVC) using electromechanical actuators for steering. The Stage 2 motor has 6,670 lbs of solid propellant with a design burn time of 71.4 seconds, developing a maximum thrust of approximately 31,000 lbf. The Stage 3 motor also uses the same solid propellant and TVC for maneuvering. It has 1,725 lbs of fuel and burns for 64.6 seconds at a maximum thrust of 9,000 lbf. A flight termination charge is mounted on each stage motor for safety requirements, capable of disintegrating the booster during launch if required.

b. DELTA WING AND AFT SKIRT SECTION

To provide lift to the vehicle during the first stage burn, a graphite wing is mounted to the Stage 1 motor. The wing is a double-wedge delta planform with a blunt leading edge, 45° sweep back, and clipped wing tips. The blunt leading edge reduces the heat transferred into the vehicle. The clipped wing span of 22 feet follows from the X-15 design, allowing integration to the existing B-52 launch platform. Using a wing allows the flight profile angle-of-attack to be limited to 20 degrees. Without the wing, it would have to fly at up to 60 degrees, with many more stresses on the airframe [Ref. 1:p. 16]. The wing is attached to the first stage by an aluminum saddle. The Pegasus attaches to the carrier aircraft via four wing adaptor points (see Figure IV.3). The aluminum aft structure houses the Stage 1 motor and supports the three electromechanically activated fins. Roll, pitch, and yaw attitude control are provided aerodynamically during the Stage 1 burn.

c. GUIDANCE, NAVIGATION AND CONTROL AVIONICS

The Pegasus booster uses an autopilot which is programmed with the specific mission flight profile. This data is loaded just prior to takeoff and can be changed in flight. An onboard inertial measurement unit (IMU) provides the autopilot with position and attitude. Guidance, navigation and control performance are monitored by the autopilot and the data is also downlinked using the vehicle's telemetry package. All avionics is contained forward of the motor in the third stage.

As mentioned above, three steerable aerodynamic fins provide maneuvering during Stage 1 powered flight. During Stage 2 and 3 burns, vectored thrust is augmented in the roll axis with a reaction control system (RCS) utilizing six nitrogen jets. The RCS, housed in the third stage, is used to control all three axes during coast phases between stages and prior to separation from Stage 3.

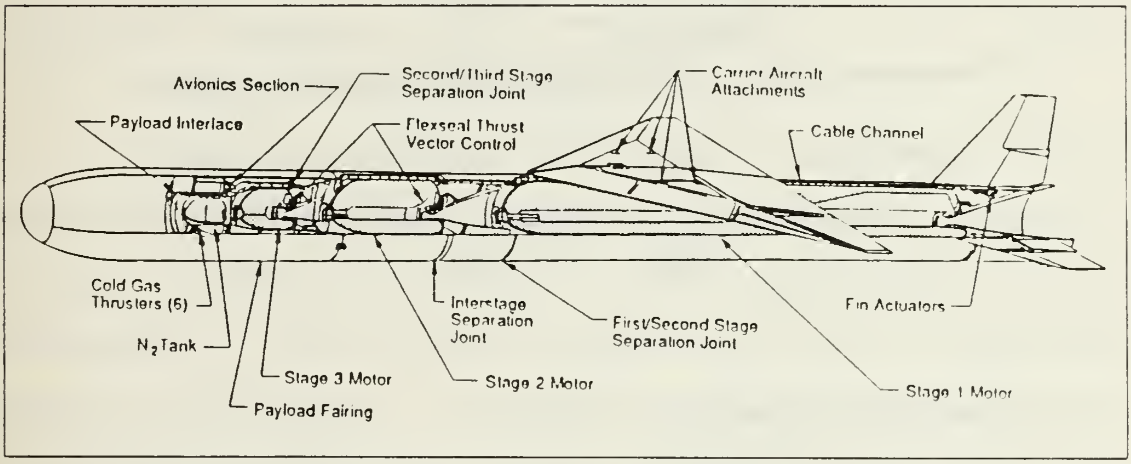

Figure IV.3 Pegasus Cutaway View
[Ref. 7:p. 2]

d. PAYLOAD SECTION

The payload section is forward of the Stage 3 motor and is protected by a two-piece graphite epoxy composite fairing (see Figure IV.4). Reaction control is available during coast phase prior to pyrotechnically separating the fairing from the payload, after Stage 3 burnout. The payload space under the fairing is approximately 76 inches long and 46 inches in diameter, tapering towards the nose to a diameter of 30.5 inches. Payload telemetry is downlinked while attached to the aircraft, with a maximum capacity of 16 kps.

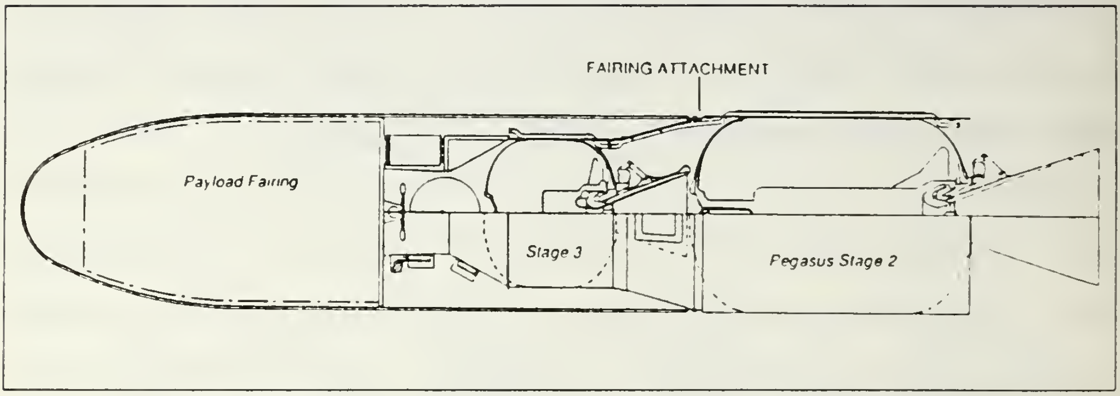

Figure IV.4 Pegasus Fairing
[Ref. 7:p. 24]

2. CARRIER AIRCRAFT

The Pegasus launch system was designed around the NASA Ames-Dryden Flight Facility NB-52B research aircraft, No. 0008. This aircraft was built in 1952 and has flown about 450 air drops of other vehicles including the X-15. The first several launches of Pegasus are planned using this aircraft. The program is planned to transition in late 1990 to a civilian heavy air transport launch platform [Ref. 1:p. 15], such as the Lockheed L-1011 aircraft.

3. AIRBORNE SUPPORT EQUIPMENT

Located onboard the carrier aircraft is the support equipment for Pegasus. This consists of a launch panel operator console, aircraft power supply, and the pylon adaptor to mate the vehicle to the aircraft. The launch panel provides a computer and display, an IMU, data storage, a power supply and a telemetry receiver. All mission data are displayed, verified, loaded, and recorded from here. The operator monitors Pegasus and the payload from this console. Regulated 28 vdc electrical power to the payload is available from the carrier aircraft during ground operations and while in captive flight.

4. GROUND SUPPORT EQUIPMENT

Relative to other space launch systems, minimal ground support equipment is needed for Pegasus. A special trailer is used for horizontal booster assembly and payload integration. Two portable cranes are used to place the motors on the trailer. A portable clean room tent is set up around the payload, if required, prior to installing the payload fairing. Once the vehicle is assembled and mated to the payload, complete systems checks are performed prior to transport to the launch aircraft.

Initially, Pegasus launches will be flown from the NASA Dryden Flight Research Facility at Edwards Air Force Base (AFB), CA. The Western Space and Missile Center at Vandenberg AFB will provide range support. A normal launch schedule requires delivery of the Pegasus subsystems 14 days prior to launch. The vehicle will be assembled and systems checked out during the next nine days and the actual payload mating begins 24 hours prior to launch. Once completed, the RCS system is filled with nitrogen and the payload fairing is installed. The Pegasus/aircraft integration begins 11 hours prior to launch, using the same trailer, requiring about seven hours to complete. After preflight of the aircraft, takeoff is scheduled two hours prior to booster launch.

