STARDUST

MISSION PLAN

February 1, 1999

Jet Propulsion Laboratory
California Institute of Technology

SD-75000-100-Revision A

JPL D-300-1-Revision B

STARDUST

MISSION PLAN

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SD-75000-100-Revision A

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List of Acronyms and Abbreviations

β	Beta
ΔV	Delta-Velocity
λ	Wavelength
μm	Micrometer
#	Number
A-h	Ampere-hour
Acq	Acquisition
ACS	Attitude Control System
AD	ER Arrival Date
Alt	Altitude
ARIA	Advanced Range Instrumentation Aircraft
AU	Astronomical Unit
bps	Bits Per Second
C3	Injection Energy Per Unit Mass
cc	Cubic Centimeters
CCD	Charge Coupled Device
C&DH	Command and Data Handling
CIDA	Cometary and Interstellar Dust Analyzer
cm	Centimeter
CMD	Command
conj	Conjunction
cos	Cosine
COSPAR	Committee On Space Research
d	Day
D	Dimension
Dap	Declination, approach
dB	Decibel
Dec	Declination
deg	Degrees
DFMI	Dust Flux Monitor Instrument
DSM	Deep Space Maneuver
DSN	Deep Space Network
DST	Deep Space Transponder
E, Enc	Encounter, Wild-2
Ear	Earth
EE	Earth-Earth
EGA	Earth Gravity Assist
EGAD	Earth Gravity Assist Date
eng	Engineering
EPS	Electrical Power System
ER	Earth Return
ET	Ephemeris Time
EW	Earth-Wild-2
FOV	Field Of View
fps	Feet Per Second
ft	Feet
g	Grams
g	Unit Of Acceleration Equal To Earth's Gravity
GCR	Galactic Cosmic Ray
Ghz	Giga-hertz
h	Altitude
h	Hour
HEF	High-Efficiency
HGA	High Gain Antenna
img	Image
IMU	Inertial Measurement Unit
ISC	Current, Short Circuit
ISP	Interstellar Dust Particle
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center

kg	Kilogram
km	Kilometer
L	Launch
L/O	Liftoff
lb	Pound
lb-f	Foot-Pound
LD	Launch Date
LGA	Low Gain Antenna
LMA	Lockheed Martin Astronautics

List of Acronyms and Abbreviations (cont)

m, min	Minute
m, M	Meter
mag	Magnitude
max	Maximum
MECO	Main Engine Cutoff
MEL	Mass Element List
mem	Memory
MeV	Million Electron Volts
MGA	Medium Gain Antenna
mm	Millimeter
MSL	Mean Sea Level
ms	Millisecond
N	North
NASA	National Aeronautics and Space Administration
Nav	Navigation
NCS	Nutation Control System
nmi	Nautical Miles
OD	Orbit Determination
OPNAV	Optical Navigation
opp	Opposition
Pmax	Potential, refers to Open Circuit Voltage
PMS	Power Management Subsystem
R	Unit Vector Along Sun-Target Body Line
Ra	Right Ascension
Rap	Right Ascension, approach
Rcvr	Receiver
RDM	Radiation Design Margin
Re	Range, Earth
Req’d	Required
RFS	Radio Frequency System
RPM	Revolutions Per Minute
Rs	Range, Solar
s, sec	Second
seg	Segment
S	South
S	Unit Vector Orthogonal To R, In Direction Of Target Body Velocity
S/A	Solar Array
S/C	Spacecraft
SECO	Stage II Engine Cutoff
SRC	Sample Return Capsule
SRM	Solid Rocket Motor
SSPA	Solid-State Power Amplifier
t	Time
T	Out Of Plane Unit Vector
TBD	To Be Determined
TBR	To Be Resolved
TCM	Trajectory Correction Maneuver
TP	Time Of Perihelion Passage

UHF	Ultra High Frequency
UTTR	Utah Test and Training Range
v	Velocity
VEGA	Soviet Mission to Venus & Comet Halley (1984-6)
Vhp,b	Velocity, hyperbolic, approach
VOC	Voltage, Open Circuit
W	Watts
w, wk	Week
W2	Wild-2, comet
WE	Wild-2-Earth
WRT	With Respect To
yr	Year

Change Log

Change Letter	Date	Affected Sections
Original Issue	10/7/1995	All
Revision A	1/28/1997	All
Revision B	2/1/1999	1.1, 1.2, 1.3, 2.2.1, 2.2.2.x, 2.3.1, 2.3.2.1, 2.3.2.2, 2.4.1, 2.4.2.1, 2.4.2.3, 2.4.3, 2.4.4*, 3.2, 3.3, 3.4, 4.1, 4.2, 4.2.x*, 4.3, 5.1, 5.2, 6.1, 6.2.2.1, 6.2.2.3*, 6.2.4, 6.3, 7.1, 7.2.1.1, 7.2.2, 7.3*, 9.2, 9.3, 10.x*, 11.x*, 12.x*, 13.0* (see change paper XF0236) * includes new sections

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1.0 Introduction

1.1 Purpose

The purposes of this document are to:

1. Provide a detailed description of the current STARDUST mission plan which constitutes the basis for flight system design and mission operations,

2. Illustrate that the STARDUST mission has been designed to fulfill the primary science objectives and maximize the secondary science objectives, and

3. Show that the planned mission adheres to the “design-to-cost and capability” paradigm and represents a balanced plan where the science goals and the current flight system capabilities are in good agreement.

The plan described herein is considered as the basis for the development of flight systems and the mission operations plan to be implemented in the project phases C/D, and E.

1.2 Scope

This document presents the baseline, end-to-end, mission scenario and is a source for establishing spacecraft performance and mission operations requirements. Although the mission architecture has considered mission parameters and profiles corresponding to a proposed 20-day launch period, the specific events and mission timelines presented herein are corresponding primarily to the first launch date, 06 February 1999. Some details will become obsolete if the launch should occur on another day. An update to selected portions of this mission plan is envisioned within a month of launch. This update will reflect changes to the mission plan as a function of the actual launch date.

Future changes, needed as project system definitions mature, will be introduced under a formal mission plan change control procedure.

1.3 Relationship to Other Documents

This version of the Mission Plan is consistent and responsive to the requirements, objectives, and detailed plans described in the following documents:

STARDUST Project Management	SD-10000-110
Project Requirements	SD-30000-200
Science Requirements	SD-40000-200
Flight Systems Requirements	SD-62000-200
STARDUST Design Reference Mission	SD-62400-300
STARDUST Sample Return Capsule Recovery Operations Plan	SD-73110-100
Navigation Plan	SD-76000-100

Mission Operation & Ground Data Systems Plans	SD-72000-100
Wild-2 Flyby Targeting Plan	SD-77000-300
STARDUST Mission Environmental Assessment	JPL-D-14159

2.0 Mission Overview

2.1 Mission Objectives

The primary science goal of the STARDUST mission is to collect comet Wild-2 coma samples, plus bonus interstellar dust samples, in an aerogel medium, and return them to Earth. Additional science return is anticipated in the form of images of the comet coma and nucleus, Comet and Interstellar Dust Analyzer (CIDA) based dust particle analysis and dust flux monitoring.

These science goals lead to the following objectives in the design of the STARDUST mission:

- Provide a flyby of a comet of interest (Wild-2) at a sufficiently low velocity (less than 6.5 km/s) such that non-destructive capture of comet dust is possible using an aerogel collector.

- Facilitate the intercept of significant numbers of interstellar dust particles using the same collection medium, also at as low a velocity as possible.

- Return as many high resolution images of the comet coma and nucleus as possible, subject to the cost constraints of the mission.

More specific definition of the science objectives can be found in Section 2.4 Science Investigation Descriptions.

2.2 Project System Descriptions

2.2.1 Launch Vehicle

The launch vehicle for STARDUST is a Boeing Delta II 7426. Given its four solid rocket motors and a Star 37FM upper stage without a Nutation Control System (NCS), thermal barrier or despin add-ons, it is capable of delivering 396 kgs at a C3 of 26 km^2/s^2. Figure 2.2-1.a shows the STARDUST spacecraft configuration while inside the launch vehicle and Figure 2.2-1.b shows the launch vehicle itself.

2.2.2 STARDUST Spacecraft

2.2.2.1 General Configuration

STARDUST is a 3-axis stabilized spacecraft designed to perform its prime mission (Wild-2 encounter) at 1.9 AU from the sun and 2.6 AU from the Earth. During the cruise periods to and from this encounter, it must be able to function adequately at a maximum distance of 2.7 AU from the sun and 3.6 AU from the Earth.

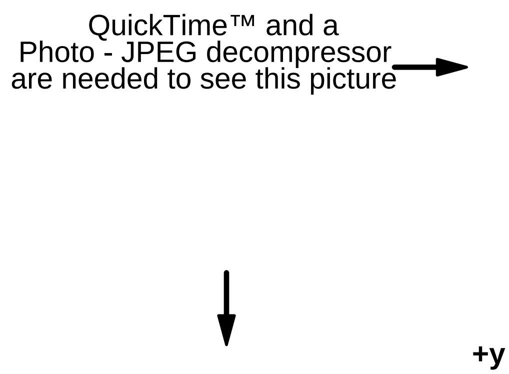


Figure 2.2-1.a STARDUST Configuration in Launch Vehicle

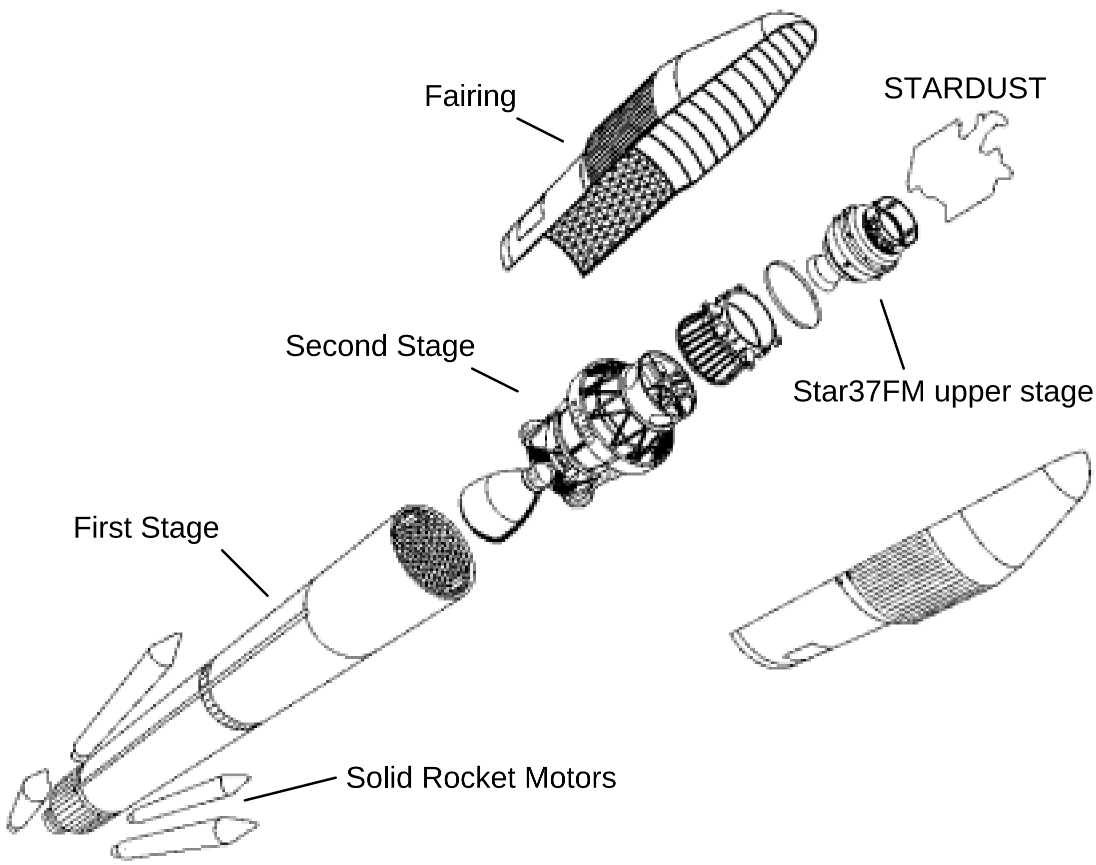


Figure 2.2-1.b Boeing Delta II 7426

The spacecraft, shown in Figure 2.2-2 in its encounter configuration, is equipped with a power subsystem, fixed solar panels and one rechargeable battery, capable of delivering a minimum of 170 watts (W) during standard cruise operations at aphelion and a minimum of 300 W at comet encounter. The solar panels have a maximum off-sun pointing constraint of 60° to avoid problems caused by refraction of light.

