PAPER AAS 93-563

Mission Design for the Mars Environmental Survey

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AAS/AIAA Astrodynamics Specialist Conference

VICTORIA, **B. C.,** CANADA AUGUST 16-19, 1993

AAS Publications Office, P.0, Box 28130, San Diego, CA 92198

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The Mars Environmental Survey (MESUR) mission is the next logical evolutionary step in the thirty year program of Mars exploration. The purpose of this mission is to perform long duration in situ scientific. measurements of the Martian environment at a number of globally distributed silts, Mission architecture studies arc currently being performed at the Jet Propulsion Laboratory to further define the mission concept and implementation approach. Mission design and analysis forms a significant component of the.se architecture studies. The complexity of the full network mission has indicated that an engineering precursor mission is appropriate before full commitment is made to the network. As a result, NASA has decided to launch a single lander to Mars in 1996 to test several of the kcy engineering capabilities required for the network, This mission, called MESUR Pathfinder, is expected to obtain a ncw start in the next fiscal year. The fast development schedule and low cost of the mission have required considerable mission design activity.

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On September 25, 1992, the United States made the latest step in the exploration of Mars with the launch of the Mars Observer (MO) mission. MO will arrive at Mars on August 24, 1993, and begin an extensive program to remotely sense the Martian atmosphere and surface environment. The next step in Mars exploration is to move beyond remote sensing and make long term in situ measurements on the Martian surface. The Viking missions performed such measurements in 1976 at two locali zed sites. The proposed Mars Environmental Survey (MESUR) mission would greatly enhance this by emplacing a network of globally distributed landers. The specific science objectives of this mission arc to make measurements of the global seismology and meteorology of Mars for one full Martian year (687 days). In addition, observations on the local geology, geochemistry and exobiology will be made a diverse set of landing sites.

Mars network missions have been studied in various forms for the last fifteen years. The MESUR concept, as originally developed by the Ames Research Center [1], uses an evolutionary approach to emplace the network, Sixteen landers arc delivered in groups of four or eight during the 1999,2001 and 2003 Earth-Mars launch opportunities. The landers arc launched four at time on a McDonnell Douglas Delta II (7925), but each is flown separately to Mars. The landers enter the Martian atmosphere directl y from the hyperbolic approach trajectory, using an aeroshell as the primary aerodynamic decelerator. This concept achieves the full set of network science objectives at a cost of more than one billion dollars. Unfortunately, this high price tag means that the mission is probably not viable in the current political and fiscal climate. As a result, a mission architecture study has

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been initiated at JPL to identify alternative concepts. The network science objectives are being reconsidered by the science peer committees (Mars Science Working Group, MESUR Science Definition Team) which advise NASA. Simultaneously, JPL is attempting to develop missions that address a range of potential science objectives. Each of the concepts is being evaluated in terms of the total program cost and risk. All lifecycle costs are being considered, including development, launch vehicle, and mission operations.

One conclusion of the architecture study is that a precursor mission is needed to prove some of the key engineering capabilities required for MESUR Network, The MESUR Pathfinder mission has been proposed to fill this role. Pathfinder is designed to be a very low cost mission with a short development cycle. The total cost for development (not including the launch vehicle or mission operations costs) is limited to !$150 million (in FY92 dollars). The project is scheduled to get a new start in FY '94, with launch in late 1996 on a Delta II (7925) launch vehicle. The current mission design calls for arrival in July 1997, followed by at least 30 sols of surface operations. A considerable amount of activity has been performed in the last year to define and develop the Pathfinder mission concept. The Pathfinder design work is much more detailed than the network conceptual studies, As a result, continued discussion of Pathfinder will be made outside the network architecture study context,

NETWORK ARCHITECTURE MISSION DESIGN STUDIES

Mission analysis and design is a major focus of the network architecture study. The primary task is to develop reference Earth-Mars trajectories for different mission scenarios. Some of the major design drivers include the launch strategy, entry profile constraints and landing site geometry constraints. The launch vehicles which appear to be viable candidates for the MESUR program range from the Taurus class to the Titan IV class. From one to all the landers could be launched on a single vehicle depending upon the available mass and volume. The payload fairing diameter is an important constraint for smaller launch vehicles because it limits the size of the entry aeroshell. The impact of this constraint on the entry mass will be discussed later in this section. The injected mass capability for a given launch vehicle depends upon the launch period design. Two primary considerations in this design is the reliability of the launch vehicle and the number of launches desired in a given opportunity. The launch vehicle reliability can be assessed through statistical analysis of prior launches (if any arc, applicable), but also depend upon the basic capabilities of the vehicle. Launch vehicles with variable launch azimuth capability provide daily launch windows, and subsequently increase the daily launch probability. The number of possible launches depends on the available launch pads (two each for a few expendable vehicles -- Delta, Atlas, etc.) and the launch turnaround time (which depends upon the specific launch procedures used by the manufacturer).

Atmospheric Entry and Landing Constraints

Atmospheric entry and descent is one of the most complex and risky portions of the MESUR mission. As a result, it is important to carefully design the entry profile to minimize the risk. In general, two different methods exist for atmospheric entry. One approach is to enter the Martian atmosphere directly from the hyperbolic approach trajectory. The other approach (used by Viking) is to place the entry capsule into orbit around Mars before atmospheric entry takes place. One difference between these two approaches is that the entry velocity is much higher (at least 2 km/s higher) for direct entry.

Direct entry results in a fixed relationship between the landing geometry and the interplanetary trajectory. The implications of this on the trajectory design will be discussed later in this section. Most of the mission architectures suggested for MESUR use the direct entry approach because of the large propulsion system requirements needed to achieve Mars orbit. Direct entry shall be assumed for the remainder of this paper. Two general approaches to descent guidance also exist, either guided (controlling the lift vector like Viking) or unguided (ballistic). The unguided method appears to be achievable for lower cost if a sufficiently robust landing system can be developed. Fortunately, a number of landing approaches have been identified (crushable impact absorbing materials with a self-righting lander is one) which favor the unguided approach,

Entry velocity is the parameter which couples the entry profile and the interplanetary trajectory design. The entry velocity (along with the ballistic coefficient and entry angle) determines the maximum stagnation heating rate during entry. This heating rate is a primary design driver for the aeroshell thermal protection system. Heating profiles for a set of initial conditions are presented in Figure 1. These curves were generated using an engineering correlation formula derived from complete aerothermodynamic studies performed at the NASA Langley Research Center (LaRC) [2]. The atmosphere model used in this analysis is the COSPAR Low Density model given in [3]. The entry velocity, entry angle and ballistic coefficient must be limited so that the maximum heating rate does not exceed the aeroshell material qualification level. in addition, the entry angle and ballistic coefficient are subject to an additional set of constraints. The terminal velocity profile is determined solely from the entry angle and ballistic coefficient. Steeper entry angles and higher ballistic coefficients result in higher velocities near the surface. If terminal descent parachutes are used, the entry profile must be constrained to allow safe parachute deployment. The achievable landing site targeting accuracy increases as the entry angle increases. Science requirements on landing site uncertainty can therefore be mapped into a lower limit on entry angle. The minimum allowable ballistic coefficient depends upon the diameter of the launch vehicle fairing and the entry mass. The effect of all these constraints is that the ballistic coefficient and entry angle are generally limited to rather small ranges. As a result, the allowable entry velocity range can be determined directly from the constraint on maximum heating rate. The entry velocity at a particular altitude is directly related to the magnitude of the hyperbolic approach v-infinity vector. The v-infinity vector is the vector difference between the heliocentric velocity vector of the spacecraft and the heliocentric velocity vector of the encounter planet. For ballistic interplanetary trajectories, this vector is determined directly from the launch and arrival dates. As a result, entry heating constraints can be mapped directly into limits on the possible launch and arrival dates.