D. FLIGHT PROFILE

Once the Pegasus booster and payload are mated to the carrier aircraft and programed with the specific mission data, the launch is ready to proceed. Two hours prior to the launch window, the aircraft departs the Dryden Facility at Edwards AFB. The aircraft will climb to an altitude of 40,000 feet and commence an S turn maneuver to allow final alignment of the Pegasus onboard IMU. The aircraft will then be at the launch point at Mach 0.82.

Once dropped, the Pegasus will free-fall for five seconds, to about 300 feet below the aircraft, when the Stage 1 motor ignites. For a typical polar orbit insertion, the booster will accelerate to supersonic and begin a gentle 2.5g pull up. The first stage burnout occurs at about 200,000 feet and Mach 8.1. The Stage 2 motor fires a few seconds later and boosts the vehicle to 105 miles altitude and a velocity of 17,500 feet per second (fps). After a five minute coast to altitude, the Stage 3 motor fires to circularize the final orbit at 250 nm at 25,000 fps (see Figure IV.5). The Stage 3 burnout normally occurs 10 minutes and 1200 nm downrange from the aircraft drop point.

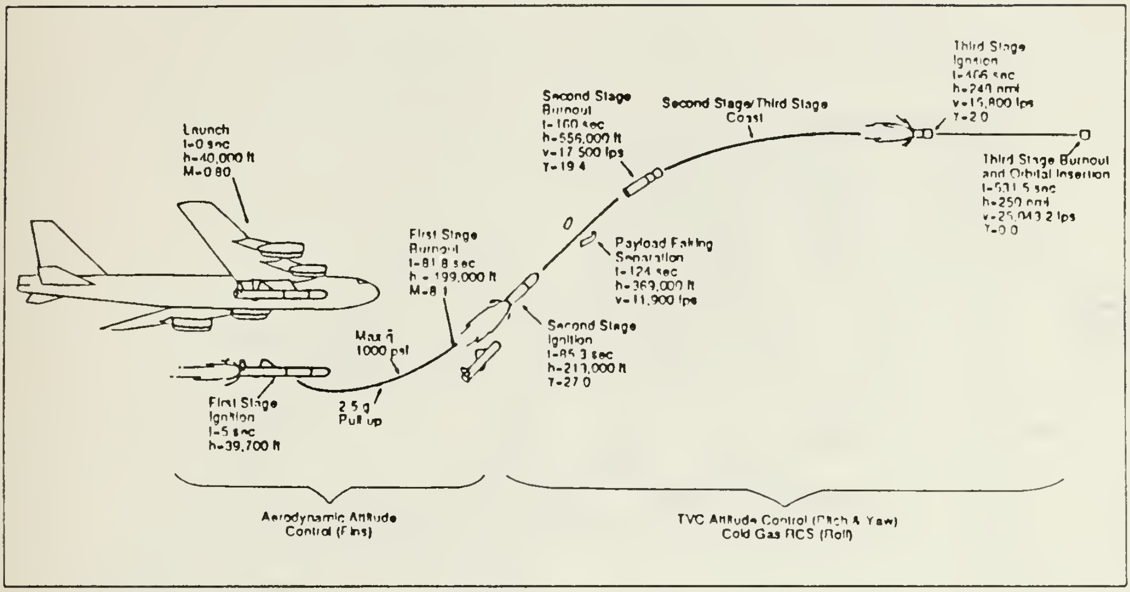

Figure IV.5 Pegasus Flight Profile
250 nm Circular Polar Orbit
[Ref. 7:p. 21]

E. PAYLOAD WEIGHT AND ORBIT CAPABILITIES

Pegasus has the capability of placing a 600 lb payload into a 250 nm polar and a 900 lb payload into a 250 nm equatorial orbit. Both circular and elliptical orbits are available with a wide variety of inclinations. Figure IV.6 shows specific payload weight versus altitude capabilities of Pegasus for inclinations from 0° to 90°, including circular and elliptical orbits.

The booster also has the capability for sub-orbital flights where high altitude and Mach number are required, such as spaceplane reentry testing. A payload weight of up to 1500 lbs is available for such missions [Ref. 1:p. 16].

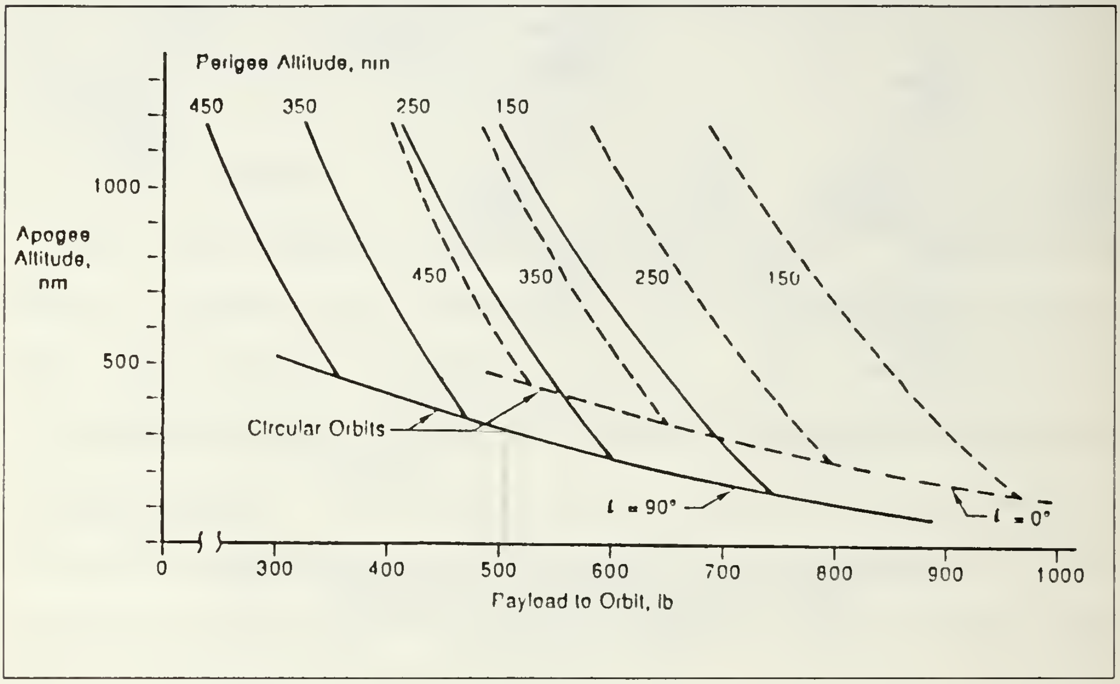

Figure IV.6 Pegasus Operational Payload Performance [Ref. 7:p. 23]

The Pegasus winged booster is a very versatile system. The required minimum ground support and quick launch times are revolutionary changes in the space industry. These long overdue features will greatly increase the number of small payloads to orbit. The mobility of the launch platform provides excellent flexibility of launch latitudes, thereby reducing cost to orbit. These attributes make the Pegasus the ideal vehicle to boost payloads to the on-orbit OMV bus.

V. PAYLOAD INTEGRATION WITH THE OMV

In this chapter the procedure of on-orbit mating of the two major subsystems of the Space-Based Payload Support Concept, namely the boosted payload and the orbiting OMV platform, will be described. Chapter IV described the flight of the payload from launch to Stage 3 motor burnout. This chapter will continue the concept discussion from the Stage 3 burnout event to the payload becoming operational on orbit. Figure V.1 shows the general scenario used to boost and mate a payload to the OMV. The Users Guide for the Orbital Maneuvering Vehicle [Ref. 3] is the primary reference for this chapter unless noted.