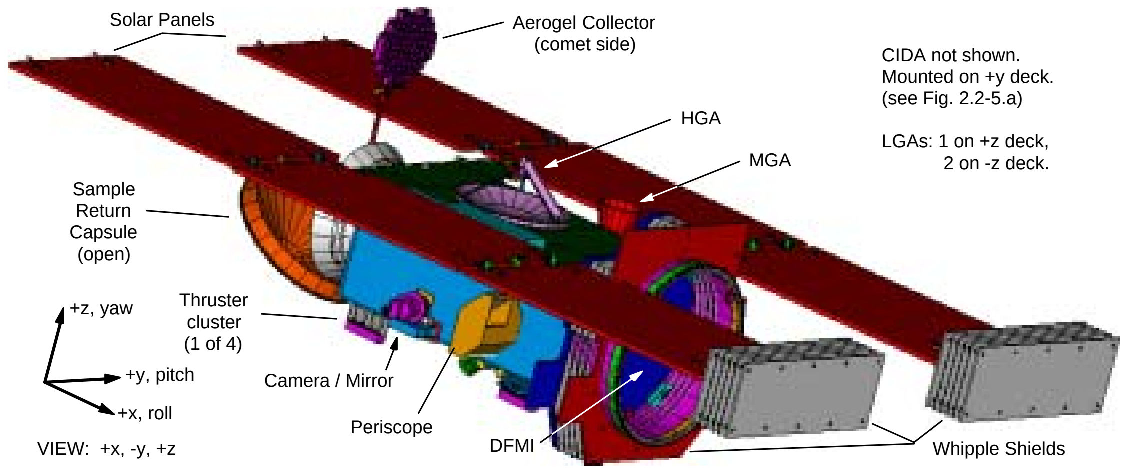


Figure 2.2-2 STARDUST Configuration during Encounter

Communications are achieved via either a high-gain, medium-gain or one of three low gain antennas. During the mission, Deep Space Network (DSN) support will be provided with primarily 34-m antennas with 70-m support being used during the close comet encounter. These antennas provide the capability for a minimum of 4000 bits per second (bps), 7900 bps expected, at encounter via the high-gain antenna and a 70-m DSN station and 40 bps at maximum Earth range via the medium gain antenna and a 34-m DSN station. The low-gain antennas, in conjunction with a 34-m DSN antenna, are ideal for near-Earth phases (Launch, Earth flyby and Earth return) when Sun-Earth-spacecraft angles are near 90°, especially since they can support communications within 0.05 AU (+3 dB margin) of the Earth at a minimum data rate of 40 bps. Antenna locations and fields-of-view are as described in Figure 2.2-2.a.

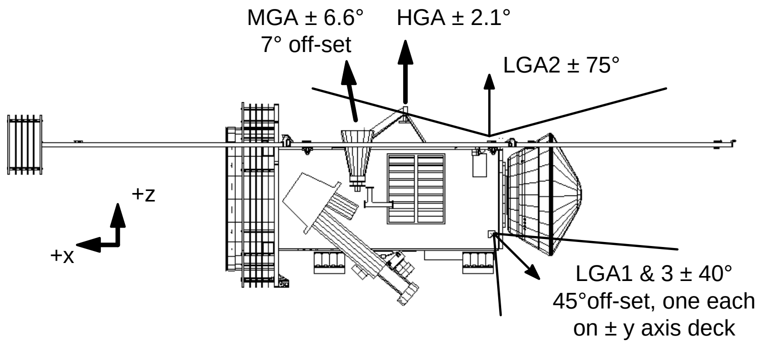


Figure 2.2-2.a Spacecraft Antennas Fields-of-View

Attitude control and propulsive maneuvers are performed using a redundant helium-fed mono-propellant (hydrazine) propulsion subsystem. The subsystem is comprised of one titanium propellant tank and a total of 16 thrusters (two strings of 8), all mounted on the lower deck of the spacecraft (opposite the high-gain antenna and solar panels - pointing toward the -z-axis of the spacecraft). Eight of these are 0.2 lb-f thrusters and are used primarily for attitude control. The other eight are 1.0 lb-f thrusters and are used for propulsive maneuvers. To avoid potential contamination of the aerogel collector, placement of thrusters on the upper deck (+z) is avoided. This configuration, however, generates uncoupled thrusts during attitude control burns and adds complexity to trajectory simulations.

The normal spacecraft attitude during the mission points the +z-axis of the spacecraft to the sun. Deviations from the normal attitude are performed during communication periods and delta-velocity (ΔV) burns. Off-sun pointing is also permitted during non-primary science experiments, CIDA and Interstellar Dust Particle (ISP) collection, as long as the power generated by the solar arrays is adequate at the desired off-sun angle. During the comet encounter period, the +x-axis is pointed to the dust stream.

Also visible in Figure 2.2-2 are the main bus and solar panel whipple shields. These shields are placed on the spacecraft to protect it from high velocity dust impacts during comet encounter. The barriers are designed to stop a 1 cm size particle traveling at 6 km/s (which is essentially equal to the comet encounter relative velocity).

Science objectives are met using three science subsystems: Aerogel Dust Collector and Sample Return Capsule (SRC), Cometary and Interstellar Dust Analyzer (CIDA) and the Dust Flux Monitor Instrument (DFMI). The imaging camera is also used for science purposes but its main function is to perform optical navigation prior to encounter with comet Wild-2.

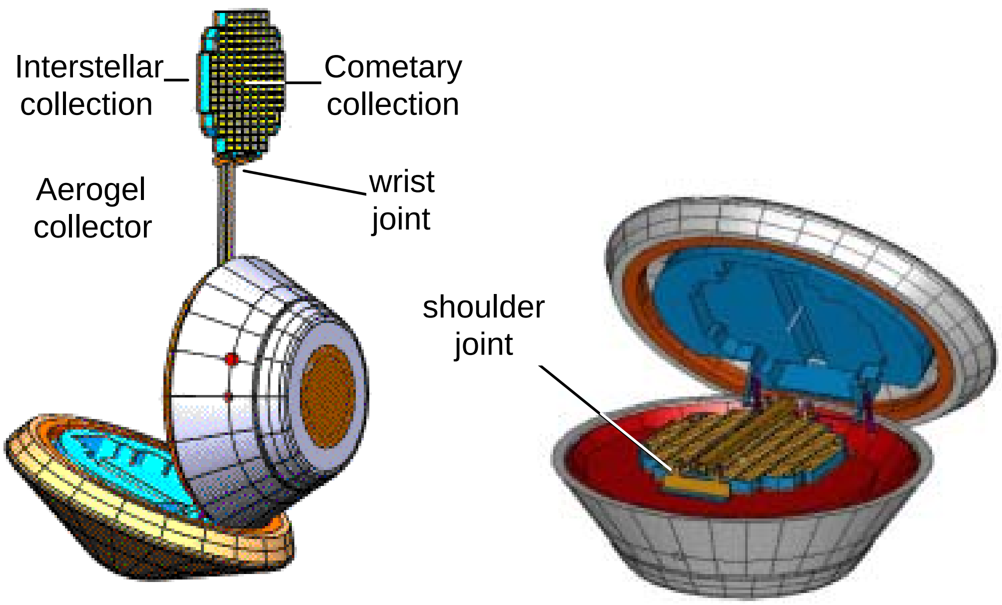
The current best estimate of the mass breakdown of the flight system is summarized in Table 2.2-1. It should be noted that this table is provided for illustrative purposes and is subject to change as per updates to the Mass Element List (MEL). Table 2.2-1 is based on Revision Z.

Table 2.2-1 STARDUST Mass Element List (Rev. Z)

Component	Mass (kg)	Component	Mass (kg)
S/C Power	33.378	Navigation Camera	12.686
S/C Harness	20.971	DFMI	1.530
S/C Telecom	19.222	CIDA	10.966
S/C ACS	9.951	SRC Avionics	1.992
S/C C&DH	10.394	SRC Harness	0.869
S/C Thermal	10.060	SRC Thermal	13.683
S/C Structures	104.412	SRC Structures	9.271
S/C Mechanisms	6.131	SRC Mechanisms	17.184
S/C Propulsion	19.538	SRC Parachute	4.194
Pressurant (He)	0.202	Total Dry	305.397
Propellant	85.000	Total Wet	390.599

2.2.2.2 Aerogel Collector

Capture of cometary and interstellar dust particles is performed using the Aerogel Dust Collector. The aerogel collector allows collection from both sides. Figure 2.2-3.a shows the aerogel collector fully deployed from the SRC canister. In the figure, the visible side of the collector is used for cometary dust collection while the hidden side is used for interstellar dust collection. The total collection area per side is required to be greater than 1000 cm^2. Stowing of the collector is achieved by first folding the collector grid onto the boom via the wrist joint and then folding the boom/collector into the SRC canister via the shoulder joint as shown in Figure 2.2-3.b



a. deployed b. stowed

Figure 2.2-3 Aerogel Collector

This deployment mechanism is the key in maximizing the amount of time available for the capture of interstellar dust particles. The mechanism allows the collector to be steered via the wrist joint about the spacecraft y-axis toward the -z-axis. The collector field-of-view remains unobstructed by the SRC backshield for 51° of this motion, half the grid is in shadow at 63°, and all of the grid is in shadow at 75°. This deployment geometry is illustrated in Figure 2.2-3.c. Note that for the shadow definition, the ISP stream is assumed to be incoming perpendicular to the aerogel grid. It is worth noting that the collector field-of-view would remain completely unobstructed for 65° of the motion should the shoulder joint be used during interstellar dust particle collection. However, usage of the shoulder joint with the collector fully deployed is considered to be an unnecessary risk. A description of the ISP collection strategy is provided in Section 4.2.1 Interstellar Particle Collection Subphases.

2.2.2.3 Imaging Camera

The STARDUST camera is necessary to perform the optical navigation (OPNAV) that is required to achieve a flyby accurate enough to assure adequate comet dust collection. This camera also provides the capability to obtain high-resolution images of the comet coma and comet nucleus during the close encounter. The imaging camera is Milstar/CASSINI-inherited with the following characteristics:

CCD: 1024 x 1024 pixels, 12 bits/pixel	Focal ratio: f/3.5
Pixel Size: 12 μmeters	Shutter speeds: 5ms - 10s, 5ms steps
FOV: 3.5°	Readout time: ~3 sec
Pixel FOV: 60 μradians	Number of Filters: 8
Focal length: 200 mm	Spectral range: 380 - 1100 nm

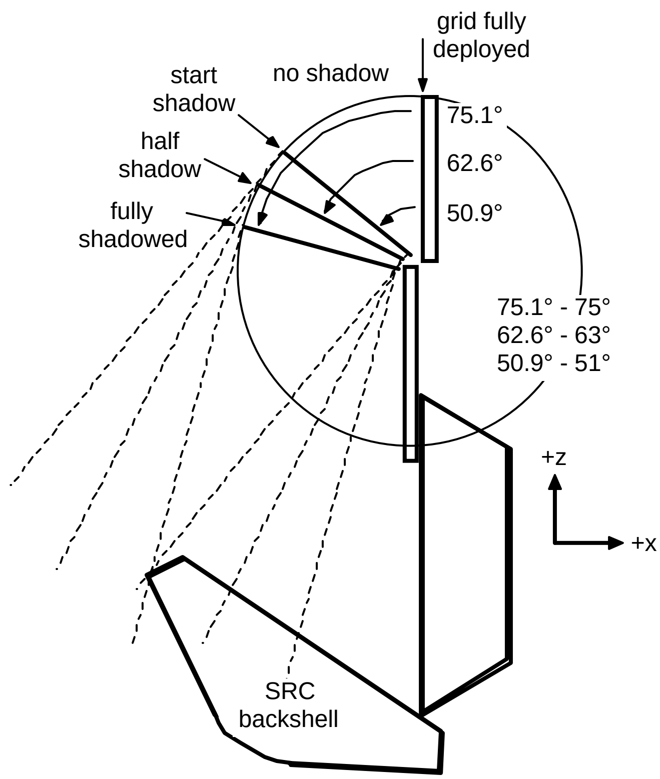


Figure 2.2-3.c Aerogel Grid Deployment Geometry

The camera, shown in Figure 2.2-4, is equipped with a one-axis movable mirror which allows for image smear compensation during cometary encounter. In addition, a periscope is introduced into the optical path while imaging through the dust shields to protect the camera optics in the cometary dust environment.