The landing sites which can be achieved by direct entry are determined from the approach v-infinity vector, the entry angle, and the target point in the trajectory B-plane, The B-plane is the plane passing through the center of the. body which is perpendicular to the v-infinity vector. The target point is the linear extension of the approach asymptote if the bending effects of gravity are ignored, The coordinates of this aim point can be expressed as a radius from the body center and an angle measured from the equatorial plane. The radius is determined if the entry angle and the corresponding entry altitude (usually 125 km for Mars) are specified. Varying the B-plane angle Θ from $0°$ to $360°$ results in different landing sites. The locus of these sites for a fixed v-infinity vector and entry angle forms a minor circle around the planet normal to the v-infinity vector. Figure 2 gives an example. Note that the maximum and minimum latitudes are not generally polar. Thus, the range of landing site latitudes available for a given interplanetary trajectory may be limited, As a result, science requirements on landing site (i.e. polar sites) may drive the trajectory

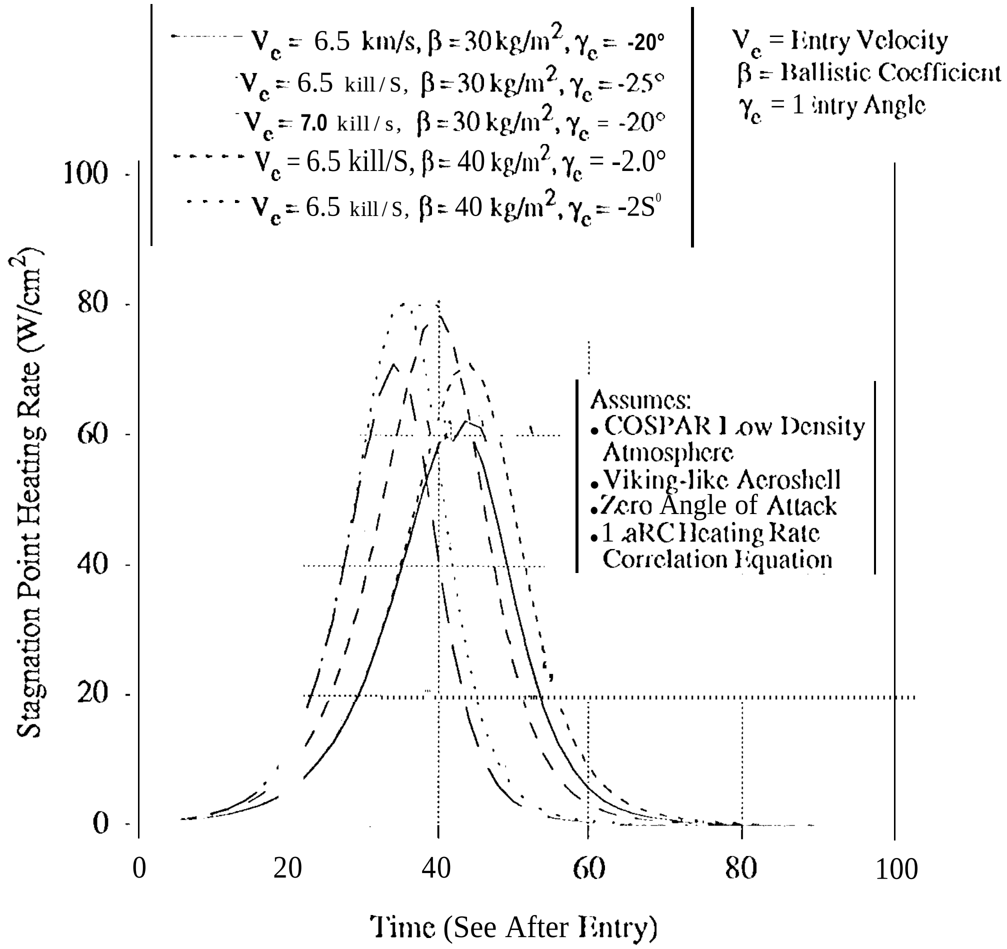


Figure 1. Entry Heating Rate Profiles

selection process. Because Mars is rotating, the longitude. of the landing site is determined by the arrival time, Any desired longitude can be achieved by varying the arrival time by one sol (88775 see). Varying the arrival time, however, does not change the geometry of the site relative to the Earth and Sun, This is because the relative geometry of the v-infinity vector and the Earth and Sun varies slowly. Since the available landing sites are fixed relative to the v-infinity vector, tbcy arc also fixed relative to the Earth and Sun. If a daylight descent is desired with specific landing solar elevation angle.s (descent imaging is an example where this might apply), then the interplanetary trajectory may have to be constrained to meet this requirement.

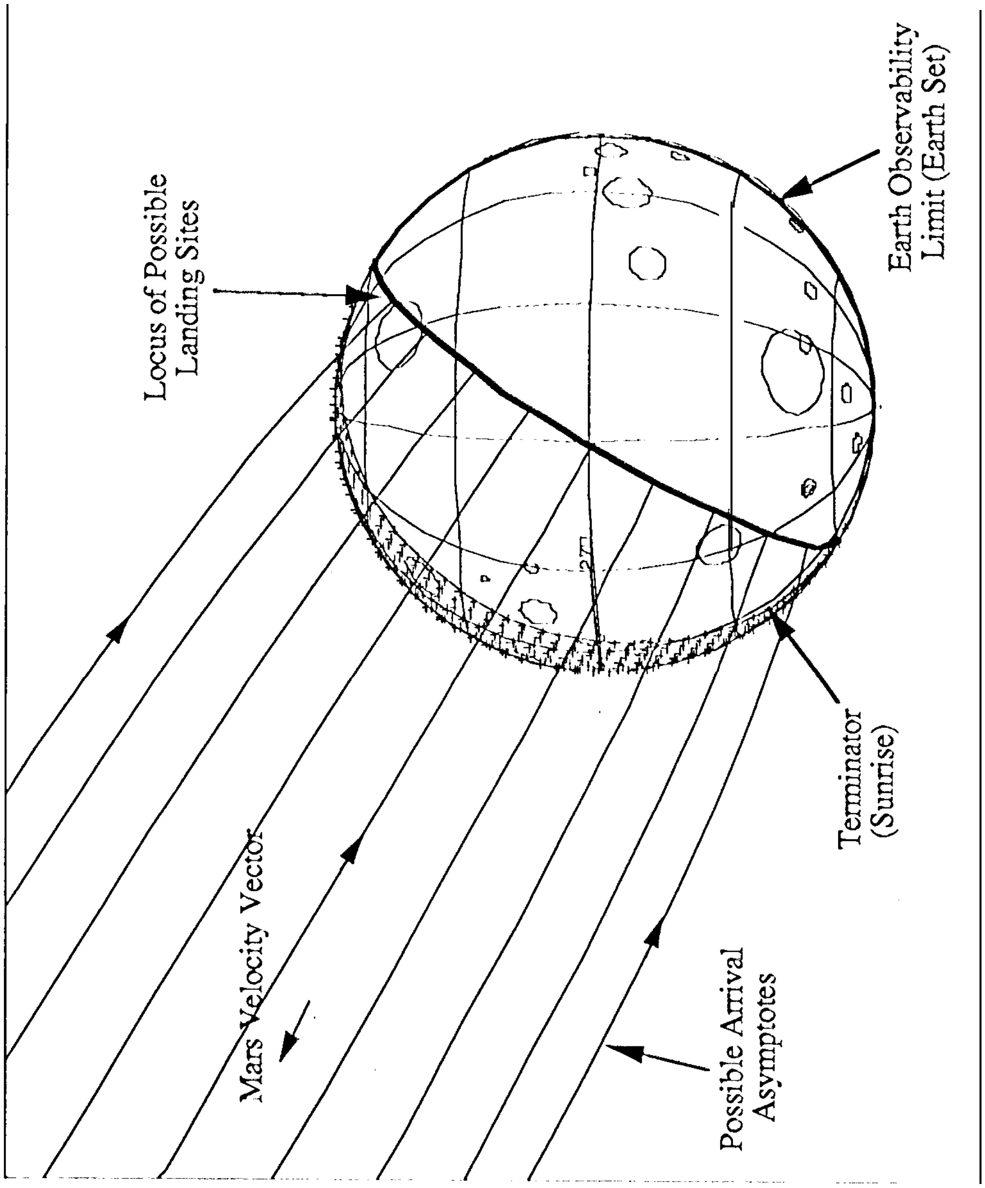


Figure 2. Sample Mars Arrival Geometry

Interplanetary Trajectory Design

All of these constraints have to be factored into the interplanetary trajectory design process. Figure 3 shows sample designs based on a particular set of requirements. Trajectories have been identified for a number of opportunities between 1998 and 2003. These transfers were developed by minimizing the sum of the launch and arrival v-infinities. The assumed launch vehicle was the Delta 11 (7925), and the desired launch mass was at least 900 kg. This corresponds to a maximum allowable launch C_3 of 15 km^2/s^2. The actual injected mass capability for the Delta is shown to illustrate the variability between opportunities. The maximum allowable entry velocity was constrained to be less than 6.5 km/s to limit the entry heating to less than 80 W/cm^2 (for a ballistic coefficient of 40 kg/n and an entry angle of -25°). No constraints were placed on the trajectory design due to landing site requirements.