A. ORBITAL INSERTION

The payload injection capabilities of Pegasus are designed to be flexible to allow mission designers great latitude for their specific requirements. Once the desired payload orbit is determined by the user, Orbital Science Corporation personnel will calculate mission trajectory and launch location. For a typical Pegasus polar orbit launch, the Stage 3 burnout occurs 531.5 seconds after launch from the aircraft at 250 nm altitude and 1200 nm downrange, achieving a final velocity of over 25,000 fps. Once the Stage 3 motor fuel is expended, the payload and the third stage coast for about 38 seconds, using cold gas thrusters to maintain 3-axis stabilization. Approximately 150 lb-sec of impulse is available for post boost maneuvering of the third stage and payload combination.

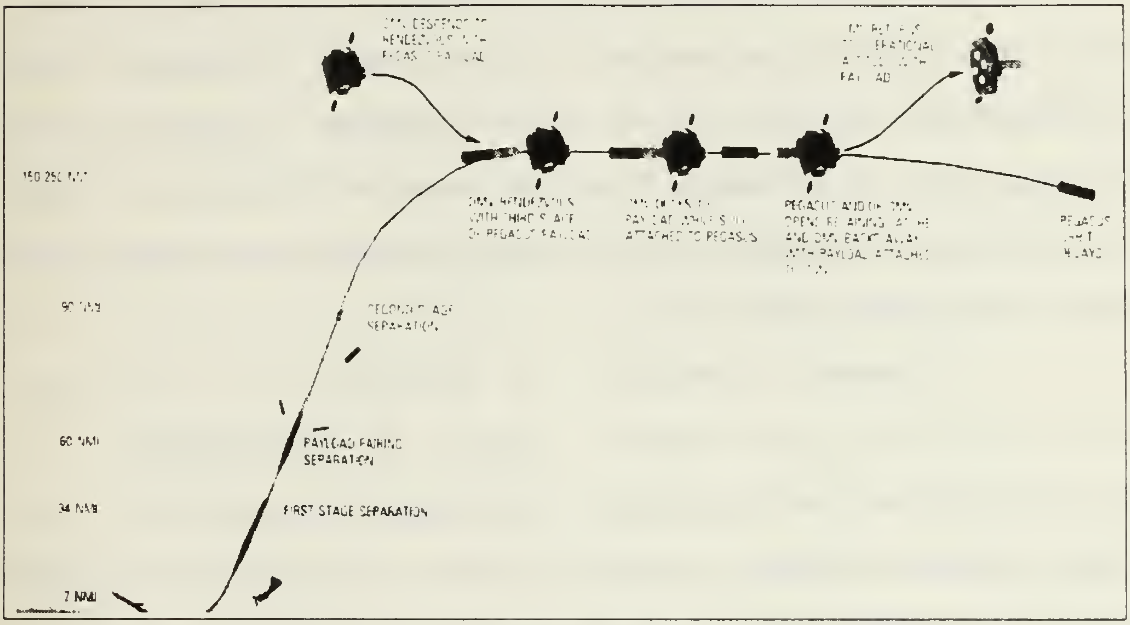

Figure V.1 Payload/OMV Mating Concept [Ref. 4:p. 49]

1. ACCURACY

Orbital accuracy for the Pegasus mission is a function of guidance system errors and variances between the solid rocket motor propulsion predictions and actual thrust provided. Estimates of launch accuracy for a 400 nm circular polar orbit are ± 0.2° inclination and ± 20 nm deviation in altitude [Ref. 7:p. 22]. The Pegasus vehicle can also accurately stabilize and orient the payload for docking with the OMV. Three axis stabilization accuracy during the coast period is ± 2.0° angular position and ± 0.1°/sec angular rate in each axis. [Ref. 8:p. 21,31]

2. PAYLOAD SUPPORT PRIOR TO SEPARATION

The current Pegasus design incorporates an electrical power bus utilizing batteries. This 28 vdc bus powers the vehicle during launch for up to 45 minutes, beginning 3-5 minutes prior to release from the carrier aircraft. Any orientation events required for the payload must be completed within this time span.

A telemetry downlink is available for payload monitoring from the Pegasus vehicle during launch. A dedicated channel with up to 16 kps capacity exist in the current Pegasus design. This channel is available until Stage 3 separates from the payload.

B. PAYLOAD STABILITY FROM PEGASUS

The Stage 3 motor provides the final impulse to circularize the payload's orbit. Following orbit insertion, the Pegasus third stage executes a series of predetermined commands contained in the mission data load to provide the desired initial payload attitude. Payload stabilization is available until the Pegasus third stage fairing is separated from the payload. A stable payload attitude is required for a successful docking to the OMV host platform. Current specifications call for the OMV to be able to dock with an object rolling at most 2.8° per second around the docking axis or tumbling less than 0.5° per second [Ref. 7:p. 47].

C. OMV DOCKING TO THE PAYLOAD

The task of actually docking the OMV with a payload on-orbit requires a real-time man-in-the-loop. Current policy dictates that a NASA astronaut be the pilot operating the controls of the OMV, based on operations around the Shuttle and/or the Space Station. Docking with unmanned payloads for this concept will not require an astronaut to fly the OMV.

1. RENDEZVOUS

The Pegasus orbit insertion point should be calculated to be as close to the OMV position as possible, to minimize the fuel requirement for docking. The initial rendezvous with the target payload/Stage 3 Pegasus booster will occur at an altitude of 250 nm. The OMV host platform will transfer to the payload orbit to begin the docking procedure, initially using radar. The OMV radar acquisition range is 4.5 nm with a ± 20° field of view. A worst-case figure of 5 minutes is given to acquire a 1 square meter target at this range [Ref. 5:p. 18].

Once the payload is within 4.5 nm and in view, the GCC enables the OMV to begin a preprogrammed docking maneuver. In this mode, the OMV performs transfer, coast, rendezvous, and orbit trim maneuver functions under the control of the onboard computer [Ref. 9:p. 3]. The OMV will fly an autonomous approach to the rendezvous point, nominally 1000 feet from the target, utilizing the rendezvous radar, and then stop and maintain its respective position. The navigation systems onboard the OMV utilize the Navstar global positioning, an inertial measurement unit, and Sun and Earth sensors for location and attitude information. The Navstar system provides the OMV accuracy to within 470 feet per axis, and velocity to within 1.4 feet per second [Ref. 5:p. 21]. Figure V.2 shows the time and distance related events of a typical docking evolution.

2. SAFETY

For safety purposes, a collision-avoidance maneuver is programmed to activate, in either the piloted or automatic operation modes, after two critical OMV component failures. This maneuver ensures the safety of both the OMV and the payload. If a failure occurs that disables the OMV while in the automatic operation mode, the vehicle automatically transitions to its space-basing mode, and awaits further commands to correct the failures or activate redundant components. If a failure occurs during the docking phase in the piloted mode, the OMV backs away from its target automatically, in a way that eliminates any chance of a collision. [Ref. 5:p. 12]