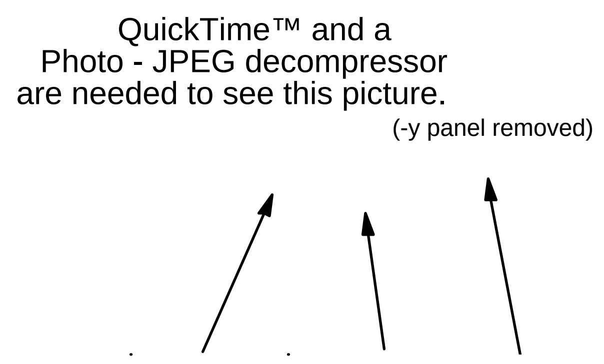


Figure 2.2-4 Imaging Camera

2.2.2.4 Cometary and Interstellar Dust Analyzer (CIDA) and Dust Flux Monitor Instrument (DFMI)

The Cometary and Interstellar Dust Analyzer (CIDA), a time-of-flight mass spectrometer, and the Dust Flux Monitor Instrument (DFMI) are shown in Figure 2.2-5.a. These instruments are mounted on the spacecraft such that their line of sight is in the same direction as the comet side of the aerogel collector (i.e. toward the spacecraft +x-axis).

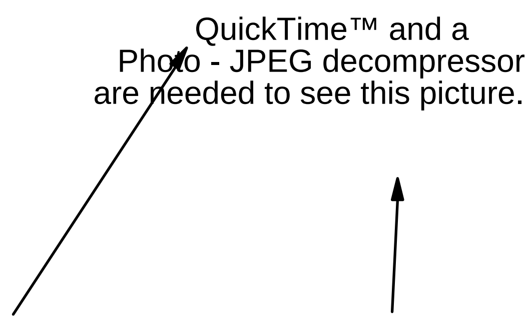


Figure 2.2-5.a. CIDA and DFMI

Without consideration of spacecraft obstructions, the field-of-view of CIDA's target surface is a 180° hemisphere. However, once mounted on the spacecraft, the CIDA field-of-view is smaller, as described in Figure 2.2-5.b. Constrained by the dust shield and spacecraft bus in the +z axis direction, the field-of-view spans 52° in the x-z plane. Along the y-axis (in and out of the page), the field-of-view is limited only by the fact that the particles must impact the target surface, which is recessed, to be analyzed.

The science investigations that use these instruments will take opportunistic observations of the comet and interstellar dust. Their observing periods are mainly constrained by available spacecraft power. CIDA operation, however, is also constrained by the need to maintain sunlight off the target surface while CIDA is powered on.

The CIDA sun avoidance constraint (which includes scattered and reflected light) is applied to the mission design as shown in Figure 2.2-5.b. In defining the constrained regions, it is assumed that sunlight cannot penetrate from the +z-axis side of the spacecraft bus to the -z-axis side, sunlight cannot penetrate through the dust shield and there are no gaps between the two. It is also assumed that the CIDA target is recessed into the target block such that the small region (1.6° in size) in the -x/+z quadrant of the figure is too small for the sun to hit the target. The sun avoidance region thus becomes the same as the CIDA field-of-view and, in light of the maximum solar array off-point angle of 60°, it is concluded that sun avoidance is of no major concern during standard operations. In fact, it should only be of concern during extreme off-pointing as may be expected during propulsive maneuvers.

It must be noted that the CIDA field-of-view, as per the current Project Requirements Document, is only required to be 20° in size. The field-of-view as described in this

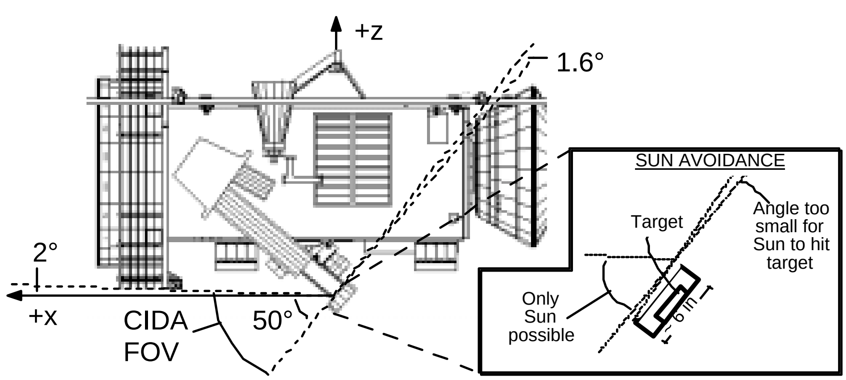


Figure 2.2-5.b. CIDA FOV and Sun Avoidance

document is what is available given the current spacecraft configuration as of the publishing of this document and should not be interpreted as a requirement on spacecraft design.

2.2.2.5 Sample Return Capsule (SRC)

The Sample Return Capsule is mounted along the -x-axis of the spacecraft. It is a key component that allows successful return of the cometary samples to Earth. Shown in Figure 2.2-6, there are four main components to the SRC: the avionics, the aeroshell (backshell and heat shield), the sample collector, and the parachute system.

The avionics design includes a UHF locator beacon that will be used as an SRC location aid for the ground recovery team. The beacon is activated upon main chute deployment. It is powered by a set of primary cell lithium sulfur dioxide batteries. Lithium sulfur dioxide was selected because of its long shelf life, tolerance to wide temperature variations, and handling safety. These batteries have enough capacity to operate the beacon for 40 hours. Additional SRC tracking is provided by skin tracking from two C-band radar sites at the Utah Test and Training Range (UTTR) landing site. A mylar target mounted on the main chute provides an equivalent one square meter of radar cross section.

The aeroshell is used to remove over 99 percent of the initial kinetic energy of the vehicle and protect the sample canister against the extreme aerodynamic heating of atmospheric entry. The heat shield is a 60° half angle blunt cone made of a graphite/epoxy composite covered with a thermal protection system. Ablative material is also applied to the backshell to protect the capsule from the effects of recirculation flow.

During the entry and descent phases, a G-switch initiated timer with backup pressure sensors provides the required parachute deployment timing. The parachute system incorporates a drogue and main chute into a single parachute canister. The parachute canister contains a mortar tube that holds the drogue chute. A gas cartridge is housed outside the canister and is used to pressurize the mortar tube and expel the drogue chute. The drogue chute is used to stabilize the descending SRC through the transonic and subsonic atmospheric regimes. The drogue is discarded using one of two redundant cutters, extracting the main chute as it moves away from the SRC. Upon ground impact, a cutter in the riser of the main chute is commanded by a G-switch, separating the main chute from the SRC to prevent surface winds from dragging the SRC across the ground.

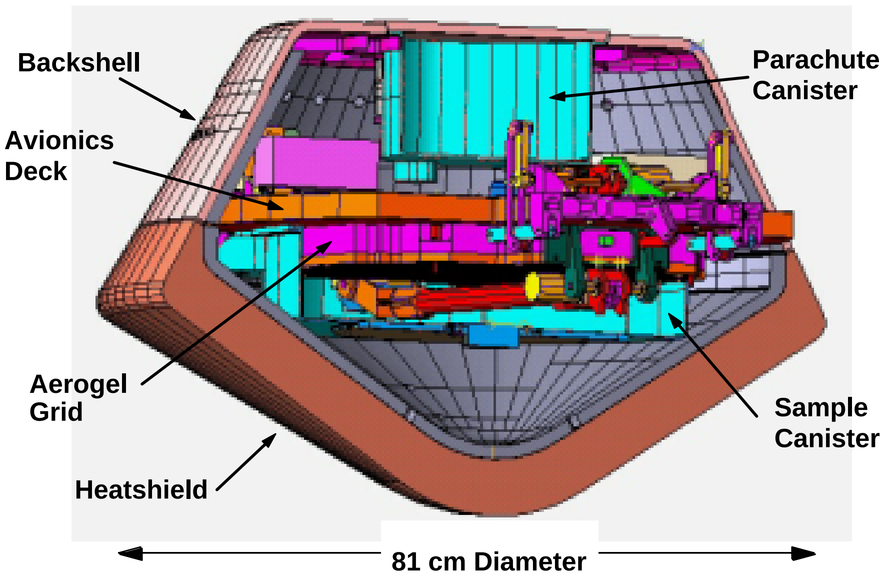


Figure 2.2-6 Sample Return Capsule

2.3 Mission Summary

2.3.1 Description

Trajectory: The STARDUST mission is designed for a low velocity (6.1 km/s) flyby of comet Wild-2 during its active period (at a solar distance of 1.9 AU) and to have a low energy Earth returning trajectory. Figure 2.3-1 shows the Wild-2 orbit and the spacecraft trajectory for the first launch date.

Deterministic Maneuvers: The first orbital loop is a two year loop with a 168 m/s deterministic ΔV near aphelion. This deep space maneuver, DSM 1, sets up the orbit for an Earth swingby that will pump the orbit up to a 2.5 year loop. The spacecraft stays on this loop twice and encounters the comet, Wild-2, approximately 163 days after the second perihelion of the mission, 98.5 days after the comet's perihelion. A small, <1 m/s, deterministic maneuver (DSM 2) is required near second aphelion to maintain the desired trajectory. At approximately 207 days before encountering Wild-2, the third deterministic ΔV, DSM 3, 69 m/s, is performed to properly target to Wild-2. The last deterministic maneuver, DSM 4, is also small, <1 m/s, is scheduled after the Wild-2 encounter, and is used to target back to Earth. The placement of these maneuvers is shifted from optimal execution times due to inferior conditions for communications at low Sun-Earth-Probe angles. In addition, due to the modest thrust level of the propulsion system and the limited capacity of the batteries, the DSM 1 and DSM 3 ΔV's cannot be achieved with single burns. This dilemma is solved by splitting the burns into three parts and two parts, respectively. Each cluster of burns is separated by two days such that full recharging of the battery is possible between the burns.

Comet Encounter: The spacecraft is aimed to flyby the comet on the sun-ward side at a closest flyby distance of 150 km with a delivery uncertainty of 10 km (1-σ). The relative velocity between the comet and the spacecraft is such that the comet approaches the spacecraft from behind when viewed from their travel around the sun. The spacecraft