These trajectories are all ballistic, and can be divided into several classes. The simplest direct Earth-Mars transfers (those that go from the Earth to Mars directly with no flybys of intermediate bodies) are either Type 1, 2, ±3 or ±4. Type 1 transfers are defined as trajectories with total transfer angles (the angle between the Earth-Sun line at launch and the Mars-Sun line at arrival) of less than 180°. Type 2 transfers have angles between 180° and 350°. Type 3 trajectories have angles between 360° and 540°, and Type 4 have angles between 540° and 720°. Two classes of trajectory solutions exist for both the Type 3 and 4 cases because they have more than one revolution. Note that Figure 3 does not show trajectory designs of every type for all opportunities. in some cases, no transfers of a particular class exist which meet all the constraints. The final class of trajectories shown in the figure are called one year resonant Earth gravity assist (EGA) transfers. In these cases, launch occurs exactly one year before a standard direct Earth-Mars transfer. The launch C_3 is the same as the direct transfer, but the launch declination is somewhat different. The resulting heliocentric trajectory is an orbit with the same period as the Earth but different inclination or eccentricity. The spacecraft launched into this orbit will meet up with the Earth again after one year. An Earth flyby can then be performed to redirect the flight path onto the correct Mars transfer orbit, The advantage of this type of transfer will be shown in the next paragraph.

The sample trajectories identified in Figure 3 can be used to develop an overall network mission architecture. One sample scenario derived from the figure is a modified Ames approach in which 12 landers are launched on three Deltas. One set of four landers is launched on a Type -4 trajectory in October 1998. Mars arrival occurs in April 2001, after one and a half revolutions around the Sun. An additional set of four landers is launched on a one year Earth gravity assist trajectory in February 2000. The final four landers are launched directly from Earth onto the Type 2 in February 2001. The reason the Earth gravity assist trajectory is used is so that only one Delta launch has to occur in 2001, rather than two. This reduced the length of launch period required in 2001 to launch two vehicles. One advantage of this mission scenario is that all twelve landers arrive at Mars within about six months of each other. This occurs even though they are launched over a two and a half year period, As a result, the landers only need to survive on the surface for a total Of 30 months to meet the science objectives. In the Ames baseline, the set Of landers sent in 1999 has to last on the surface for three Mars years before the mission is completed. One drawback to this modified scenario, however, is that some of the landers have to spend three Earth years in space on the way to Mars. The deep space environment may be more benign than the surface environment, however, so this may be a more favorable approach.

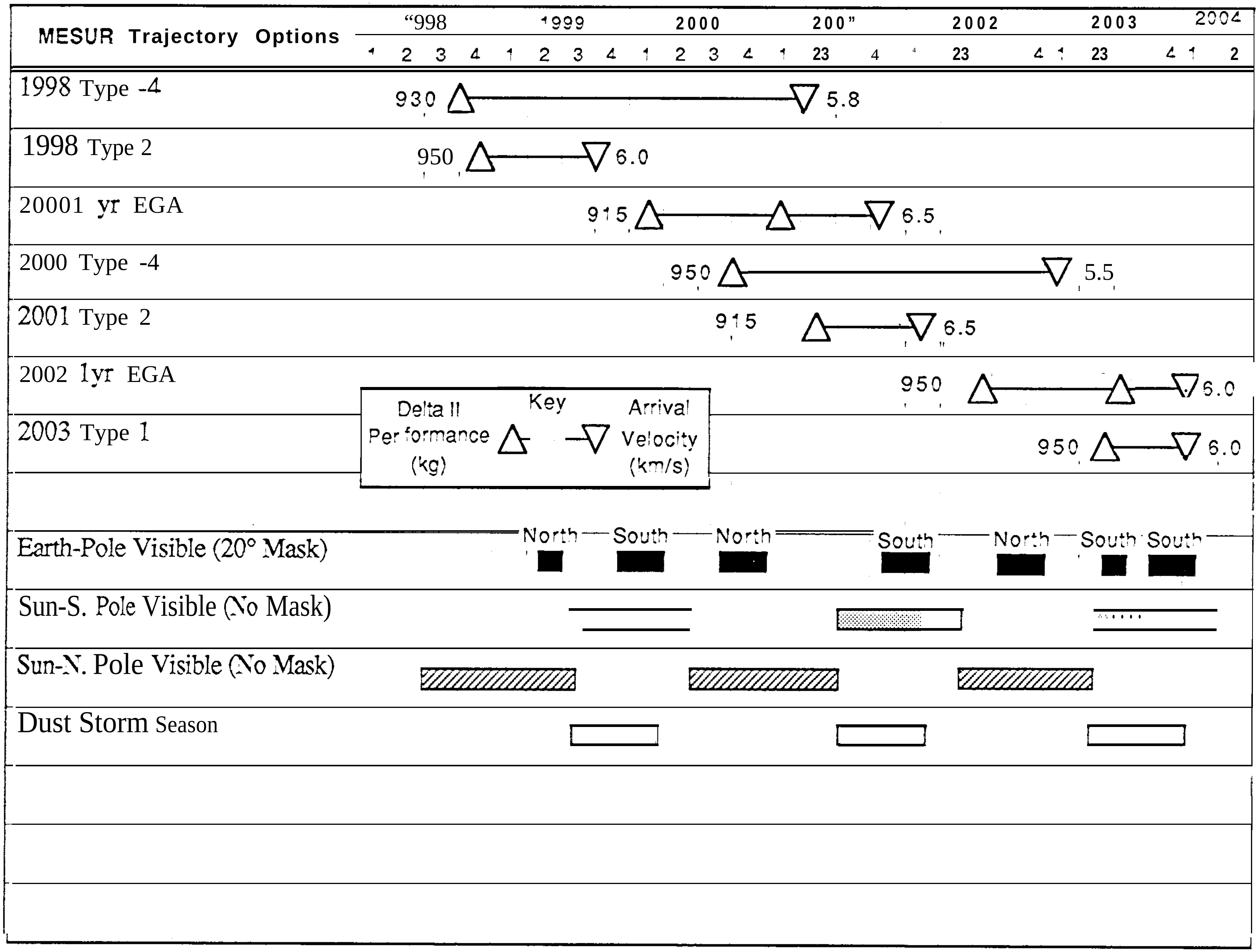


Figure 3. Sample Network Trajectory Design Schedule (999.

PATHFINDER MISSION OVERVIEW

The key engineering objective of Pathfinder is to develop and verify a low cost entry, descent, and landing approach for emplacing small science packages on the surface of Mars. This approach could then be scaled directly for use on the full network mission. Other engineering objectives include developing a spacecraft architecture which uses highly integrated subsystems and testing the performance of solar arrays on the surface of Mars. in addition, Pathfinder will carry a free ranging, partially autonomous microrover to investigate the mobility of rovers on the surface of Mars. This type of rover shows great promise as an instrument deployment device for MESUR Network, and might also be an integral part of follow-up sample return missions. in besides its role as a MESUR Network precursor, Pathfinder has also been identified as the first Discovery mission The Discovery program has been proposed by NASA as a cent inuing series of low cost missions to perform focused high priority science. A small instrument package will be carried on Pathfinder to obtain atmospheric structure information during entry (similar to the data obtained by Viking), to obtai n high resolution color images of the terrain surroundi ng the lander, and to measure the elemental composition of soil and rocks near the lander with an Alpha/Proton/X-ray Spectrometer (APXS). The APXS will be carried by the microrover so that it can be used on a range of sample materials.