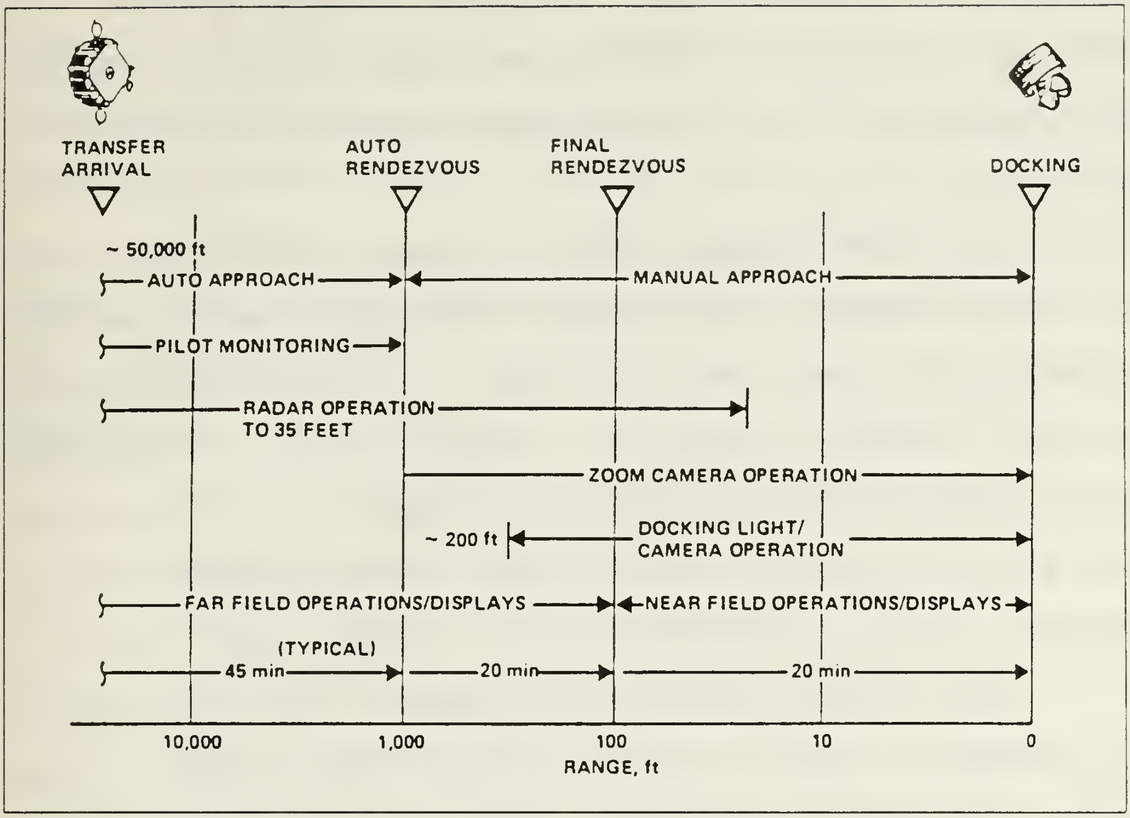

Figure V.2 OMV Proximity Operations and Docking [Ref. 4:p. 19]

3. PILOT CONTROL

The programmed Pegasus approach to the target is monitored by a pilot at one of two identical Ground Control Consoles (GCC) and if an anomaly occurs, the pilot takes control of the OMV. The last 1000 feet of the approach, the pilot mode, must be manually flown by the pilot from the GCC. In the pilot mode, all maneuvers are under the direct control of the GCC pilot who commands the translation and attitude of the OMV. A copilot assists the pilot from the backup GCC pilot station during the critical mission phases and otherwise as required. Docking and pan/tilt/zoom cameras provide necessary views of the target via the OMV video link. [Ref. 9:p. 3]

The pilot selects control modes and thrusters to approach the target. Radar range data is available from 4.5 nm down to 100 feet from the target. At closer distances, the pilot visually guides the vehicle via an illuminated docking guide on the target payload. Graphic aids on the GCC pilot station displays help the pilot in his approach and in effecting contact and latch with the target. [Ref. 9:p. 4]

The crew for the OMV will operate from the Johnson Space Center. They will rely on video from two television cameras mounted at the base of the docking device on the face of the OMV. Two additional cameras on deployable arms are used for large payloads, if needed. Lights are mounted with both sets of cameras to permit docking during darkness. The TV camera range for detection of a payload target exceeds 6 nm in sunlight and 200 feet in darkness using lights [Ref. 5:p. 22].

Communications links between the OMV and the GCC will utilize a Tracking Data Relay Satellite (TDRS) S-band link which has a 3-second land-line/satellite link time delay. Most of the time is for data formatting, not link delay. This delay requires extensive training for the OMV pilot to overcome the time lag between control inputs and actual response, when making delicate docking movements. Simulators now exist for pilot training of docking maneuvers utilizing full scale mockups of the OMV and the aft end of the Hubble Telescope as the payload target [Ref. 10:p. 26].

The GCCs will be located in the Operation Support Center (OSC) and will have the processing capability to be self contained units. The GCC will have the following capabilities [Ref 4:p. 28]:

-Control and monitor critical vehicle systems needed for pilot operations.

-Uplink transfer orbit parameters.

-Verify the achievement of rendezvous.

-Execute man-in-the-loop-piloting for approach, fly around, and other proximity operations.

-Close and open latches and umbilical connectors to payloads.

-Communicate with all operations elements in the OSC and elsewhere.

-Decompress and display video data.

-Reduce and display critical vehicle data.

-Format and generate uplink commands.

A sketch of the entire OMV control process is shown in Figure V.3.

4. PAYLOAD ATTACHMENT

The main attachment point to the OMV will be through a Three Point Docking Mechanism (TPDM) to provide structural and electrical interface between the OMV and the payload (see Figure V.4). The payload will be fitted with an OMV compatible flight support system docking interface prior to launch on a Pegasus vehicle.

The OMV docking mechanism is centrally located on the face of the SRV and includes a structural ring with four EVA tie-down bolts, three docking latch mechanisms, two umbilical connector mechanisms, an interconnecting harness, and camera and light mountings [Ref. 4:p. 26].

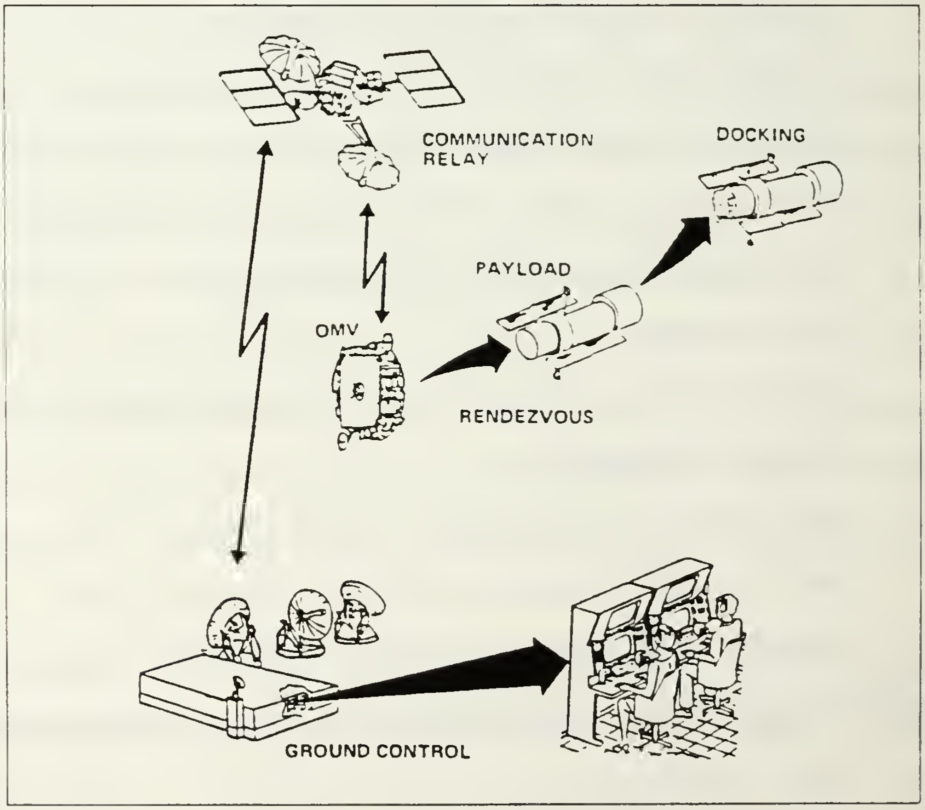

Figure V.3 OMV Operations Concept
[Ref. 11:p. 23]

The TPDM latch has hard-lock retention jaws which are driven by an electrically redundant DC motor. Made of high-strength aluminum, the TPDM's structural ring attaches to the front face of the OMV with four bolts. For normal operations, a clear access to the docking fixture must be provided by the payload designer.