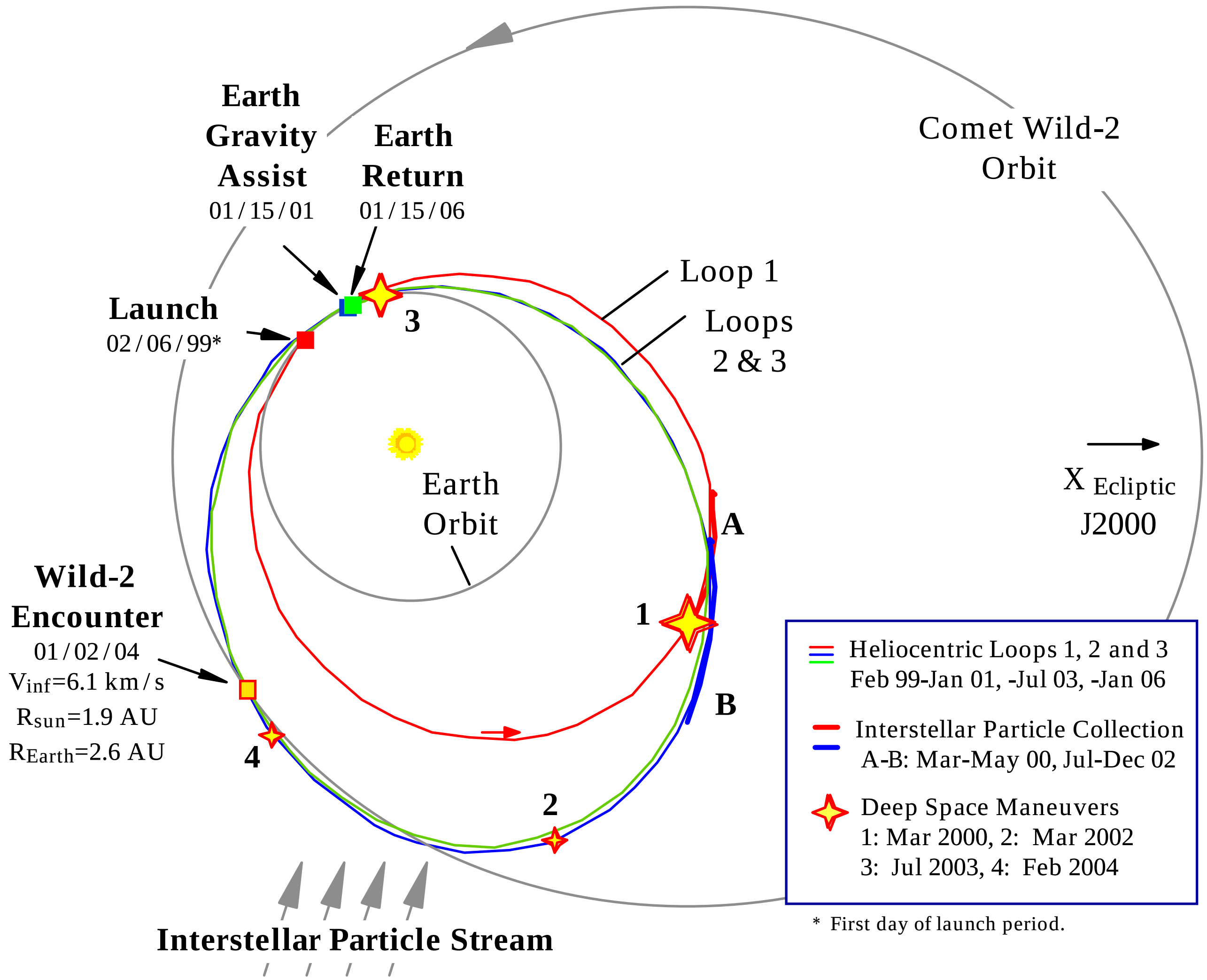


Figure 2.3-1 STARDUST (E-E-W2-E) Heliocentric Trajectory

approaches Wild-2 on the sun-lit side with a phase angle of 73°, reaching a minimum near 0° just prior to closest approach and departing at a phase angle of 107°.

Interstellar Dust Collection: Interstellar dust collection periods are planned near first and second aphelion of the trajectory, when the spacecraft velocity direction is such that the spacecraft-dust relative velocity is at a minimum. These portions of the orbit are indicated in Figure 2.3-1 by A and B. Though possible, no collection is performed on the third loop as it is undesirable to re-open the SRC after the comet encounter. In addition to the favorable velocity alignment, these collection periods are further defined by the need to avoid large off-sun pointing, collection of beta meteoroids, and deep space maneuvers.

Particle Analysis: CIDA and DFMI experiment periods are planned at every available opportunity during the mission. The main constraint on their operation will be the availability of spacecraft power and conflicts with other mission activities. Prime experiment periods are defined, however, as those where the interstellar particle is made to fall within the CIDA field-of-view.

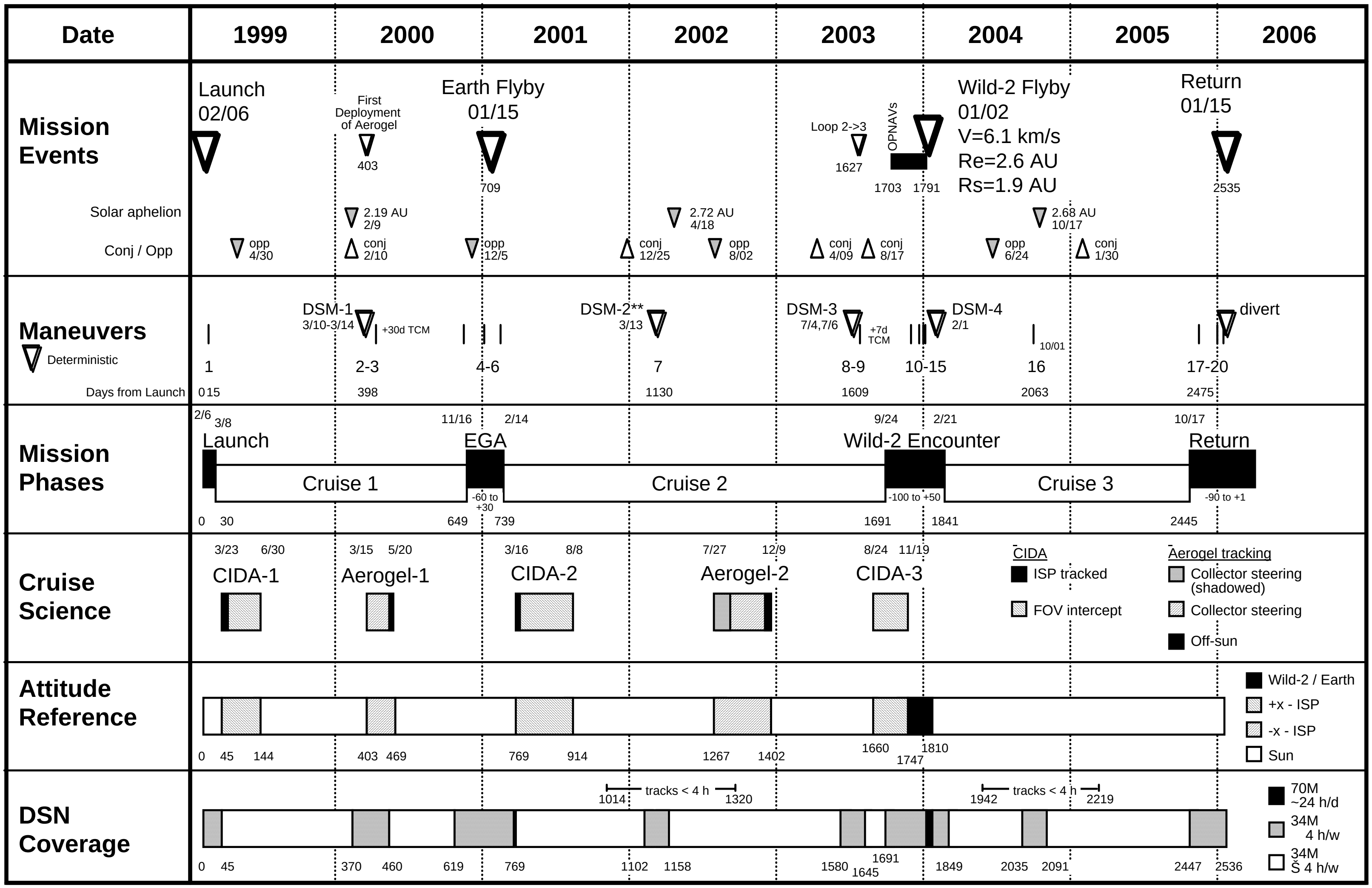
Earth Return: Upon Earth return, the Sample Return Capsule (SRC) will directly enter the atmosphere and land with the aid of a parachute. The planned landing site is the Utah Test and Training Range (UTTR). Following touchdown, the SRC will be recovered by helicopter or ground vehicles and transported to the staging area at UTTR for the retrieval of the sample canister. The canister will then be transported to the planetary materials curatorial facility at Johnson Space Center. A divert maneuver will be performed on the spacecraft after the release of the SRC. The maneuver will retarget the spacecraft to prevent re-entry into Earth's atmosphere and will place the spacecraft in a heliocentric orbit.

Mission Phases and Key Events: A chronologically ordered listing of the various STARDUST mission phases can be found in Table 2.3-1. The Wild-2 Encounter phase is the primary mission phase. Interstellar dust collection and analysis are contained in the Cruise phase. The Launch, Earth Gravity Assist and Return phases are the three other important mission phases. Figure 2.3-2 shows the overview of the mission plan depicting major science, spacecraft (engineering), navigation and ground events. A mission data set containing Earth, sun, Wild-2 ranges, and sun, body, probe angles can be found in Section 9.1. Similar trajectory data sets are also available for each mission phase.

Table 2.3-1 STARDUST Mission Phases

Main Phase	Subphases	Time (L+days)	Duration (days)
Launch	Initial Acquisition, Activation and Checkout, TCM 1	0 - 30	30
Cruise 1 (Earth - Earth)	ISP Collection, DSM 1, TCM 3	30 - 649	619
Earth Gravity Assist (EGA-60d to +30d)	TCM 4-6	649 - 739	90

Cruise 2 (Earth-Wild-2)	ISP Collection, DSM 2, DSM 3, TCM 9	739 - 1691	952
Wild-2 Encounter (E-100d to E+50d)	Far, Near, Close, Closest, Post TCM 10-14, DSM 4	1691 - 1841 E-100 to +50 d	150
Cruise 3 (Wild-2 - Earth)	TCM 16	1841 - 2445	604
Earth Return (ER-90d to ER+1d)	Approach, Entry, Descent, Recovery, Post Recovery, TCM 17-19, Divert (TCM 20)	2445 - 2536	91



* Overview corresponds to 06 Feb 1999 launch.
** DSM-2 is free to move in current trajectory optimization scheme.

Figure 2.3-2 STARDUST Mission Overview (1999-2006)

2.3.2 Launch Period Strategy

2.3.2.1 Baseline Launch Period

A 20-day launch period has been selected for the STARDUST mission. The baseline launch period opens on 06 February and closes on 25 February 1999. The Wild-2 encounter date is fixed at 98.5 days past comet perihelion (TP+98.5d) for all launch dates. This is done to minimize the differences in encounter geometry as a function of launch date.

Table 2.3-2 shows the baseline mission parameters as a function of launch date. The deterministic ΔV requirement has been minimized, but varies from 236 to 260 m/s over the launch period. Deep space maneuvers have been scheduled to fall outside of solar conjunction periods (defined as Sun-Earth-Probe angles $< 3°$) and interstellar dust collection periods.

The injection and Earth return times are consistent with the launch and landing site constraints. The launch profiles are in accordance with the Boeing trajectory analysis contained in document CDRL C37, Contract NAS5-332933, "Detailed Test Objectives (DTO) Trajectories for the STARDUST Spacecraft Mission", dated July 1, 1998. The Earth return time is not exact, but is a best estimate based on LMA 3-D entry analysis. The error in entry time is not more than a few minutes and will be removed after launch.

The accuracy of the trajectories described in Table 2.3-2 is limited by the accuracy of the modeling included in the trajectory optimization software (program CATO-STAR). STARDUST is the first JPL mission where attitude control burns are unbalanced, and attitude control activity has non-negligible effects on the trajectory design and ΔV budget. However, the modeling of attitude control activity is incomplete in CATO-STAR, in that it accounts for perturbations caused only by deadband control, i.e. limit cycling. The following three items have been intentionally left unaccounted for in CATO-STAR:

1. The unbalanced ACS forces imparted during periodic slewing of the spacecraft for communications and maneuvers (about 700 slews). See section 10 for the details of the total ACS force model.

2. A detailed solar pressure model. Solar pressure is modeled with a single flat plate.

3. A detailed engine performance model. The engine performance parameters (blow-down system) at each burn are approximate and based on best estimates.

Correction of the errors due to the first two will be made in the trajectory propagation (ODP) process used by the navigation team. The third error, a small one, will be fixed prior to launch.

The launch specification process used on STARDUST offers simplifications to the calculation of Delta II/37F ascent burn profiles. Constant C3 (26 km^2/s^2) and constant burn duration eliminate the need to manage launch vehicle ballast. Further, the same launch declination is used for several consecutive launch days, thus fixing the Stage II motor restart time. In all, STARDUST requires only five different launch profiles to accommodate its 20-day launch period. The daily variations in launch right ascension are controlled by adjusting the lift-off time.