The Pathfinder spacecraft is composed of three major elements: the surface lander, the entry module, and the cruise stage. The lander is a tetrahedron shaped structure containing an electronics package, the science instruments and the rover. The tetrahedron is composed of four similarly shaped triangular panels. The electronics package and payload ate attached to one panel. The remaining three panels are attached to the edges of the center panel. 'I'he positions of these panels can be changed during flight to form different lander configurations, During transit to Mars, the panels arc positioned to create a closed tetrahedron. This shape is used so that when the lander touches down on Mars, it comes to rest on one of the four sides. The side panels can then be moved so that all four panels form a single flat sheet, Opening the tetrahedron in this way causes the lander to right itself with the electronic and payload facing up. Figure 4 shows a schematic of the lander in the open configuration. This lander is required to self-right itself because the passive entry, descent, and landing approach adopted by Pathfinder does not guarantee upright landing.

The entry capsule is used to protect the lander during entry and deliver it to the surface. This element consists of an aeroshell (front and back pieces) used to absorb the heat pulse associated with atmospheric entry ant] a parachute, which slows the descent velocity from several hundred meters per second to sixty. The entry capsule also contains small solid retrorockets used for terminal deceleration and an airbag system used to absorb the actual surface impact shock. The airbags are a simple and robust system that protect against uneven surface features, horizontal velocities due to wind shears, and bouncing/recontact with the surface. The cruise stage. is the set of hardware carried outside, the entry module which performs cruise specific functions. These functions include propulsion (for trajectory correction maneuvers), attitude control sensing, and telecommunications. The spacecraft is a simple spinner which maintains an Earth-point configuration during cruise. The cruise stage is separated just before entry to allow the entry module to enter the atmosphere unencumbered.

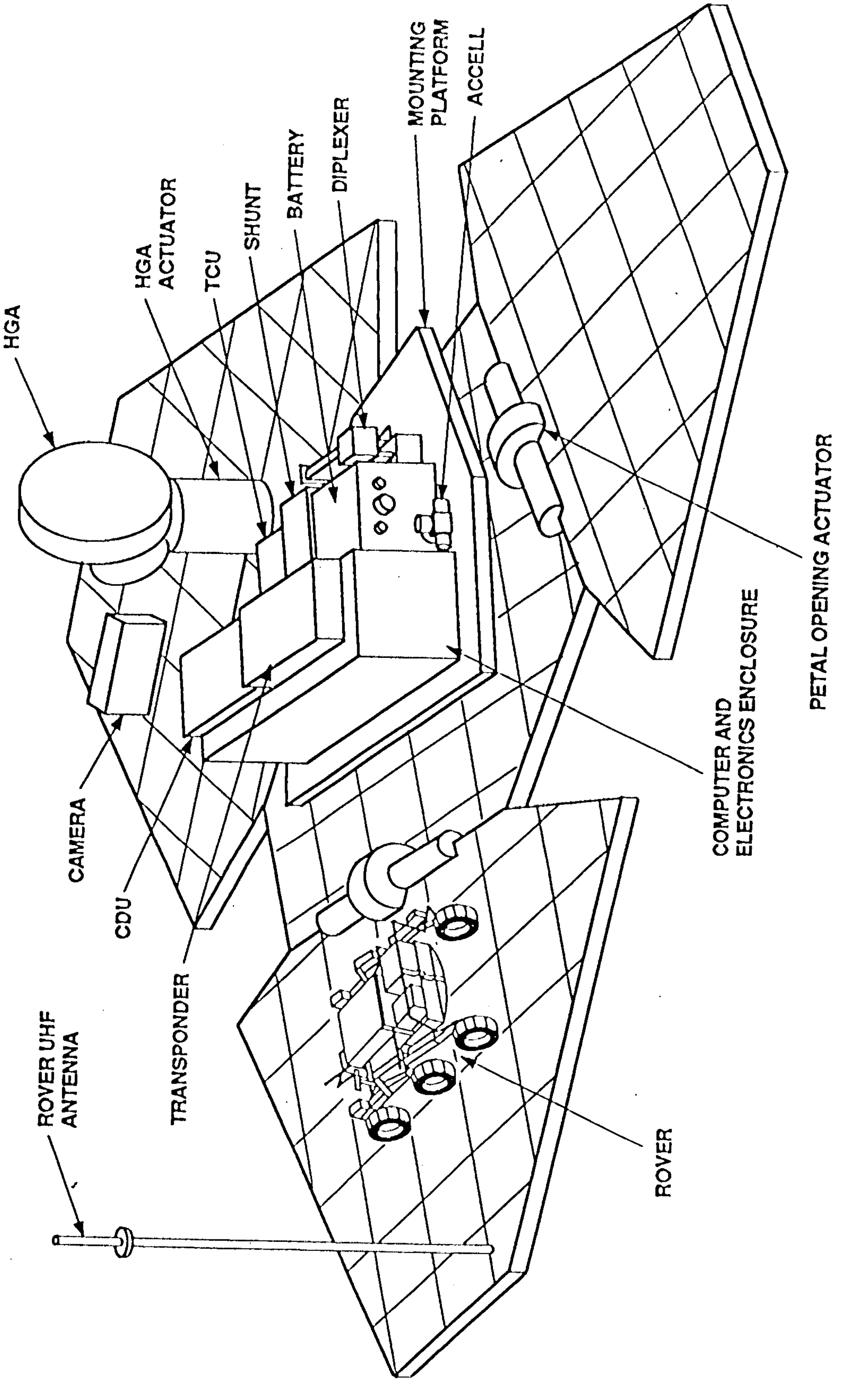


Figure 4. MESUR Pathfinder Surface, Lander Configuration

PATHFINDER MISSION DESIGN

Launch Strategy

The low cost and fast development schedule for Pathfinder place a premium on early mission definition, As a result, a considerable amount of work has been performed in the last year to develop a baseline launch strategy, interplanetary trajectory design, and entry profile design, At first glance, the launch strategy for Pathfinder appears (o be relatively straightforward because the spacecraft mass is much lower than the launch vehicle capability. 'There is an inherent property of the Delta, however, which complicates the design, All previous interplanetary missions used launch windows to increase the daily launch probability. This is very important for interplanetary missions because they have short launch periods that do no{ repeat often. The most efficient way to obtain daily windows is to vary the launch azimuth with time. Unfortunatel y, the Delt a does not currently have a variable launch azimuth (VLA) capability. The Delta uses a fixed daily launch azimuth, which means that launch can only occur on (near) instantaneous daily opportunities. The implications of this on launch probability and overall mission risk arc significant.

A number of ways to mitigate this risk have been addressed by JP1. and McDonnell Douglas Aerospace. Onc approach is to simpl y implement variable launch azimuth guidance on the Delta. The cost of this is probably too large for a low cost mission like Pathfinder. Another approach is to use the second stage to perform an out-of-plane (dog-leg) maneuver to correct the parking orbit orientation, If the correct launch time is used for a given launch azimuth, then the parking orbit is correctly oriented for trans-Mars injection. If, however, the launch time is slightly earlier or later, then the parking orbit orientation has to be changed. A dog-leg maneuver allows variable launch times, but also results in a performance penalt y. Furthermore, the second stage must be able to vary the maneuver to allow continuously variable launch times. Unfortunately, the Delta second stage **cannot** perform this type of adapt ive guidance, Instead, discrete maneuvers must be loaded into the guidance software for each specific launch time. Multiple daily launch opportunities arc possible, but each of them is still nearly instantaneous. "The performance penalty is a function of how many discrete opportunities arc used plus the time difference between them. Statistic analysis of previous Delta launches indicates that most flights launched within 30 minutes of the desired time. As a result, the project has adopted a strategy of requiring two daily launch opportunities separated by at least 30 minutes. The performance penalty for the dog-leg needed to correct a 15 minute launch time error (the opportunities arc distributed even] y around t he correct launch t ime) is about 125 kg. This approach has also affected the overall launch period design. Becau sc cent inuous windows do not exist on every day, the requirement was levied to have a minimum 30 day launch period.