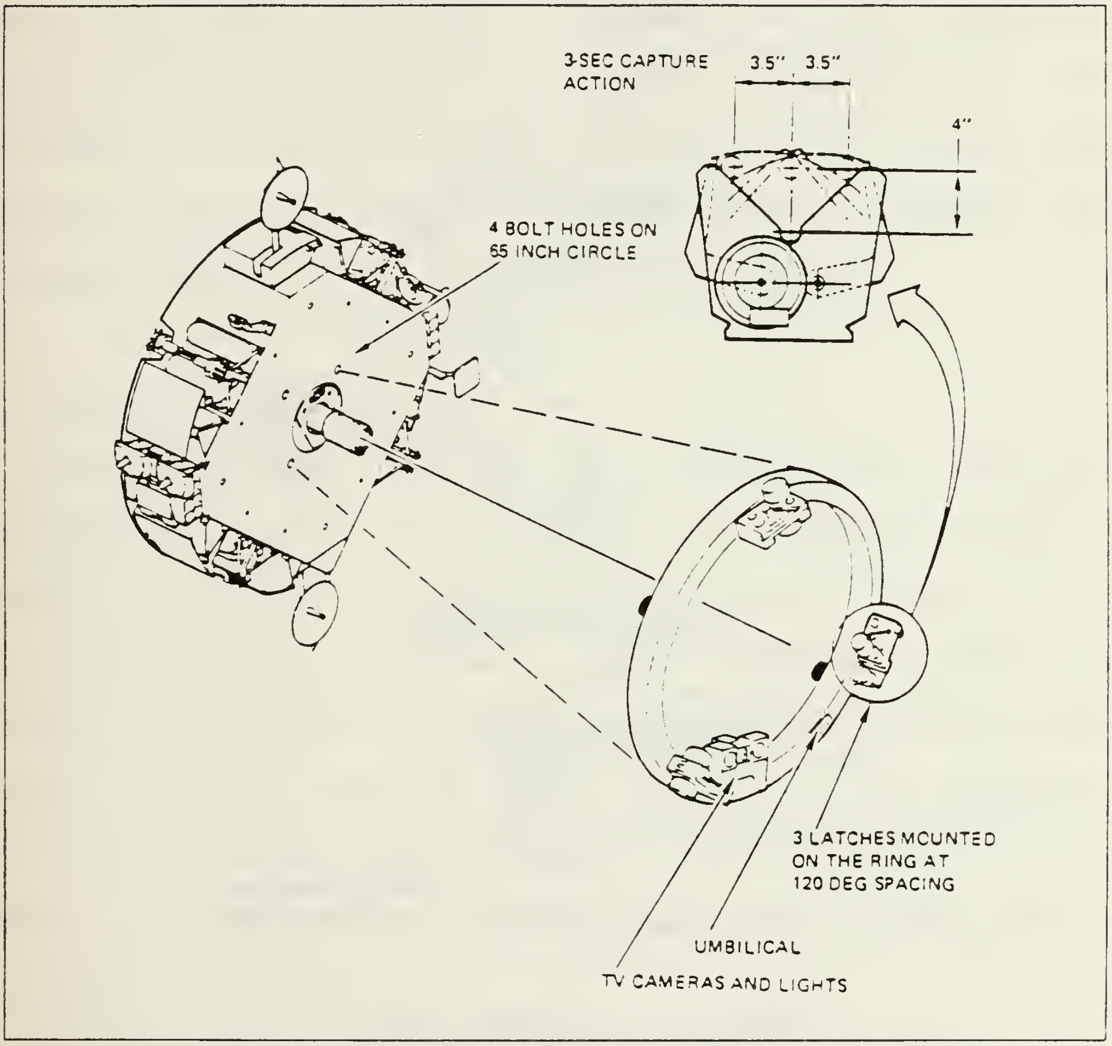

Figure V.4 OMV With Three Point Docking Mechanism [Ref. 11:p. 29]

5. ALIGNMENT AIDS FOR THE OMV

A visual target will be required on the payload for final docking alignment with the OMV host vehicle. Figure V.5 shows a current NASA design to be used on the first OMV mission with the Hubble Telescope. The pilot will use the two berthing targets as visual references, via a TV link, for close-in docking adjustments.

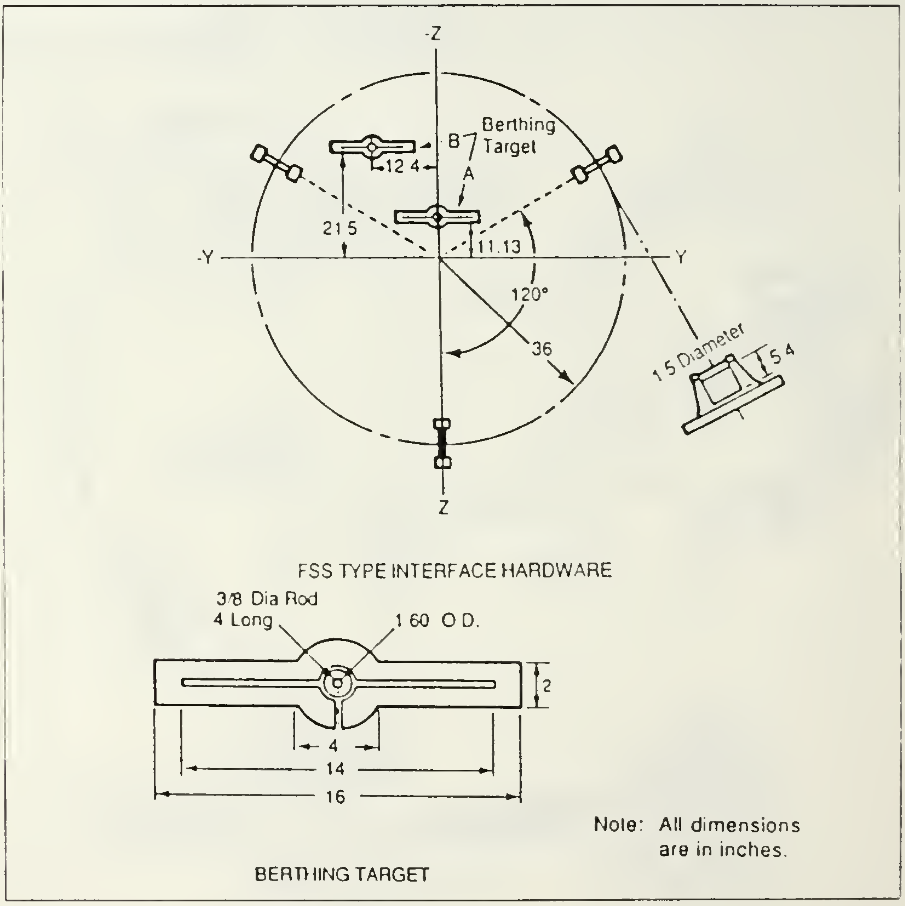

Figure V.5 DOCKING AIDS
[Ref. 11:p. 21]

6. ELECTRICAL CONNECTIONS

Electrical connections with the payload are provided on the TPDM using redundant 56-pin umbilicals shown in Figure V.6. The connectors are operated by OMV-provided DC current for connect/disconnect functions. The active connectors are mounted on the OMV and transverse laterally with respect to the OMV's axis. The passive connectors are used on the payload side. Alignment with the berthing targets during docking also assures alignment for the electrical connectors. These connections will provide the payload access to the OMV computer memory, command and telemetry channels, as well as electrical power.

D. PAYLOAD ACTIVATION

Once connected the OMV will enable the umbilical connections to power up the payload and begin the on-orbit mission life. If required, a translation to the desired orbit will then be performed. Maintaining the current 250 nm orbit will extend the OMV fuel supply, increasing the overall on-orbit lifetime before servicing is required. With the OMV solar power wings modification discussed in Chapter III, any payload attitude will now be continuously available.