Table 2.3-2 Baseline Mission Parameters vs.Launch Date

Event	Quantity	02/06/99	02/07/99	02/08/99	02/09/99
Launch	Time (UTC)	21:07:24.0	21:04:57.3	21:00:26.2	21:18:02.5
	Injection (ET)	21:34:37.4	21:32:10.7	21:27:39.7	21:44:42.4
	C3(km^2/s^2)	26.0	26.0	26.0	26.0
	DLA (deg)	-19.695	-19.695	-19.695	-20.500
	RLA (deg)	234.800	235.173	235.026	238.140
	Mass (kg)	394.000	394.000	394.000	394.000
DSM11	Date	3/10/00	12/24/99	11/20/99	3/10/00
	DV (m/s)	71.952	71.940	71.934	71.952
	Propellant mass (kg)	13.440	13.440	13.440	13.440
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	-0.652	5.906	4.121	-1.581
	*Burn Right Ascension (deg)	242.333	229.129	204.624	237.167
DSM12	Date	3/12/00	12/26/99	11/22/99	3/12/00
	DV (m/s)	61.247	61.236	61.231	61.247
	Propellant mass (kg)	11.164	11.164	11.164	11.164
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	-0.660	6.085	4.499	-1.603
	*Burn Right Ascension (deg)	242.663	229.437	205.111	237.564
DSM13	Date	3/14/00	12/28/99	11/24/99	3/14/00
	DV (m/s)	34.873	38.440	45.713	37.139
	Propellant mass (kg)	6.246	6.880	8.168	6.649
	*Burn Duration (s)	1324.2	1458.7	1731.8	1409.5
	*Burn Declination (deg)	-0.668	173.738	4.876	-1.626
	*Burn Right Ascension (deg)	242.993	-310.255	205.594	237.960
EGA	*Date	01/15/01	01/15/01	01/15/01	01/18/01
	*Time (ET)	11:01:24.1	11:00:14.3	11:10:11.5	08:03:07.7
	*Altitude (km)	5964.5	6002.9	6030.2	4151.0
	*B-plane Angle (deg)	144.446	144.218	144.082	148.268
	*V infinity (km/s)	6.480	6.480	6.480	6.505
	*Mass (kg)	362.213	361.587	360.305	361.812
DSM2	Date	03/13/02	06/10/01	06/10/01	03/13/02
	DV (m/s)	0.001	0.003	0.003	1.474
	Propellant mass (kg)	0.000	0.001	0.001	0.263
	*Burn Duration (s)	0.0	0.1	0.1	63.1
	*Burn Declination (deg)	-90.000	-180.000	-180.000	-4.037
	*Burn Right Ascension (deg)	-360.000	-360.000	-360.000	204.639
DSM31	Date	07/04/03	07/04/03	07/04/03	07/14/03
	DV (m/s)	28.484	28.419	28.116	23.014
	Propellant mass (kg)	5.041	5.021	4.950	4.071
	*Burn Duration (s)	1213.7	1208.9	1191.8	980.1
	*Burn Declination (deg)	7.154	7.153	7.078	-0.214
	*Burn Right Ascension (deg)	3.892	3.891	3.936	14.379
DSM32	Date	07/06/03	07/06/03	07/06/03	07/16/03
	DV (m/s)	41.003	41.074	41.215	40.970
	Propellant mass (kg)	7.152	7.152	7.152	7.152
	Burn Duration (s)	750.0	750.0	750.0	750.0
	*Burn Declination (deg)	7.407	7.445	6.367	-0.484
	*Burn Right Ascension (deg)	5.758	5.758	5.709	16.311
Wild-2 Encounter	Date	01/02/04	01/02/04	01/02/04	01/02/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	*V infinity (km/s)	6.120	6.120	6.120	6.124
	*Mass (kg)	348.721	348.116	346.906	349.035
	z - Earth angle (deg)	19:20:00.0	19:20:00.0	19:20:00.0	0.010
	z - Sun angle (deg)	6.120	6.120	6.120	16.764
DSM4	Date	02/01/04	02/01/04	02/01/04	02/01/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	DV (m/s)	0.613	0.611	0.740	0.000
	Propellant mass (kg)	0.107	0.106	0.128	-0.000
	Burn Duration (s)	30.5	30.3	36.6	0.0
	*Burn Declination (deg)	-3.469	-177.647	-32.609	-90.000
	*Burn Right Ascension (deg)	143.582	-36.458	142.391	-180.983
Earth Return	Date	01/15/06	01/15/06	01/15/06	01/18/06
	Time (ET)	09:58:07.1	09:58:07.0	09:58:07.0	09:34:57.6
	*V infinity (km/s)	6.418	6.418	6.418	6.449
	*B plane angle (deg)	-41.049	-41.051	-41.050	-40.835
	*Declination (deg)	10.958	10.958	10.959	11.223
	*Right Ascension (deg)	207.679	207.679	207.679	205.263
	*Mass (kg)	347.953	347.349	346.117	348.366
Total DV (m/s)		238.173	241.723	248.952	235.796

Note: ET-UTC = 64.185 sec at Launch

Table 2.3-2 Baseline Mission Parameters vs.Launch Date (cont)

Event	Quantity	02/10/99	02/11/99	02/12/99	02/13/99
Launch	Time (UTC)	21:19:15.0	21:20:51.3	21:19:15.0	21:20:02.9
	Injection (ET)	21:45:54.9	21:47:31.3	21:45:54.9	21:46:42.8
	C3(km^2/s^2)	26.0	26.0	26.0	26.0
	DLA (deg)	-20.500	-20.500	-20.500	-20.500
	RLA (deg)	239.429	240.817	241.400	242.586
	Mass (kg)	390.000	394.000	394.000	394.000
DSM11	Date	3/10/00	3/10/00	3/10/00	3/10/00
	DV (m/s)	72.703	71.952	71.951	71.951
	Propellant mass (kg)	13.440	13.440	13.440	13.440
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	0.497	2.771	3.774	5.677
	*Burn Right Ascension (deg)	242.394	252.099	231.389	235.429
DSM12	Date	3/12/00	3/12/00	3/12/00	3/12/00
	DV (m/s)	61.907	61.246	61.246	61.246
	Propellant mass (kg)	11.164	11.164	11.164	11.164
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	0.503	2.800	3.839	5.767
	*Burn Right Ascension (deg)	242.757	252.361	231.817	235.850
DSM13	Date	3/14/00	3/14/00	3/14/00	3/14/00
	DV (m/s)	38.340	47.121	47.254	50.138
	Propellant mass (kg)	6.787	8.415	8.438	8.947
	*Burn Duration (s)	1438.9	1784.0	1789.0	1896.9
	*Burn Declination (deg)	0.509	2.828	3.903	5.856
	*Burn Right Ascension (deg)	243.120	252.626	232.244	236.270
EGA	*Date	01/19/01	01/20/01	01/20/01	01/21/01
	*Time (ET)	06:13:57.7	05:11:34.4	14:42:34.3	10:05:08.6
	*Altitude (km)	3568.3	2910.5	2744.6	2231.9
	*B-plane Angle (deg)	149.508	150.816	151.369	152.468
	*V infinity (km/s)	6.523	6.550	6.556	6.583
	*Mass (kg)	357.681	360.047	360.025	359.518
DSM2	Date	12/19/01	02/08/02	07/05/01	08/17/01
	DV (m/s)	0.000	2.105	0.000	0.012
	Propellant mass (kg)	-0.000	0.373	-0.000	0.002
	*Burn Duration (s)	0.0	89.7	0.0	0.4
	*Burn Declination (deg)	-90.000	30.248	89.993	-90.000
	*Burn Right Ascension (deg)	-360.000	199.426	0.000	-30.000
DSM31	Date	07/14/03	07/14/03	07/14/03	07/14/03
	DV (m/s)	20.234	21.343	20.425	19.437
	Propellant mass (kg)	3.543	3.757	3.600	3.421
	*Burn Duration (s)	853.1	904.6	866.7	823.8
	*Burn Declination (deg)	-4.099	-12.531	5.580	4.035
	*Burn Right Ascension (deg)	15.783	16.853	15.969	14.611
DSM32	Date	07/16/03	07/16/03	07/16/03	07/16/03
	DV (m/s)	41.361	41.152	41.092	41.131
	Propellant mass (kg)	7.152	7.152	7.152	7.152
	Burn Duration (s)	1800.0	1800.0	1800.0	1800.0
	*Burn Declination (deg)	-3.582	-10.529	4.262	3.113
	*Burn Right Ascension (deg)	17.630	18.827	17.441	16.354
Wild-2 Encounter	Date	01/02/04	01/02/04	01/02/04	01/02/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	*V infinity (km/s)	6.124	6.131	6.130	6.135
	*Mass (kg)	345.701	347.480	347.990	347.660
	z - Earth angle (deg)	0.070	0.130	0.143	0.204
	z - Sun angle (deg)	16.824	16.883	16.896	16.958
DSM4	Date	02/01/04	02/01/04	02/01/04	02/01/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	DV (m/s)	2.930	0.000	5.802	2.227
	Propellant mass (kg)	0.505	-0.000	1.006	0.386
	Burn Duration (s)	144.2	0.0	287.3	110.3
	*Burn Declination (deg)	20.828	-90.000	-71.777	-41.582
	*Burn Right Ascension (deg)	139.302	-141.965	103.798	-220.762
Earth Return	Date	01/19/06	01/20/06	01/20/06	01/21/06
	Time (ET)	09:27:01.6	09:18:56.8	09:18:54.1	09:10:47.1
	*V infinity (km/s)	6.469	6.494	6.495	6.524
	*B plane angle (deg)	-40.758	-40.674	-40.663	-40.588
	*Declination (deg)	11.301	11.382	11.398	11.458
	*Right Ascension (deg)	204.455	203.644	203.650	202.840
	*Mass (kg)	344.526	346.806	346.310	346.597
Total DV (m/s)		237.475	244.919	247.770	246.142

Note: ET-UTC = 64.185 sec at Launch

Table 2.3-2 Baseline Mission Parameters vs.Launch Date (cont)

Event	Quantity	02/14/99	02/15/99	02/16/99	02/17/99
Launch	Time (UTC)	19:01:15.5	19:01:42.5	19:02:24.4	19:03:19.6
	Injection (ET)	19:30:49.8	19:31:16.7	19:31:58.7	19:32:53.8
	C3(km^2/s^2)	26.0	26.0	26.0	26.0
	DLA (deg)	-16.030	-16.030	-16.030	-16.029
	RLA (deg)	220.385	221.483	222.644	223.860
	Mass (kg)	394.000	394.000	394.000	394.000
DSM11	Date	3/10/00	3/10/00	3/10/00	3/10/00
	DV (m/s)	71.947	71.947	71.947	71.947
	Propellant mass (kg)	13.440	13.440	13.440	13.440
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	-3.632	0.686	5.323	10.075
	*Burn Right Ascension (deg)	232.074	233.673	235.109	236.936
DSM12	Date	3/12/00	3/12/00	3/12/00	3/12/00
	DV (m/s)	61.243	61.242	61.242	61.242
	Propellant mass (kg)	11.164	11.164	11.164	11.164
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	-3.675	0.693	5.390	10.212
	*Burn Right Ascension (deg)	232.528	234.096	235.503	237.285
DSM13	Date	3/14/00	3/14/00	3/14/00	3/14/00
	DV (m/s)	39.794	35.936	35.251	36.655
	Propellant mass (kg)	7.120	6.435	6.314	6.563
	*Burn Duration (s)	1509.4	1364.3	1338.6	1391.4
	*Burn Declination (deg)	-3.718	0.701	5.458	10.348
	*Burn Right Ascension (deg)	232.980	234.517	235.897	237.634
EGA	*Date	01/10/01	01/12/01	01/13/01	01/14/01
	*Time (ET)	20:39:16.2	03:22:12.9	07:16:13.1	10:34:16.3
	*Altitude (km)	8801.7	8073.8	7333.2	6604.3
	*B-plane Angle (deg)	138.446	140.255	141.705	143.133
	*V infinity (km/s)	6.529	6.503	6.492	6.485
	*Mass (kg)	361.371	362.054	362.176	361.927
DSM2	Date	07/16/01	01/12/03	01/22/03	01/22/03
	DV (m/s)	4.070	5.889	2.671	3.484
	Propellant mass (kg)	0.724	1.048	0.476	0.620
	*Burn Duration (s)	174.1	252.0	114.4	149.1
	*Burn Declination (deg)	63.881	-58.772	-18.182	42.693
	*Burn Right Ascension (deg)	-47.245	287.076	270.807	281.540
DSM31	Date	07/14/03	07/14/03	07/14/03	07/14/03
	DV (m/s)	31.225	29.761	28.451	26.862
	Propellant mass (kg)	5.497	5.247	5.027	4.743
	*Burn Duration (s)	1323.7	1263.3	1210.5	1142.0
	*Burn Declination (deg)	-0.957	-2.023	-1.814	0.970
	*Burn Right Ascension (deg)	14.205	15.156	14.600	15.034
DSM32	Date	07/16/03	07/16/03	07/16/03	07/16/03
	DV (m/s)	41.245	41.173	41.066	41.080
	Propellant mass (kg)	7.152	7.152	7.152	7.152
	Burn Duration (s)	1800.0	1800.0	1800.0	1800.0
	*Burn Declination (deg)	0.712	-0.934	-1.423	-0.040
	*Burn Right Ascension (deg)	15.789	16.794	16.497	16.799
Wild-2 Encounter	Date	01/02/04	01/02/04	01/02/04	01/02/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	*V infinity (km/s)	6.129	6.127	6.124	6.122
	*Mass (kg)	346.686	347.298	348.214	348.096
	z - Earth angle (deg)	0.167	0.179	0.165	0.144
	z - Sun angle (deg)	16.588	16.577	16.590	16.611
DSM4	Date	02/01/04	02/01/04	02/01/04	02/01/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	DV (m/s)	10.017	0.000	0.000	0.000
	Propellant mass (kg)	1.728	-0.000	-0.000	-0.000
	Burn Duration (s)	493.6	0.0	0.0	0.0
	*Burn Declination (deg)	112.650	0.167	0.000	0.007
	*Burn Right Ascension (deg)	-73.517	0.196	0.000	1.416
Earth Return	Date	01/11/06	01/12/06	01/13/06	01/14/06
	Time (ET)	10:27:08.5	10:20:02.8	10:12:53.0	10:05:34.3
	*V infinity (km/s)	6.441	6.429	6.421	6.417
	*B plane angle (deg)	-41.280	-41.218	-41.169	-41.113
	*Declination (deg)	10.566	10.683	10.774	10.866