Interplanetary Trajectory Design

The key to selecting the interplanetary trajectory for Pathfinder is to first determine the constraints and requirements on the design. One requirement is the minimum 30 day contiguous launch period, Another is a maximum declination of the launch asymptote of 40°. The source of this requirement is range safety constraints on the launch azimuth. Mission operations concerns drive the requirement for a constant arrival date (for every day in the launch period). The total flight time should be minimized to increase the likelihood of mission success (especially for the single string Pathfinder design). Project cost constraints have severel y limited the capabilities of the spacecraft propulsion system. As a rc.suit, the trajectory design must not require any significant deep space maneuvers (total more than 1()() m/s). Verification of the passive entry, descent, and landing approach means that engineering telemetry must be obtained throughout entry (the data will be recorded on-board the spacecraft, but real-time communications is also required in case of catastrophic failure). Communications can only occur if the spacecraft antenna points at Earth (or within some number of degrees of Earth depending on the antenna beam pattern). Because the spacecraft is spinning, the only stable position for an antenn a is along the spin axis. Thus, a critical parameter in the trajectory design process is the angle between the spin axis and the Earth direction. Since Pathfinder uses a shallow, zero angle of attack entry profile, the spin axis at entry is parallel to the velocity vector and nearly perpendicular to the radius vector. During parachute descent, however, the spin axis (and velocity vector) is parallel to the radius vector. This changing geometry makes entry communications extremely difficult, The entry velocity vector (and thereby the approach v-infinity vector) must be carefully selected to improve the likelihood of maintaining the link throughout entry. The post-landed Earth geometry is also important because the project wants to perform as many activit ics as possible during the first day. This means that the landing time should be selected to maximize the number of hours of remaining Earth and Sun visibility. The implication of this requirement is that the, v-infinity vector must be selected so that landing occurs near the morning terminator, Some additional lower priority requirements on the interplanetary trajectory design include minimizing the Sun-Probe-llarth angle during cruise (high SPE angles cause power problems because the spacecraft solar arrays arc pointed towards the Earth), and minimizing the Earth-Mars range at landing (this improves telecommunications system performance). 'The ent ry velocit y for Pathfinder is not a strong driver on the interplanetary trajectory design because the spacecraft has been designed to withstand a high heating rate. Minimizing the entry velocity is a low priority objective, however, because it will reduce overall mission risk,

The problem of locating a set of trajectories which satisfy all of these constraints is non-trivial. The approach that has been adopted is to look at al 1 possible Earth-Mars trajectories in a paramet ric sense. Fortunatel y, t he requirements on short flight t imes and ballistic trajectories mean that only standard Type 1 and Type 2 transfers need to be considered. Complete launch date/arrival date parametric studies can be performed on these trajectories by using patched conic approximations. Figure 5 shows the results of onc particular trade study, in which the Earth geometry at entry and landing have been calculated for a range of possible launch and arrival dates. The trajectories shown here arc Type 2 transfers with posigrade landing. Posigrade landing occurs if the approach hyperbola has a II-plane angle Θ between 270° and 3600 or 0° and 90°. Retrograde landings correspond to B-plane angles between 90° and 270°. A given Latitude can be with either a posigrade or retrograde landing, but the resulting Sun/Earth geometry is different, One set of contours gives the number of hours left after landing before the Earth sets. The other set shows the angle between the Earth and the spacecraft spin axis at entry. Note that to get more time on the ground after landing, the Earth-spin axis angle must increase. "J'bus, a trade-off exists between entry communications and first day activities. Additional contour curves arc given to show the variations in launch C_3. Figure 6 shows the results of a similar trade study for Type 1 trajectories with retrograde arrivals. In this case, contours arc give.n for the number of hours before Earth rise (since landing **occurs** slightly before Earth rise assuming a 200 horizon mask).