The payload orbit and attitude will be maintained by the host OMV for the agreed mission lifetime. After the mission is over, the OMV will disconnect from the payload by unlatching the TPDM and backing safely away. Once clear, the OMV will begin a docking maneuver with another subsequent payload, boosted with a Pegasus vehicle at the appropriate time. This sequence will conceivably continue for the OMV's design life of ten years.

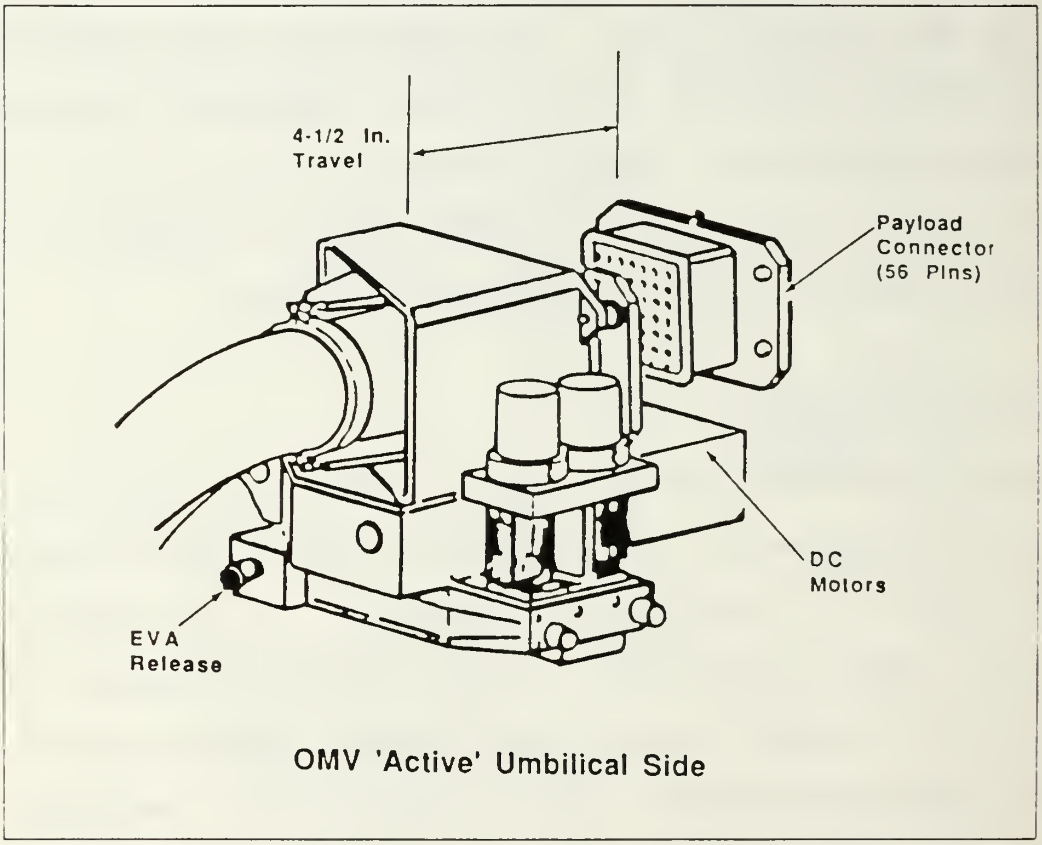

Figure V.6 OMV Payload Umbilical
[Ref. 3:p. 26]

VI. COMPARISON OF OMV HOST PLATFORM FOR PEGASUS LAUNCHED PAYLOADS WITH A CURRENT LAUNCH AND OPERATING SYSTEM

A. INTRODUCTION

One true measure of the worth of a new concept is to compare it with a current and acceptable method. A practical school of thought often subscribed to is why change something if it works, especially when great sums of money are involved? In the space industry, change historically comes slowly. Few dare to try new state-of-the-art methods. All desire 'proven technology' before implementing a system into their design. Innovation often surrenders to standard methods, even if the standards are more expensive or technologically outdated.

The value of the OMV/Payload Support Concept for the Pegasus Boosted Payloads will be measured against a comparable mission payload. To be as objective as possible, an orbit and payload weight, similar to the capabilities of the OMV and Pegasus, was chosen for comparison. Specifically, an existing satellite in a low earth polar orbit will be compared to the OMV/Pegasus concept.

B. CURRENT NOAA SATELLITE SYSTEM: DMSP

The Defense Meteorological Satellite Program (DMSP), managed by the National Oceanic and Atmospheric

Administration (NOAA), was chosen for comparison to the OMV/Pegasus concept. Both have similar orbit inclinations and altitudes, lifetimes, and on-orbit payload weights.

A DMSP satellite is a low, polar orbiter with a design lifetime of 24 months. It is inclined at 98.7° in a 450 nm circular sun-synchronous orbit. A recent 1985 launch version weighed 1451 kilograms (kg), or almost 3200 lbs. The main mission of a DMSP satellite is to provide global visual and infrared cloud data and other specialized meteorological, oceanographic, and solar-geophysical data. The mission requires real-time data to be transmitted to ground stations, with onboard data storage and playback capabilities for analysis and backup. [Ref. 14;p. II-2]

The current DMSP system consists of an on-orbit mass of approximately 800 kg or 1760 lbs. The DMSP satellite design is broken into the following subsystems, with each corresponding weight listed [Ref 14;p. III-9]:

SUBSYSTEM	WEIGHT (KG)
Structure	122.04
Thermal	22.93
Attitude Control	57.89
Power	129.84
Communications	7.99
Command and Control	26.33
Data Handling	10.31
Harness	40.68
* GFE Payload	134.25
GFE Growth	35.78
Apogee Kick Motor Case	48.12
Balance	96.16
Spacecraft Margin	35.00

* Mission Sensors

Spacecraft Dry Total	767.33	
Biopropellant (N_2H_4)	17.21	
Dry Gas Propellant (GN_2)	2.41	
Apogee Kick Motor Expendables	664.66	
Satellite at Liftoff	1451.60	(3194 lbs)

C. DMSP USING OMV/PEGASUS DESIGN

Redesigning the DMSP system and omitting subsystems provided by the OMV, would allow the weight to be reduced to within Pegasus capabilities. The following list of subsystems and weights are required for the OMV/Pegasus concept to perform the DMSP mission. These are from the above list:

SUBSYSTEM	WEIGHT (KG)	
Structure	60.00	
Thermal	15.00	
Communications	7.99	
Data Handling	10.31	
Harness	20.00	
GFE Payload	134.25	
Satellite Margin	35.00	
Satellite Launch Total	282.55	(622 lbs)

These subsystems represent the actual payload of the current DMSP design. The Structure, Thermal, and Harness subsystems are assumed to require less weight, as the Power and Command and Control subsystems are eliminated. These fewer subsystems also will require less wiring harness. The OMV will not only provide the power and command and control functions for the payload, but balance, apogee kick motor, and propellants are not required. The Pegasus will insert the payload into the OMV's orbit and, once mated to the payload, the OMV will transfer to the desired mission orbit. This first rough-cut redesign results in a weight reduction of over 80.5% in required launched mass, from 1451.60 (3194 lbs) to 282.55 kg (622 lbs).

From Figure IV.6, Pegasus could boost a 622 lb payload to a 250 nm polar orbit, making this redesign a realistic possibility. Figure III.4 shows the OMV could easily transfer this payload from the 250 nm Pegasus injection orbit to the operational altitude of 450 nm currently used by the DMSP satellites.

The intent of this comparison is not to re-engineer the DMSP satellite or to devise a new way of boosting and operating a meteorological payload. It is merely to show the feasibility of the OMV/Pegasus concept using a currently operating system. The elimination of OMV redundant satellite subsystems allows a large reduction in required payload weight to be launched. This reduction allows a smaller booster, like Pegasus, to lift only the actual payload to low earth orbit and still accomplish the basic DMSP mission. The mission could conceivably even be enhanced through orbital inclination and altitude changes available with the OMV.