	*Right Ascension (deg)	210.808	210.045	209.264	208.474
	*Mass (kg)	344.293	346.630	347.542	347.413
Total DV (m/s)		259.541	245.948	240.628	241.270

Note: ET-UTC = 64.185 sec at Launch

Table 2.3-2 Baseline Mission Parameters vs.Launch Date (cont)

Event	Quantity	02/18/99	02/19/99	02/20/99	02/21/99
Launch	Time (UTC)	19:04:31.4	19:27:43.5	19:29:09.4	19:30:46.8
	Injection (ET)	19:34:05.7	19:55:44.9	19:57:10.8	19:58:48.2
	C3(km^2/s^2)	26.0	26.0	26.0	26.0
	DLA (deg)	-16.029	-18.500	-18.500	-18.500
	RLA (deg)	225.146	225.838	227.182	228.575
	Mass (kg)	394.000	394.000	394.000	394.000
DSM11	Date	3/10/00	3/10/00	3/10/00	3/10/00
	DV (m/s)	71.946	71.946	71.946	71.946
	Propellant mass (kg)	13.440	13.440	13.440	13.440
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	14.836	-15.472	-10.724	-5.812
	*Burn Right Ascension (deg)	238.615	236.247	237.801	239.406
DSM12	Date	3/12/00	3/12/00	3/12/00	3/12/00
	DV (m/s)	61.242	61.242	61.242	61.242
	Propellant mass (kg)	11.164	11.164	11.164	11.164
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	15.035	-15.691	-10.878	-5.896
	*Burn Right Ascension (deg)	238.948	236.611	238.159	239.759
DSM13	Date	3/14/00	3/14/00	3/14/00	3/14/00
	DV (m/s)	40.231	41.201	39.759	40.282
	Propellant mass (kg)	7.197	7.369	7.114	7.206
	*Burn Duration (s)	1525.9	1562.3	1508.1	1527.8
	*Burn Declination (deg)	15.233	-15.910	-11.032	-5.980
	*Burn Right Ascension (deg)	239.280	236.976	238.518	240.111
EGA	*Date	01/15/01	01/16/01	01/17/01	01/18/01
	*Time (ET)	13:16:14.0	16:31:10.1	16:39:19.4	16:04:46.0
	*Altitude (km)	5856.8	5209.1	4554.5	3917.3
	*B-plane Angle (deg)	144.490	146.181	147.574	148.889
	*V infinity (km/s)	6.484	6.483	6.493	6.509
	*Mass (kg)	361.293	361.122	361.378	361.286
DSM2	Date	01/12/03	02/07/03	02/28/03	03/11/03
	DV (m/s)	5.808	0.000	0.000	0.000
	Propellant mass (kg)	1.032	-0.000	-0.000	-0.000
	*Burn Duration (s)	248.0	0.0	0.0	0.0
	*Burn Declination (deg)	60.504	-180.000	-180.000	-180.000
	*Burn Right Ascension (deg)	299.217	-360.000	-360.000	-360.000
DSM31	Date	07/14/03	07/14/03	07/14/03	07/14/03
	DV (m/s)	25.253	23.980	22.999	22.113
	Propellant mass (kg)	4.448	4.235	4.066	3.909
	*Burn Duration (s)	1070.9	1019.7	979.0	941.2
	*Burn Declination (deg)	2.346	3.232	3.946	4.587
	*Burn Right Ascension (deg)	15.613	16.006	16.072	16.098
DSM32	Date	07/16/03	07/16/03	07/16/03	07/16/03
	DV (m/s)	41.167	41.040	40.990	40.982
	Propellant mass (kg)	7.152	7.152	7.152	7.152
	Burn Duration (s)	1800.0	750.0	1800.0	1800.0
	*Burn Declination (deg)	1.019	1.848	2.578	3.238
	*Burn Right Ascension (deg)	17.219	17.511	17.560	17.579
Wild-2 Encounter	Date	01/02/04	01/02/04	01/02/04	01/02/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	*V infinity (km/s)	6.121	6.119	6.120	6.122
	*Mass (kg)	347.349	348.438	348.865	348.932
	z - Earth angle (deg)	0.116	0.063	0.021	0.026
	z - Sun angle (deg)	16.639	16.691	16.733	16.780
DSM4	Date	02/01/04	02/01/04	02/01/04	02/01/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	DV (m/s)	0.000	8.414	8.296	7.487
	Propellant mass (kg)	-0.000	1.460	1.441	1.301
	Burn Duration (s)	0.0	416.9	411.6	371.6
	*Burn Declination (deg)	0.000	-69.336	-109.420	-70.990
	*Burn Right Ascension (deg)	0.000	111.907	287.970	106.505
Earth Return	Date	01/15/06	01/16/06	01/17/06	01/18/06
	Time (ET)	09:58:06.8	09:50:27.3	09:42:44.1	09:34:54.0
	*V infinity (km/s)	6.418	6.425	6.435	6.450

	*B plane angle (deg)	-41.051	-40.967	-40.895	-40.821
	*Declination (deg)	10.958	11.072	11.160	11.243
	*Right Ascension (deg)	207.678	206.886	206.080	205.270
	*Mass (kg)	346.665	346.299	346.741	346.946
Total DV (m/s)		245.647	247.823	245.232	244.052

Note: ET-UTC = 64.185 sec at Launch

Table 2.3-2 Baseline Mission Parameters vs.Launch Date (cont)

Event	Quantity	02/22/99	02/23/99	02/24/99	02/25/99
Launch	Time (UTC)	19:32:33.3	19:34:26.4	19:42:45.1	19:44:49.7
	Injection (ET)	20:00:34.6	20:02:27.8	20:10:20.7	20:12:25.3
	C3(km^2/s^2)	26.0	26.0	26.0	26.0
	DLA (deg)	-18.500	-18.500	-19.150	-19.150
	RLA (deg)	230.005	231.463	232.811	234.317
	Mass (kg)	394.000	394.000	394.000	394.000
DSM11	Date	3/10/00	3/10/00	3/10/00	3/10/00
	DV (m/s)	71.946	71.946	71.946	71.946
	Propellant mass (kg)	13.440	13.440	13.440	13.440
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	-0.927	3.757	-0.533	3.789
	*Burn Right Ascension (deg)	241.049	242.672	242.822	243.078
DSM12	Date	3/12/00	3/12/00	3/12/00	3/12/00
	DV (m/s)	61.241	61.241	61.241	61.241
	Propellant mass (kg)	11.164	11.164	11.164	11.164
	Burn Duration (s)	2100.0	2100.0	2100.0	2100.0
	*Burn Declination (deg)	-0.940	3.811	-0.540	3.841
	*Burn Right Ascension (deg)	241.394	243.011	243.179	243.463
DSM13	Date	3/14/00	3/14/00	3/14/00	3/14/00
	DV (m/s)	42.786	47.179	51.368	56.697
	Propellant mass (kg)	7.649	8.426	9.165	10.102
	*Burn Duration (s)	1621.7	1786.3	1942.9	2141.8
	*Burn Declination (deg)	-0.953	3.865	-0.547	3.892
	*Burn Right Ascension (deg)	241.740	243.351	-116.463	243.848
EGA	*Date	01/19/01	01/20/01	01/21/01	01/22/01
	*Time (ET)	14:48:45.7	12:50:12.0	10:02:34.5	06:28:10.5
	*Altitude (km)	3303.1	2716.5	2157.1	1649.0
	*B-plane Angle (deg)	150.153	151.368	152.562	153.587
	*V infinity (km/s)	6.529	6.554	6.584	6.616
	*Mass (kg)	360.843	360.068	359.330	358.394
DSM2	Date	03/19/03	07/26/01	08/17/01	10/01/01
	DV (m/s)	0.000	0.000	1.845	0.002
	Propellant mass (kg)	-0.000	-0.000	0.327	0.000
	*Burn Duration (s)	0.0	0.0	78.5	0.1
	*Burn Declination (deg)	-180.000	-180.000	-43.382	-90.000
	*Burn Right Ascension (deg)	-360.000	-360.000	171.221	-360.000
DSM31	Date	07/14/03	07/14/03	07/14/03	07/14/03
	DV (m/s)	21.283	20.463	20.335	17.748
	Propellant mass (kg)	3.759	3.607	3.574	3.116
	*Burn Duration (s)	905.0	868.4	860.5	750.2
	*Burn Declination (deg)	5.154	5.536	4.782	-3.261
	*Burn Right Ascension (deg)	16.033	15.712	13.247	15.350
DSM32	Date	07/16/03	07/16/03	07/16/03	07/16/03
	DV (m/s)	41.016	41.088	41.208	41.226
	Propellant mass (kg)	7.152	7.152	7.152	7.152
	Burn Duration (s)	1800.0	1800.0	1800.0	1800.0
	*Burn Declination (deg)	3.833	4.273	3.818	-3.017
	*Burn Right Ascension (deg)	17.524	17.256	15.188	17.223
Wild-2 Encounter	Date	01/02/04	01/02/04	01/02/04	01/02/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	*V infinity (km/s)	6.126	6.130	6.136	6.140
	*Mass (kg)	348.643	348.023	346.994	346.845
	z - Earth angle (deg)	0.079	0.138	0.201	0.283
	z - Sun angle (deg)	16.833	16.892	16.954	17.036
DSM4	Date	02/01/04	02/01/04	02/01/04	02/01/04
	Time (ET)	19:20:00.0	19:20:00.0	19:20:00.0	19:20:00.0
	DV (m/s)	6.070	4.128	0.006	2.529
	Propellant mass (kg)	1.054	0.716	0.001	0.437
	Burn Duration (s)	301.1	204.5	0.3	124.9
	*Burn Declination (deg)	-70.212	-65.645	-90.000	10.523
	*Burn Right Ascension (deg)	109.459	120.855	-360.000	140.904
Earth Return	Date	01/19/06	01/20/06	01/21/06	01/22/06
	Time (ET)	09:26:57.6	09:18:55.1	09:10:47.2	09:02:33.3
	*V infinity (km/s)	6.470	6.495	6.524	6.559

*B plane angle (deg)	-40.744	-40.667	-40.591	-40.508
*Declination (deg)	11.321	11.392	11.454	11.518
*Right Ascension (deg)	204.460	203.649	202.838	202.036
*Mass (kg)	346.900	346.615	346.300	345.711
Total DV (m/s)	244.342	246.045	247.949	251.389

Note: ET-UTC = 64.185 sec at Launch

2.3.2.2 ΔV Budget

The total ΔV budget is summarized in Table 2.3-2.a. It is based primarily on the maximum total of deterministic maneuvers across the launch period, 260 m/s, and the estimate of the required statistical trajectory correction maneuvers. Note that the unallocated ΔV reserve amounts to 37 m/s. The statistical maneuver history for a Feb. 6 launch is shown in Table 2.3-2.b and leads to the allocation of 63 m/s indicated in Table 2.3-2.a.