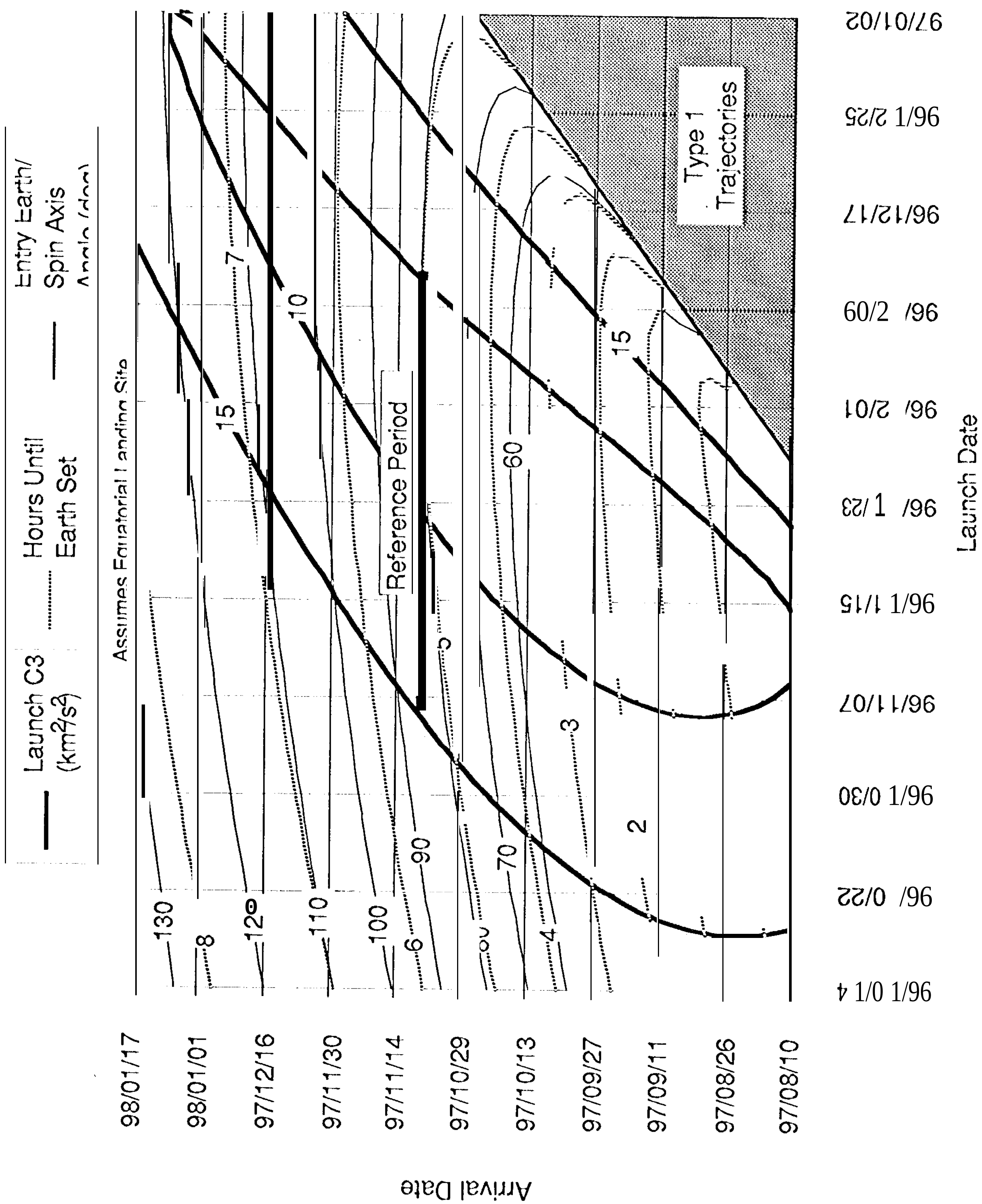


Figure 5. Type 2 Launch/Arrival Space

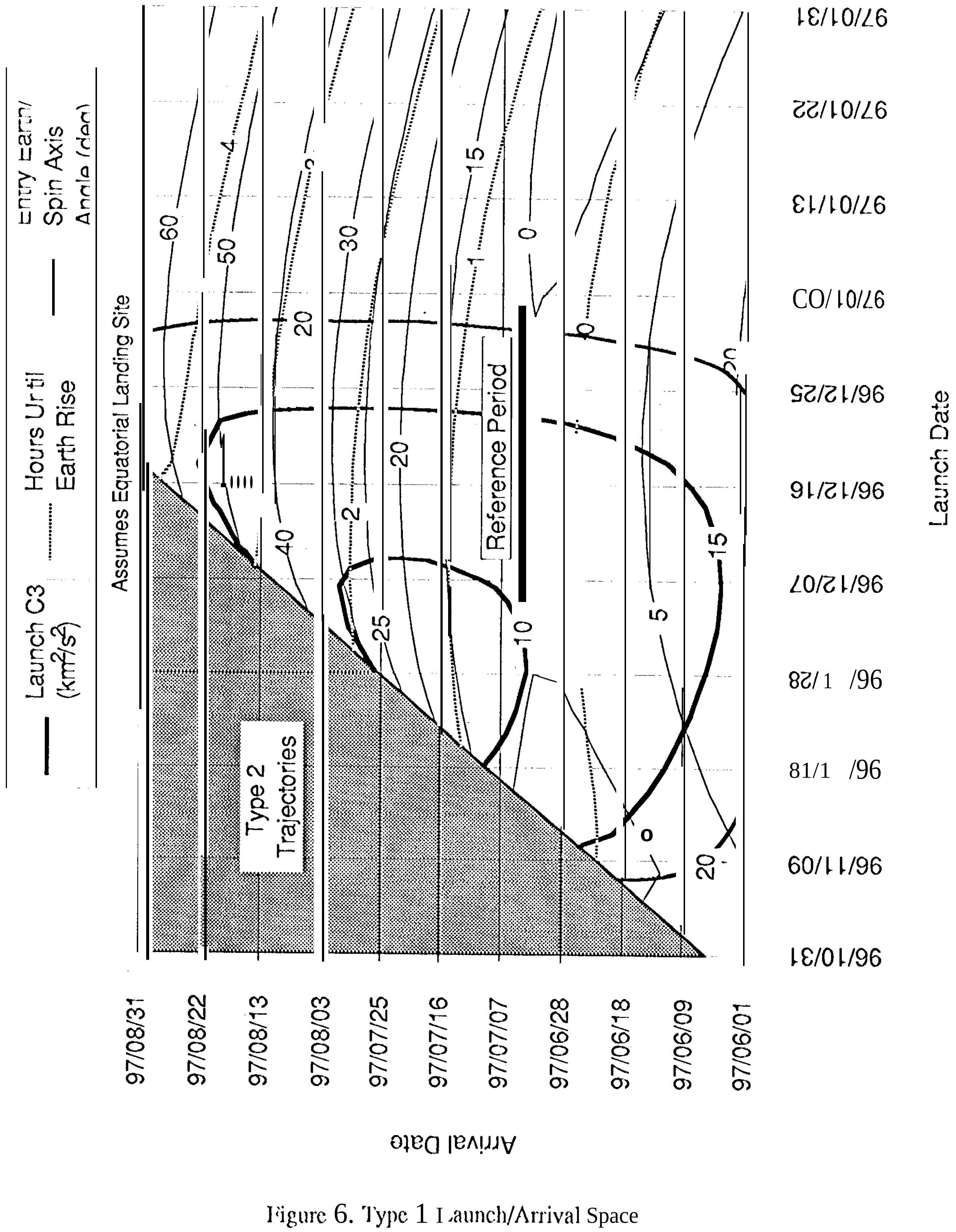


Figure 6. Type 1 Launch/Arrival Space

Two potential sets of interplanetary trajectories were identified as a result of these parametric studies. One set are late Type 2 transfers, with launch dates in November/December 1996 and arrival cm November 10, 1997. Figure 5 shows the locat ion of these trajectories in launch/arrival space. The primary advantages of this design include low launch energy (maximum ~~of15.5 km^2/s^2), low Earth-spin axis angle during parachute descent (120), long Earth visibility period after landing (5.5 hours), and low entry velocity (6.25 km/s). The disadvantages arc a long relative flight time (12 months), high Earth-spin axis angle at entry (83°), high Sun-Probe-Earth angle near launch, and large Earth-Mars range at arrival (~300 million km). The large entry Earth-spin axis angle is a major spacecraft design driver because the antennas m ust be able to communicate 83° off boresight. The other set of possible trajectories are early Type 1 transfers, with launch dates in December 1996 and January 1997, and arrival on Jul y 4, 1997. Figure 5 shows the location of these trajectories in launch/arrival space. The primary advantages of this design include short flight time (6-7 months), low launch declinations (<150), low Earth-spin axis angle at entry (80), long Earth visibility after landing (30 minutes until Earth rise, followed by 12 hours of visibility), and small Earth-Mars range (200 million km) at arrival. The di sadvantages arc high launch energy (maximum C_3 of 21.5 km^2/s^2), high entry velocity (7.4 km/s), and large Earth-spin axis angle during parachute descent (780). The Delta is capable of launching about 700 kg at this C_3 (including two daily launch opportunities separated by 30 minutes). This is mom than enough gi ven the current spacecraft mass of about 560 kg. The higher entry velocity causes somewhat higher heating, but well within the ablative capabilities of the entry aeroshell. The onl y serious disadvantage is the high Earth-spin axis angle during parachute descent. Unfortunately, this angle is always going to be large when the entry Earth-spin axis angle is small. Figure 7 shows a schematic of the change in Earth-spin axis angle during entry and descent for a sample Type 1 trajectory. The project has decided to emphasize early descent communications over parachute descent, so the Type 1 trajectory has been selected as the project base.tine.

Entry Profile Desi gn

The one remaining area of pathfinder mission design activity to discuss is the entry profile design. The entry profile dots not drive the interplanetary trajectory selection, but it presents a set of unique mission design problems. The primary parameters that effect the entry profile are the entry velocity, the ballistic coefficient, the parachute deployment conditions, and the entry angle. The maximum entry velocity for the reference Type 1 trajectory set is 7.4 km/s (inertial) at an altitude of 125 km. The atmosphere relative entry velocity is about 0.25 km/s faster because entry occurs on the, retrograde or upwind side of the planet. The ballistic coefficient is determined by the entry mass, the diameter of the aeroshell, and the drag coefficient. Pathfinder uses a Viking-like. blunt cone aeroshell with a hypersonic drag coefficient of 1.7. The Pathfinder aeroshell is constrained to a maximum size of 2.65 m by the Delta payload fairing. This combined with an entry mass of 438 kg gives a ballistic coefficient of about 47 kg/m^2 (for comparison, the ballistic coefficient for Viking was around 62 kg/m^2). Pathfinder is also planning to use a Viking-1ike disk gap band parachute to slow the descent to a terminal velocity of about 60 m/s. This parachute is designed to open at a dynamic pressure of 660 N/m^2. The entry angle mus(be selected so that this dynamic pressure occurs at a sufficiently high altitude to allow full parachute inflation and deceleration before reaching the ground. The maximum landing site altitude for Pathfinder is 2 km, and approximately 4-5 km of altitude buffer is needed to insure safe deployment. Consequently, the minimum allowable deploy altitude is 6-7 km. Figure 8 shows a parametric analysis of parachute deploy altitude for (he low density COSPAR