D. METHODOLOGY FOR LAUNCH AND SUPPORT COSTS

To compare a current satellite system to the proposed OMV/Pegasus space-based support system, specific system costs were looked at. Launch costs were compared for the current polar orbiting satellite and the Pegasus. On orbit costs were compared next. The OMV procurement and launch costs were summed and divided over the proposed ten year lifetime. The resulting figure gives the OMV on orbit support costs, representing the annual rental fee for the OMV on orbit services. The total yearly cost of on orbit payloads are then compared for the one to four year missions. In both cases the cost of the satellite itself is omitted. As suggested above, there is also a substantial reduction in procurement costs of the payload, as a much simpler and lighter payload is now required with the OMV/Pegasus payload support concept. The format in Table VI.1 will be used for comparison of the two design concepts.

E. PAYLOAD LAUNCH COSTS

The boosters currently used for the DMSP payloads are the liquid propelled Atlas E and F models, launched from Vandenberg AFB. The current costs for an Atlas launch is approximately $40 million. [Ref. 2;p. 179]

The Pegasus booster used to launch the payload to a 250 nm polar orbit for this comparison is surprisingly affordable. A company representative for the Orbital

Sciences Corporation has stated it will sign a guaranteed-to-orbit contract at a firm fixed price of $6 million. This contract stipulates a free relaunch in the event of a booster failure on launch. The closest competitor to Pegasus with similar payload boost capability is the Scout booster, costing in excess of $12 million per launch, but with no stated launch guarantee. These figures are shown below in Table VI.2. [Ref. 13]

TABLE VI.1 DMSP VS. OMV/PEGASUS COST TABLE FORMAT

	DMSP	OMV/Pegasus
1. LAUNCH COST		
2. ON ORBIT SUPPORT Shuttle launch Titan-34D launch Titan IV launch		
3. TOTAL ORBIT COST 1st year Shuttle launched Titan-34D launched Titan IV launched 2nd year Shuttle launched Titan-34D launched Titan IV launched 3rd year Shuttle launched Titan-34D launched Titan IV launched 4th year Shuttle launched Titan-34D launched Titan IV launched		

TABLE VI.2 LAUNCH COST

	DMSP	OMV/Pegasus
LAUNCH COST	Atlas $40 mil.	Pegasus $6 mil.

F. ON-ORBIT SUPPORT COST FOR THE OMV/PEGASUS SYSTEM

The OMV is currently under final development for NASA at the TRW plant in Redondo Beach, CA. The first vehicle is being funded by NASA. OMV research, development, and construction costs are forecast to be $100 million. A second vehicle is also contracted by NASA at a follow on cost of $65-70 million. [Ref. 12]. The required changes to the current NASA design for the ten year extended on-orbit mission are minimal, as stated in Chapter III. It is therefore assumed that the NASA follow on procurement cost of $65-70 million is also accurate for a modified OMV. [Ref. 12]

The launch cost for the OMV itself is substantial. Currently, only the Shuttle is capable of deploying the OMV to low earth orbit. Since the lead time is so long for a shuttle launch and shuttle launches are highly vulnerable to delays, an alternative launch vehicle was selected. TRW is currently investigating the possibility of launching the OMV with a Titan-34D booster, both to supplement the Shuttle scheduling and for access to polar orbits, launching from Vandenberg. Under current plans, the cost of a Shuttle launch for the OMV is $100 million. To boost the OMV with a Titan-34D, the launch cost would be $115 million. Once in orbit, the OMV must be monitored and controlled from the GCC. The infrastructure and cost for controlling the vehicle are similar to other low orbiting satellite systems, and therefore will not be considered in the comparison. [Ref 12]

The total procurement and Shuttle launch costs for the extended capability OMV are approximately $165 ($65 + $100) million. Using a Titan-34D booster the cost increases to $180 ($65 + $115) million. Assuming the individual payload lifetimes are one year, the OMV cost is then divided among the ten users resulting in on-orbit costs per year of $16.5 million for a Shuttle launch, or $18.0 million for a Titan-34D launch.

The Titan IV booster could also be used to boost the OMV. Having a 39,000 lb payload capacity to LEO, the Titan IV could boost two OMVs, doubling the on-orbit hosting opportunities. A Titan IV booster currently costs $210 million per launch. Two OMVs at $65 million each results in an initial procurement cost of $130 million for two vehicles on orbit. This now requires $17 million per year per OMV, [($210 + $130)/20], for on-orbit support costs. These results are shown in Table VI.3. [Ref. 2:p. 140]

TABLE VI.3 ON-ORBIT SUPPORT COST FOR OMV/PEGASUS

	DMSP	OMV/Pegasus
ON ORBIT SUPPORT COSTS YEARLY (TEN YEAR LIFE)	$0	
1. Shuttle launch		OMV cost $ 65 mil. Launch $100 mil. Total = $165 mil.
Yearly Cost		$16.5 mil.
2. Titan-34D launch		OMV cost $ 65 mil. Launch $115 mil. Total = $180 mil.
Yearly Cost		$18.0 mil.
3. Titan IV launch (2 OMVs launched)		OMV cost $130 mil. Launch $210 mil. Total $340 mil.
Yearly Cost		$17.0 mil.

G. COMPARISON RESULTS

The cost figures from the comparison of the DMSP system to OMV/Pegasus DMSP concept are very favorable. The launch cost using Pegasus instead of an Atlas is reduced from $40 million to $6 million, and Pegasus guarantees a successful launch. Adding in the OMV use fee, regardless of launcher type, results in an orbit cost figure which is basically equivalent to current expenditures for the two year mission. Substantial savings are realized in the one, three, or four year mission cases. These results are presented in Table VI.4 below. If the $100 million Shuttle launch cost, the $115 million Titan-34D/OMV launch cost, or the $210 million double

OMV launch cost with a Titan IV could be subsidized by a national agency, such as DARPA or NASA, the OMV use fee could be drastically reduced, making the OMV/Pegasus concept even more attractive.

TABLE VI.4 DMSP VS. OMV/PEGASUS SYSTEM COST

	DMSP	OMV/Pegasus
1. LAUNCH COST	$ 40 mil.	$ 6.0 mil.
2. ON ORBIT SUPPORT COST PER YEAR	$ 0	
Shuttle launched		$ 16.5 mil.
Titan-34D launched		$ 18.0 mil.
Titan IV launched		$ 17.0 mil.
3. TOTAL ORBIT COST		
1st year	$ 40 mil.	
Shuttle launched		$ 22.5 mil.
Titan-34D launched		$ 24.0 mil.
Titan IV launched		$ 23.0 mil.
2nd year	$ 40 mil.	
Shuttle launched		$ 39.0 mil.
Titan-34D launched		$ 42.0 mil.
Titan IV launched		$ 40.0 mil.
3rd year	(Requires second Atlas launch) $ 80 mil.	
Shuttle launched		$ 55.5 mil.
Titan-34D launched		$ 60.0 mil.
Titan IV launched		$ 57.0 mil.
4th year	$ 80 mil.	
Shuttle launched		$ 72.0 mil.
Titan-34D launched		$ 78.0 mil.
Titan IV launched		$ 74.0 mil.

Another substantial savings results from reduced satellite hardware procurement costs. By using OMV support, four major subsystems are eliminated: attitude control, electrical power, command and control, and propulsion. Three others are greatly reduced in volume and weight and therefore cost. These cost savings could be used to defray the OMV user fee.

If current DMSP satellite lifetime is largely dependent on propellant available for attitude control and stationkeeping, large savings could also be realized. If a continuous payload in orbit is desired, increasing the payload life beyond 24 months would reduce the number of launches required. Also, fewer payloads would be required, effecting a major cost reduction over the life of the DMSP project.