Table 2.3-2.a ΔV Budget Summary

Deterministic	(m/s)	Notes
DSMs	260	Three or four DSMs depending on LD. Max of 20-day LP (2/14).
Launch Window ± 1 min	2	For collision avoidance with space debris etc.
Slew ΔV effects	5	Cost of ACS Slew ΔV when modeled in Navigation software
Return divert	15	For S/C divert away from earth, executed at ~ 4 hrs before entry
Statistical		
TCMs (19)	63	See Table 2.3-2.b for representative profile
ACS Modeling Error	10	Cost in ΔV due to the difference between models and actuals
Sub-Totals	355	
Reserve	22	Additional 17 m/s available for full propellant load (85 kg)
Total	377	Initial design requirement

Table 2.3-2.b Maneuver History

Maneuver	Epoch	Execution Date	ΔV-95% (m/s)
TCM-1	L + 15 d	21 Feb 99	44.93
TCM-2	DSM-1	10-14 Mar 00	169.80
TCM-3	DSM-1 + 30 d	13 Apr 00	2.86
TCM-4	EP - 60 d	16 Nov 00	0.44
TCM-5	EP - 10 d	05 Jan 01	0.32
TCM-6	EP + 30 d	14 Feb 01	2.74
TCM-7	DSM-2	13 Mar 02	0.75
TCM-8	DSM-3	04-06 Jul 03	69.87
TCM-9	DSM-3 + 7 d	13 Jul 03	1.48
TCM-10	WCA - 30 d	03 Dec 03	2.26
TCM-11	WCA - 10 d	23 Dec 03	1.46
TCM-12	WCA - 2 d	31 Dec 03	2.60
TCM-13	WCA - 18 h	02 Jan 04	2.02
TCM-14	WCA - 6 h	02 Jan 04	1.31
TCM-15	DSM4 (WCA + 30 d)	01 Feb 04	7.52
TCM-16	3rd aphelion	01 Oct 04	0.66
TCM-17	ER - 60 d	16 Nov 05	2.63
TCM-18	ER - 13 d	02 Jan 06	0.36
TCM-19	ER - 1 d	14 Jan 06	0.23

* Analysis completed 11/20/98, corresponds to 2/6 launch, DTO trajectories and PMA LV covariance.

2.3.2.3 Alternate Launch Periods

A serendipitous phasing of Earth and Wild-2 for the 2003 apparition presents additional opportunities to perform the mission at later dates with the resulting mission characteristics similar to the baseline launch period mission. The two launch opportunities correspond to 2^+ year and 2^- year Earth Gravity Assist trajectory types but with comet encounter occurring pre-perihelion. The current spacecraft configuration (fixed solar arrays and HGA) can be preserved exactly, for encounter, if the encounter date is set at TP-103d. The spacecraft +z-axis (HGA) can remain pointed at Earth at comet closest approach with an off-sun angle close to 13° versus 17° in the baseline mission. Likewise, the heliocentric range is 1.88 AU compared to 1.86 AU and the Earth range is 2.74 AU compared to 2.61 AU. Although the alternate mission performance is yet to be thoroughly analyzed, it appears that the mass margin is comparable to that of the baseline mission. These alternate flights would require slightly higher C3's, but this is compensated for by lower post launch ΔV. Tables 2.3-3 and 2.3-4 show the specific mission parameters for these alternate launch periods.

2.3.3 Space Environment

This section contains space radiation and micrometeoroid data generated by JPL for the STARDUST project. The format of the data is a fairly standard and widely used by system designers.

2.3.3.1 Ionizing Radiation Fluence and Dose

Fluence: Three sources of natural space charged particles are considered: galactic cosmic rays, solar winds and solar proton events. The resulting 7-year cumulative proton and electron integral fluences are shown in Table 2.3-5. The fluence values shown correspond to a 99% probability level. The rationale for choosing a 99% confidence level is that the spacecraft may experience a 95% probabilistic size flare every 2.8 years and a 98.7% probabilistic size flare every 7 years according to the JPL solar flare model. Therefore, it is deemed prudent to adopt the 99% probabilistic confidence level for a 7 year STARDUST mission.

Radiation Dose: The ionizing dose to which the spacecraft is expected to be exposed as a function of aluminum thickness is shown in Figure 2.3-3. The calculation is made using Monte Carlo radiation transport code NOVICE and assumes a spherical shell geometry. These dose-depth data are generated based on the sum of the proton and electron fluence data listed in Table 2.3-5. This does not include the radiation design margin (RDM) required to account for other uncertainties associated with the mass distribution, electronic parts responses and transport calculations. A RDM of 2 is assumed somewhat arbitrarily based for the most part on past JPL managed missions.

Accumulation of Radiation with Time: Radiation fluence as a function of time is generated to accommodate concerns regarding solar array design. Figure 2.3-4 shows the accumulated levels of proton and electron fluences at L+380, 1180, 1820, 2090 and 2535 days. These data points correspond roughly to each of three aphelions, Wild-2 encounter and end of mission.

To expedite practical applications, the complex degradation profile of solar cell performance due to the above radiation (multiple sources, wide range of energies and omni-directional) is converted and measured in terms of the equivalent damage caused by the incidence of a single 1-MeV electron on silicon cells. The equivalent damage conversion factors are different for different performance parameters: open circuit voltage (VOC or Pmax) and for short circuit current (ISC). Figure 2.3-5 shows the resulting equivalent 1-MeV electron fluence behind a coverglass of variable thickness and are given for solar cell performance parameters VOC and ISC, respectively.

Table 2.3-3 STARDUST Alternate-1 Mission Parameters : 2^+ yr ΔV-EGA Trajectory

	Launch Parameters					Earth Return Parameters				Wild-2 Enc. Parameters			EGA Parameters	
	LD 1999	C3 $(km/s)^2$	Dec deg	Ra deg	ΔV[1] m/s	AD 2006	Vhp km/s	Dap deg	Rap deg	Vhb km/s	phase(i)[2] deg	phase(o)[2] deg	EGA.D 2001	Alt km
	4/20	27.00	-18.79	308.30	242	5/17	6.322	-3.81	337.86	5.88	103.0	77.0	5/18	20631
	4/21	27.00	-18.56	309.23	239	5/17	6.301	-3.96	337.34	5.88	103.0	77.0	5/19	8331
	4/22	27.00	-18.33	310.16	237	5/19	6.270	-4.27	336.50	5.88	103.0	77.1	5/20	9215
	4/23	27.00	-18.10	311.08	235	5/20	6.244	-4.62	335.57	5.88	102.9	77.1	5/20	10157
2	4/24	27.00	-17.86	311.98	233	5/21	6.224	-4.99	334.57	5.88	102.9	77.1	5/21	11156
0	4/25	27.00	-17.62	312.88	231	5/23	6.212	-5.40	333.48	5.88	102.8	77.2	5/22	12239
	4/26	27.00	-17.39	313.75	229	5/24	6.210	-5.83	332.34	5.88	102.8	77.2	5/23	13382
D	4/27	27.00	-17.15	314.61	228	5/26	6.221	-6.28	331.14	5.88	102.8	77.2	5/24	14598
A	4/28	27.00	-16.92	315.43	226	5/27	6.245	-6.77	329.88	5.88	102.8	77.2	525	15883
Y	4/29	26.71	-17.82	312.13	232	5/25	6.216	-6.14	331.52	5.88	102.8	77.2	5/24	14133
	4/30	26.72	-17.59	313.01	230	5/27	6.237	-6.62	330.25	5.88	102.8	77.2	5/25	15418
P	5/ 1	26.74	-17.36	313.85	228	5/29	6.272	-7.13	328.95	5.88	102.8	77.2	5/26	16764
E	5/ 2	26.73	-17.29	314.12	227	5/29	6.290	-7.27	328.47	5.89	102.8	77.2	5/26	17686
R	5/ 3	26.74	-17.25	314.27	226	5/30	6.304	-7.35	328.15	5.89	102.8	77.2	5/27	18527
I	5/ 4	26.75	-17.21	314.41	226	5/30	6.319	-7.42	327.81	5.89	102.8	77.2	5/28	19390
O	5/ 5	26.78	-17.17	314.53	225	5/31	6.336	-7.50	327.46	5.90	102.8	77.2	5/28	20267
D	5/ 6	26.82	-17.15	314.62	225	5/31	6.355	-7.59	327.10	5.90	102.8	77.2	5/29	21149
	5/ 7	27.00	-17.88	311.91	223	5/30	6.314	-7.40	327.91	5.89	102.8	77.2	5/27	19130
	5/ 8	27.00	-17.51	313.31	224	5/31	6.359	-7.61	327.03	5.90	102.8	77.2	5/29	21312
	5/ 9	27.00	-17.08	314.87	226	6/02	6.428	-7.88	325.92	5.91	102.9	77.2	5/31	23918
	5/10	27.00	-16.58	316.62	234	6/05	6.552	-8.26	324.39	5.94	103.0	77.0	6/03	27237

1. Post launch deterministic ΔV requirement
2. Phase angle , inbound and outbound

Table 2.3-4 STARDUST Alternate-2 Mission Parameters : 2^{-} yr ΔV-EGA Trajectory

	Launch Parameters					Earth Return Parameters				Wild-2 Enc. Parameters			EGA Parameters	
	LD 1999	C3 $(km/s)^2$	Dec deg	Ra deg	ΔV^* m/s	AD 2006	Vhp km/s	Dap deg	Rap deg	Vhb km/s	phase(i) deg	phase(o) deg	EGA.D 2001	Alt km
	6/13	26.65	-1.52	356.50	243	5/21	6.228	-4.89	334.86	5.88	102.9	77.1	5/21	15541
	6/14	26.65	-1.17	357.30	241	5/22	6.213	-5.35	333.60	5.88	102.8	77.2	5/22	14253
	6/15	26.65	-0.82	358.11	239	5/24	6.210	-5.81	332.39	5.88	102.8	77.2	5/23	13055
	6/16	26.65	-0.47	358.91	237	5/26	6.220	-6.26	331.19	5.88	102.8	77.2	5/24	11939
2	6/17	26.65	-0.12	359.72	235	5/27	6.241	-6.69	330.07	5.88	102.8	77.2	5/25	10900
0	6/18	26.65	0.23	0.52	234	5/29	6.271	-7.12	328.99	5.88	102.8	77.2	5/26	9942
	6/19	26.51	-0.47	358.93	236	5/28	6.255	-6.90	329.53	5.88	102.8	77.2	5/25	10381
D	6/20	26.50	-0.20	359.54	235	5/29	6.283	-7.23	328.67	5.88	102.8	77.2	5/26	9560
A	6/21	26.50	-0.06	359.86	234	5/29	6.293	-7.29	328.40	5.89	102.8	77.2	5/26	8959
Y	6/22	26.49	0.10	0.24	234	5/30	6.305	-7.35	328.12	5.89	102.8	77.2	5/27	8354
	6/23	26.65	-1.50	356.53	234	5/28	6.259	-6.96	329.38	5.88	102.8	77.2	5/25	10257
P	6/24	26.65	-1.11	357.44	233	5/29	6.288	-7.26	328.53	5.89	102.8	77.2	5/26	9258
E	6/25	26.65	-0.72	358.34	232	5/30	6.306	-7.35	328.10	5.89	102.8	77.2	5/27	8337
R	6/26	26.65	-0.33	359.25	232	5/30	6.326	-7.45	327.67	5.89	102.8	77.2	5/28	7478
I	6/27	26.65	0.07	0.17	232	5/31	6.348	-7.56	327.24	5.90	102.8	77.2	5/29	6678
O	6/28	26.65	0.47	1.09	233	6/01	6.371	-7.66	326.81	5.90	102.8	77.2	5/29	5931
D	6/29	26.65	0.88	2.02	234	6/01	6.397	-7.76	326.39	5.91	102.8	77.2	5/30	5235
	6/30	26.65	1.28	2.96	235	6/02	6.424	-7.86	325.98	5.91	102.8	77.2	5/31	4585
	7/01	26.65	1.69	3.89	236	6/03	6.453	-7.96	325.58	5.92	102.9	77.1	6/01	3977
	7/02	26.65	2.09	4.83	238	6/03	6.483	-8.06	325.18	5.92	102.9	77.1	6/01	3409
	7/03	26.65	2.50	5.77	240	6/04	6.515	-8.16	324.80	5.93	102.9	77.1	6/02	2877
	7/04	26.65	2.90	6.71	242	6/04	6.548	-8.25	324.43	5.94	103.0	77.0	6/03	2378
	7/05	26.65	3.30	7.65	244	6/05	6.582	-8.34	324.07	5.94	103.0	77.0	6/04	1910