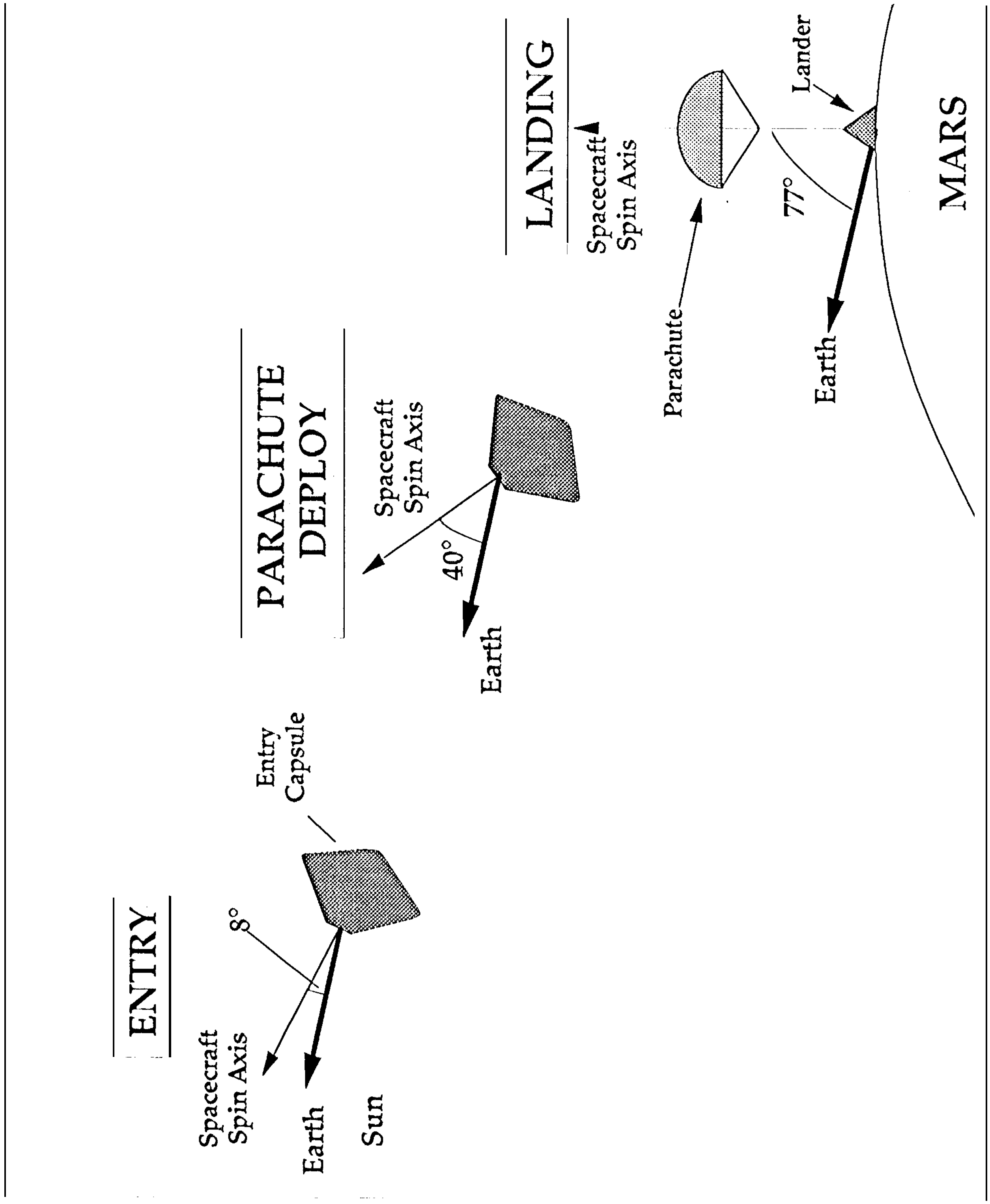
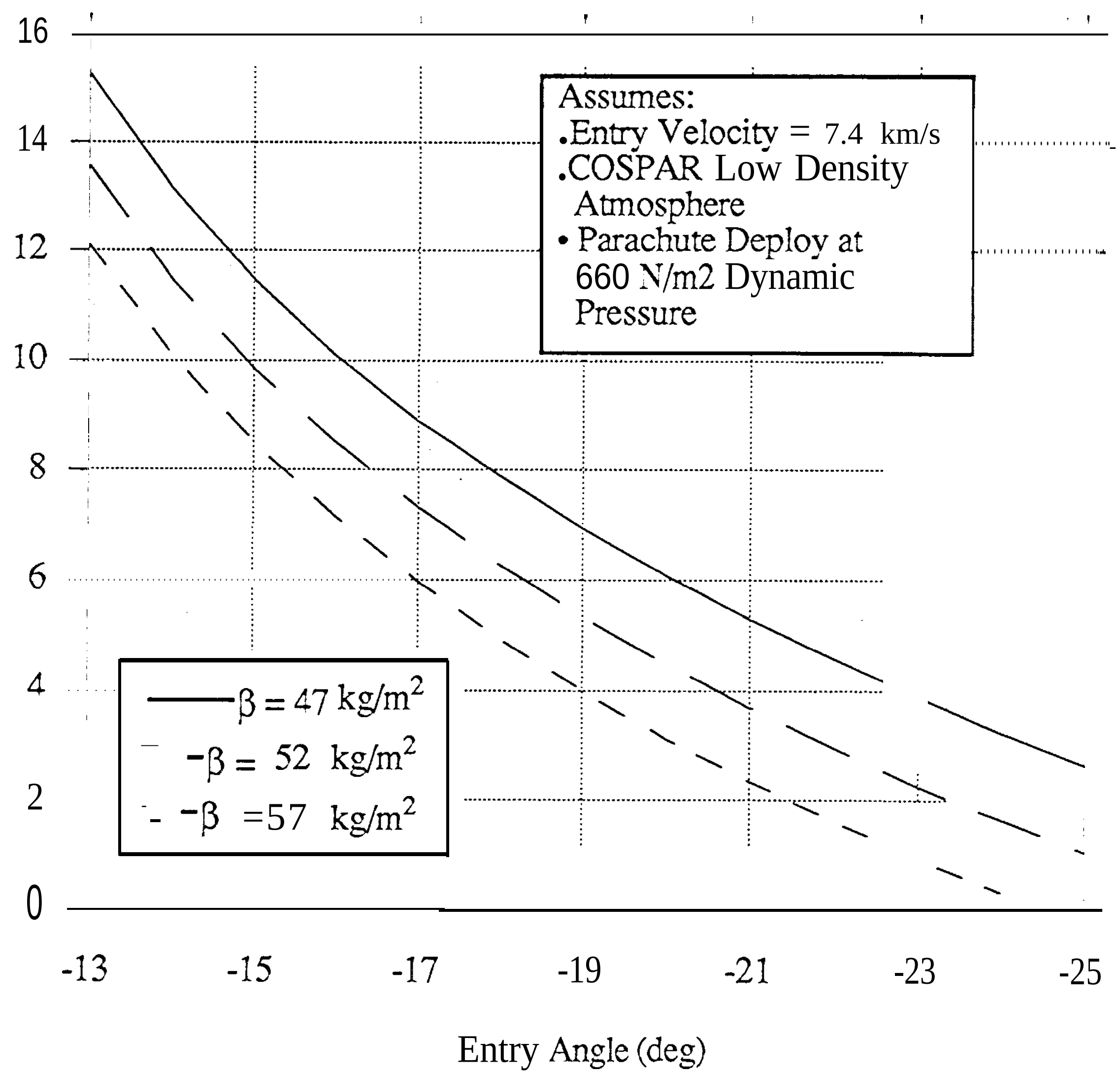


Figure 7. llarlh/Spacecraft Geometry During Entry



igure 8. Parachute Deploy Parametrics

atmosphere as a function of entry angle. The nominal entry angle for Pathfinder is 18°. Curves for higher ballistic coefficients than 47 kg/m^2 arc also given to show that the entry must become shallower if the mass increases (Viking used an entry angle of about 13° because of the large ballistic coefficient). Unfortunately, the ability to target the landing site accurately degrades significant] y as the entry angle decreases. Figures 9 and 10 show the variations in altitude and velocity for the reference Pathfinder entry profile. The entire entry takes approximately four minutes, with parachute deploy occurring after 100 seconds.

CONCLUSIONS

The MESUR mission represents the next major step in the continuing exploration of Mars. The complexity of the objectives and extreme cost constraints on the network mission drive the need for a mission architect ure that opt imizes the overall science and mission return. Mission design is an especially important element in developing such an architecture. Fortunately, a significant amount of design flexibility is possible in both the interplanetary trajectory design and end-to-end mission profile. MESUR Pathfinder is a near term engineering mission that will help validate and accelerate the network, Satisfying the rapid development schedule for Pathfinder hinges on early development of an end-to-end mission scenario. Detailed analysis has been performed over the last year to identify a launch strategy for the Delta II vehicle, an interplanetary trajectory design which satisfies all the project and spacecraft constraints, and an entry profile which permits safe delivery of the lander to the surface of Mars.