This specific comparison clearly shows the feasibility of the general OMV/Pegasus payload support concept. Simplifying current payload design is a benefit from this concept due to the elimination of most of the supporting subsystems. The cost savings from a new booster and less complicated payload will help offset the user fee of the OMV. The ability of the OMV to host a payload for as long as required coupled with orbital altitude and inclination change capabilities are great advantages over current operating satellites. The OMV/Pegasus payload support concept is superior for existing systems such as DMSP, and it has capabilities which make it a much more versatile and capable strategy for employment.

VII. CONCLUSION

The new concept of a space-based payload support system has been proposed and evaluated here. By using two existing systems, the Pegasus booster and the OMV, the concept could promptly become an operating system. The Pegasus air-launched space booster is state-of-the-art and the most economical low earth orbit booster available today. No modifications are required for the Pegasus booster and only minor changes are needed to the current OMV design to increase its on-orbit life to the required ten years.

The orbiting OMV will provide the satellite host functions for a payload, such as electrical power, attitude and orbit control, and communications. Eliminating these satellite subsystems allow a substantial weight reduction in the boosted payload to orbit. To test this concept, the DMSP satellite design was proposed to be modified to eliminate unnecessary systems. The launch weight was reduced from 3200 lbs to an estimated 622 lbs, enabling the booster requirements to be scaled down from the $40 million Atlas to a $6 million Pegasus. Another option available to the DMSP system is to use the 2578 lb weight excess, created from redesigning the satellite, to boost more actual payload with the current Atlas booster, allowing much more capability to be placed in orbit per launch.

The present NASA OMV design need be only slightly modified to enable a continuous on-orbit lifetime of ten years. Only the electrical power, radiation protection, and thermal control systems require alteration. Two sun-tracking solar panels using gallium-arsenide solar cells will replace the current body mounted silicon cells to allow any desired payload attitude. Higher radiation tolerant piece parts are required to withstand a larger ten year dosage. Long-life thermal protection will use second-surface mirroring instead of the Teflon tape currently being used.

Utilizing the Pegasus air-launched space booster allows a 10-15% reduction in the total delta-V required to orbit a payload. This three stage, solid propellant, inertially guided, all composite, winged vehicle is launched from 40,000 feet at Mach 0.82, which is above 75% of the earth's atmosphere. The first stage motor nozzle is designed to be much more efficient. Its lower vehicle dynamic pressure, structural, and thermal stresses allow lighter graphite materials to be used. Minimum prelaunch handling requires only six to seven technicians for on-site assembly and checkout. Horizontal mating of the payload to the booster allows easy access for systems checks of the payload and requires only modest hangar space. Covertness is available, should it be desired, as a launch is possible within two hours of rollout.

The Pegasus final stage will provide attitude control to the payload until mated with the OMV. The OMV will plug into the three-axis stabilized payload in a 250 nm circular orbit. Once the system is powered up by the OMV, a transfer will be completed to the desired orbital altitude, such as the 450 nm orbit for the DMSP example. The OMV will support the payload for a specified length of time, nominally 12 months. After mission completion, it detaches and backs away from the payload, and will transfer back to the 250 nm Pegasus third stage injection orbit and begin a rendezvous with a newly boosted payload.

By incorporating the Pegasus booster into the payload support concept, the versatility of a mobile launch platform with useful payload weights-to-orbit capabilities are realized. Great flexibility exists as any runway longer than 11,000 feet can support a Pegasus carrier aircraft. There are now more than 250 Strategic Air Command B-52G/H bombers capable of launching a Pegasus booster with only minor modifications to the Air Launched Cruise Missile pylons. The current Pegasus can put a 600 lb payload into a 250 nm polar orbit and a 900 lb payload into a 250 nm equatorial orbit.

The comparison of a payload support concept designed DMSP satellite to the current design proved not only feasible but favorable. The launch costs were only 15% of the present system. Savings from the elimination of redundant satellite hardware subsystems provided by the OMV host platform are substantial. The OMV payload support services must be leased at $16.5-$18 million per year of on-orbit use, if not subsidized by a Federal agency such as NASA or DARPA. This fee would be offset by the savings from the hardware procurement and launch savings.

One of the most valuable results of this concept is the ability to change orbital altitudes and inclinations, although the latter is very fuel expensive and would probably decrease the OMV on-orbit life. Another option now available to the user is to increase the on-orbit life of the payload. Presently the greatest limitation on satellite life is the attitude propellant and the OMV could extend the life of asset with up to ten years of fuel.

With this concept there is no longer a need to boost heavy and non-productive satellite support systems along with every payload. With the cost of access to space directly tied to boosted weight and as demand for space access continues to increase, a more economical method must be found. The simplicity of the newly designed payloads will increase reliability and greatly decrease construction costs for the same on-orbit capability. The Pegasus booster is capable of orbiting useful payload weights to low earth orbit. The OMV, used as a payload support platform for Pegasus boosted non-autonomous satellites, is an economical solution for orbiting newly designed payloads for research, development, and deployment.

LIST OF REFERENCES

1. "Commercial Winged Booster To Launch Satellites From B-52", Aviation Week & Space Technology, p. 14-16, 6 June 1988.

2. Lyon, D. C. and Cipollone, L. V., Space Launch Vehicle Alternatives For Small Satellites And The Current Commercial, Political And Physical Environments, Master's Thesis, Naval Postgraduate School, Monterey, CA., September, 1988.

3. National Aeronautics and Space Administration, User's Guide for the Orbital Maneuvering Vehicle, p. 1-25, October 1987.

4. Gruninger, J., "Orbital Maneuvering Vehicle Program Status", TRW Space & Technology Group, 1988.

5. Frew, A. M., and Stephenson, A. G., "Designing a first: The Orbital Maneuvering Vehicle", TRW Quest Magazine, p. 5-25, Summer 1987.

6. Eagle-Picher Industries, Electronics Division, Couples Department, An Improved, High Specific Energy (Lightweight) Space Based System, p. 1-7, Miller, L.

7. Colucci, F., "Space Tug On The Slipway', Space, March-April 1988, p. 44-48.

8. Orbital Sciences Corporation, Pegasus Air-Launched Space Booster Payload Users Guide, December 1988.

9. 27TH Aerospace Sciences Meeting, AIAA-89-0587, OMV Mission Operations, J. Sarina, 9 January 1989.

10. Stephenson, A. G., "The orbital maneuvering vehicle", Aerospace America, p. 24-28, November 1988.

11. TRW Space & Technology Group, Report number 51000.88.100-002, OMV Preliminary Design Review, 22 August 1988.

12. Phone interview between Mr. J. Gruninger, TRW Space & Technology Group, and the author, 1 June, 1989.

13. Interview between Dr. A. Fuhs, Consultant and Past Chief Scientist for Orbital Sciences Corporation, Fairfax, VA., and the author, 23 May, 1989.

14. National Oceanic and Atmospheric Administration, ENVIROSAT-2000 Report, Comparison of the Defense Meteorological Satellite Program (DMSP) and the NOAA Polar-orbiting Operational Environmental Satellite (POES) Program, October 1985.

15. TRW Space & Technology Group, Report number 43267.000, OMV/Payload Preliminary Control Document, 30 August, 1985.

16. TRW Space & Technology Group, Results of the Orbital Maneuvering Vehicle Study for Space Based Interceptor Servicing, undated.

17. "Pegasus Delayed", Aviation Week & Space Technology, p. 11, 7 August 1989.

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Fairfax, VA 22033

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Jerry Gruninger R11/2762
One Space Park
Redondo Beach, CA 90278

12. Navy Space Systems Activity..........................1
Attn: LCDR Steve Ambrose
P.O. Box 92960
Los Angeles, CA 30009-2960

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Attn: CDR W. Meyers, Code 9120
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Washington, D.C. 20375

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Washington, D.C. 20375

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Arlington, VA 22209

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Monterey, CA 93943

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R359 Repper
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