ACKNOWLEDGMENTS

The research described in this paper was performed by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

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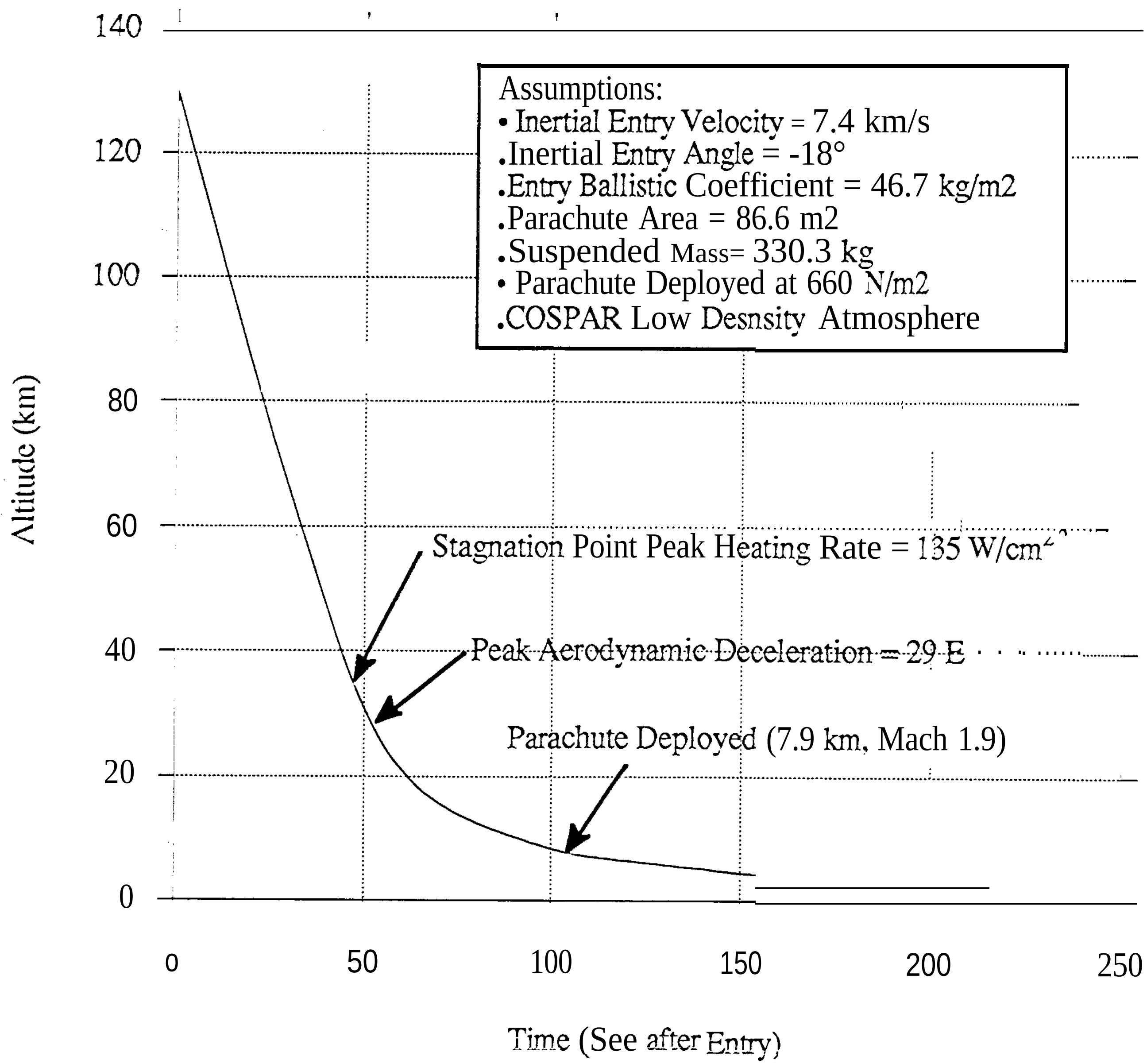

igure 9. Altitude versus Time for Nominal Entry Profile

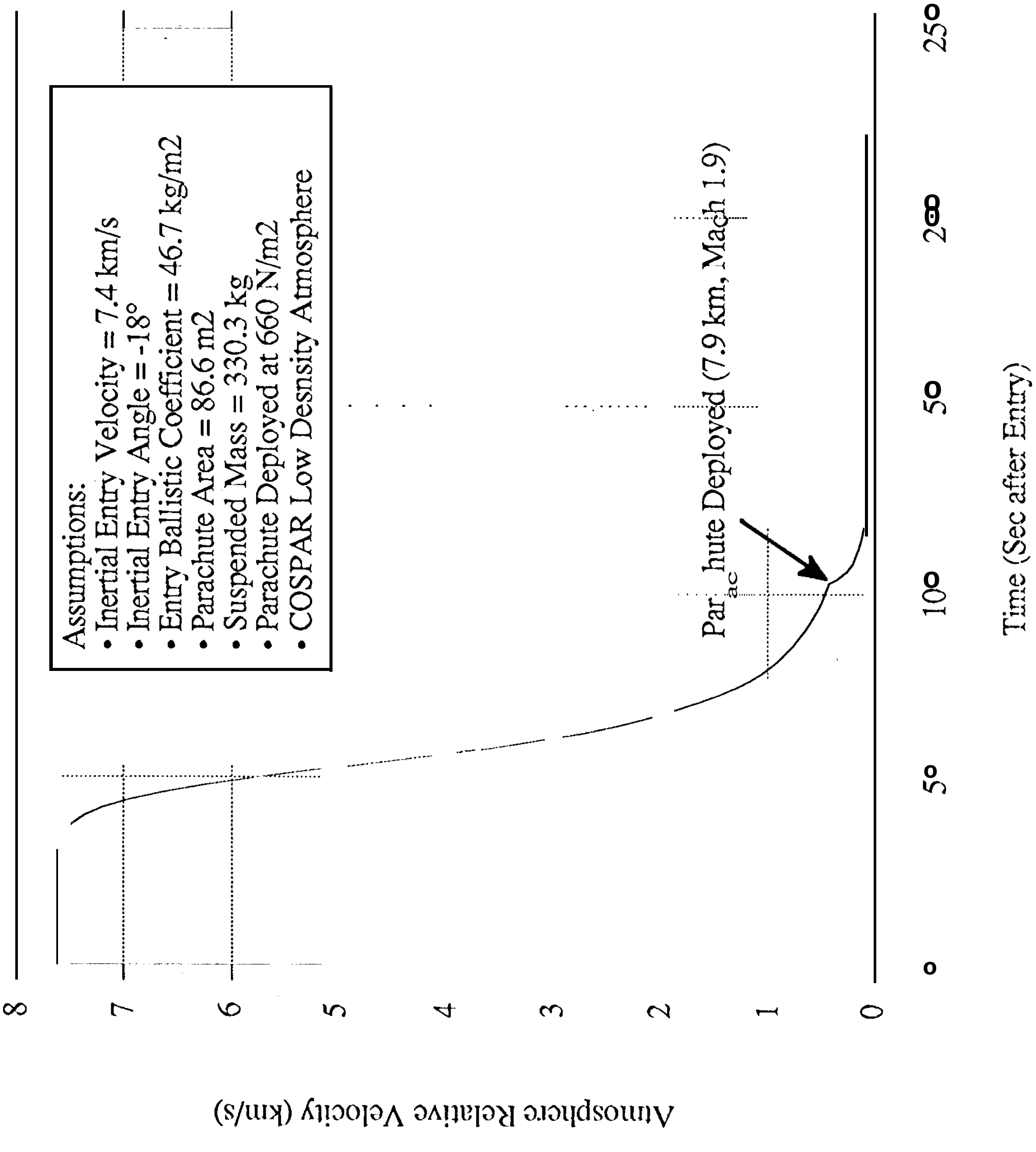

Figure 10. Velocity versus Time for Nominal Entry Profile