1. Post launch deterministic ΔV requirement
2. Phase angle , inbound and outbound

Table 2.3-5 Proton and Electron Integral Fluence Spectra for STARDUST Mission

Proton		Electron	
Energy (MeV)	Fluence (cm^{-2})	Energy (MeV)	Fluence (cm^{-2})
Solar Event		Total Electron	
9.00E-04	1.48E+16	1.00E-03	3.90E+13
1.00E-03	1.26E+16	1.00E-02	3.90E+11
2.00E-03	4.35E+15	1.00E-01	3.90E+09
5.00E-03	1.07E+15	2.00E-01	9.80E+08
1.00E-02	3.70E+14	3.00E-01	4.40E+08
2.00E-02	1.28E+14	4.00E-01	2.50E+08
5.00E-02	3.15E+13	5.00E-01	1.60E+08
1.00E-01	1.09E+13	6.00E-01	1.50E+08
2.00E-01	3.77E+12	7.00E-01	1.50E+08
5.00E-01	9.27E+11	8.00E-01	1.50E+08
1.00E+00	3.21E+11	9.00E-01	1.50E+08
4.00E+00	1.81E+11	1.00E+00	1.50E+08
1.00E+01	7.57E+10	1.25E+00	1.10E+08
3.00E+01	2.90E+10	1.50E+00	9.50E+07
6.00E+01	1.36E+10	1.75E+00	8.30E+07
1.00E+02	7.90E+09	2.00E+00	7.40E+07
2.00E+02	3.70E+09	2.25E+00	6.80E+07
3.00E+02	2.40E+09	2.50E+00	6.30E+07
4.00E+02	1.70E+09	2.75E+00	5.90E+07
5.00E+02	1.40E+09	3.00E+00	5.60E+07
1.00E+03	6.50E+08	3.25E+00	5.40E+07
Cosmic Proton		3.50E+00	5.20E+07
1.00E+00	4.10E+08	3.75E+00	5.00E+07
4.00E+00	4.10E+08	4.00E+00	4.90E+07
1.00E+01	4.10E+08	4.50E+00	4.70E+07
3.00E+01	4.10E+08	5.00E+00	4.50E+07
6.00E+01	4.10E+08	5.50E+00	4.40E+07
1.00E+02	4.10E+08	6.00E+00	4.30E+07
2.00E+02	4.00E+08	6.50E+00	4.20E+07
3.00E+02	3.80E+08	7.00E+00	4.10E+07
4.00E+02	3.60E+08	1.00E+02	3.40E+07
5.00E+02	3.40E+08	1.00E+03	1.30E+07
1.00E+03	2.50E+08		

2.3.3.2 Single Event Upsets

Heinrich flux**:** The environmental data required to address concerns for Single Event Upsets (SEU) is provided in Figure 2.3-6 in the form a Heinrich flux versus LET (LET = dE/dX or energy deposition per unit mass at normal incidence). The data are provided for 99% and 95% magnitude solar flares based on current solar models and also includes the contributions of 90% galactic cosmic rays. The measurement of flux as a function of energy deposition eliminates the need to specify specific individual particle species (protons, alpha particles and heavy ions) and specific energy deposit characteristics. The figures provide only simple radiation design references as a function of the flux behind a spherical shield of variable thickness (0-1000 mils) of Aluminum. Actual SEU rate calculations will require more detailed shielding geometries and consideration of long diagonal path lengths through the sensitive volume of electronic chips.

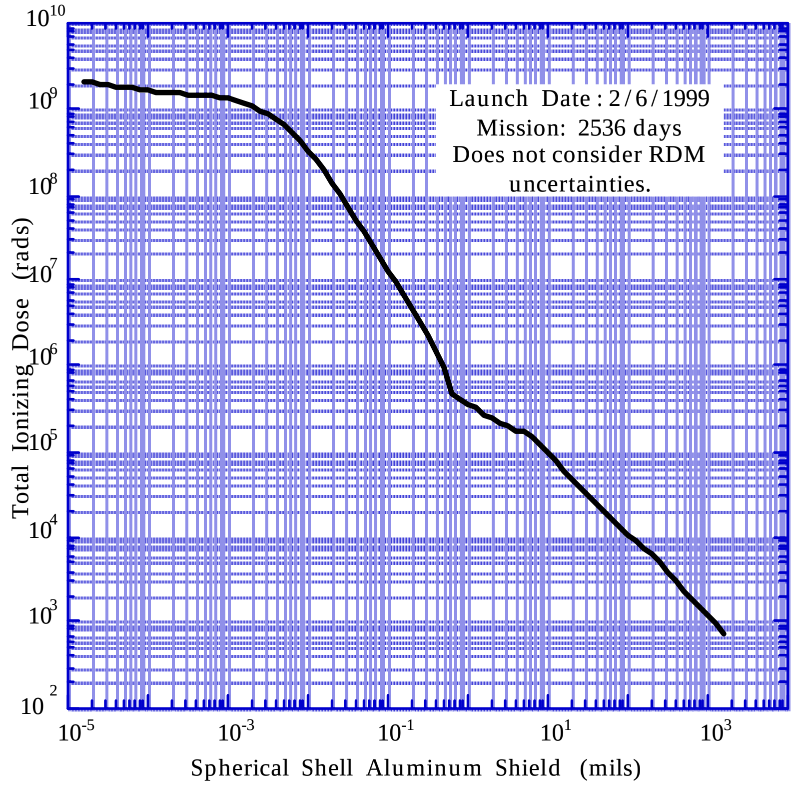


Figure 2.3-3 Radiation Dose vs Shield Depth (Spherical Aluminum Shell)

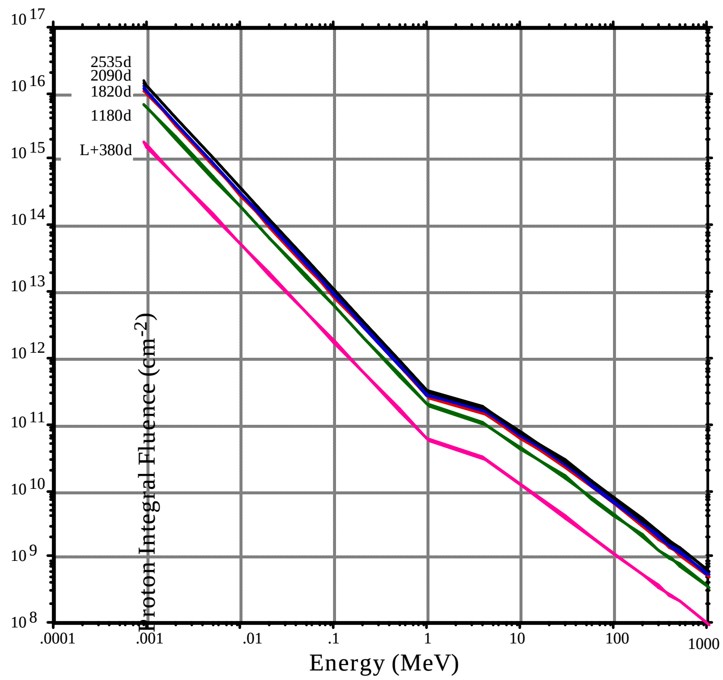


Figure 2.3-4.a. Proton Fluence vs Energy as a Function of Time from Launch

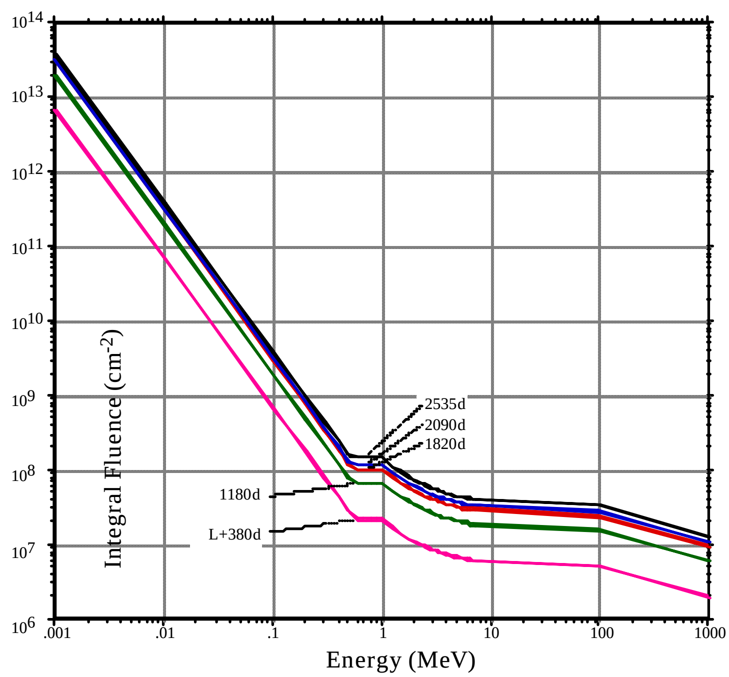


Figure 2.3-4.b. Electron Fluence vs Energy as a Function of Time from Launch

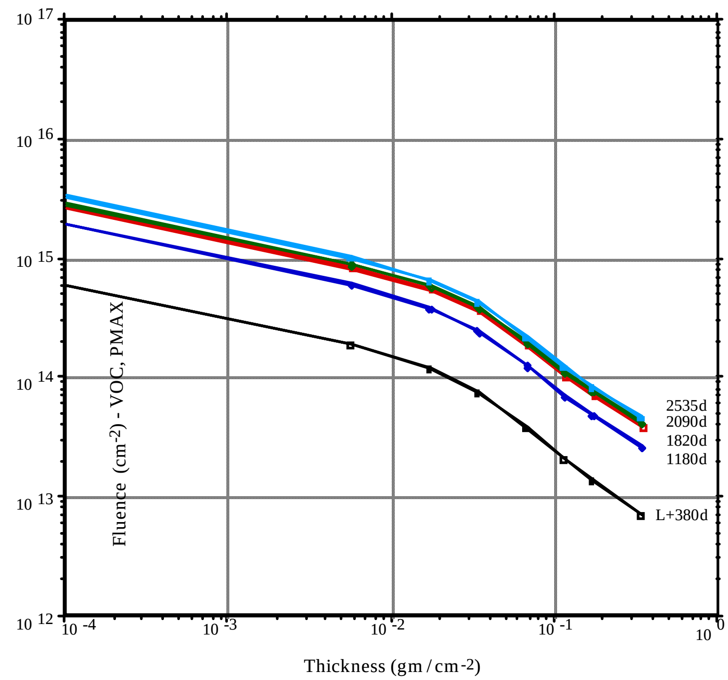


Figure 2.3-5.a Equivalent 1-MeV Electron Fluence vs Thickness and Time from Launch for Effects on Open Circuit Voltage or Max Power

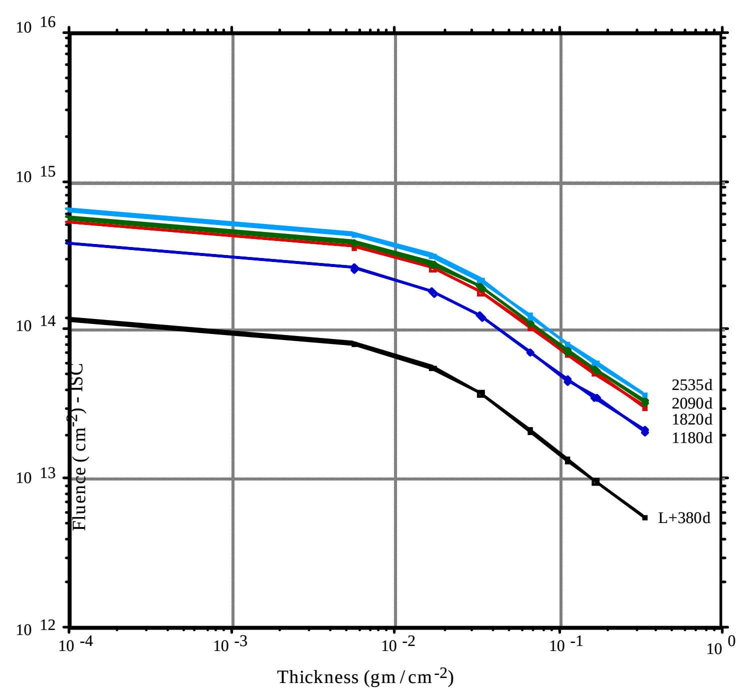


Figure 2.3-5.b Equivalent 1-MeV Electron Fluence vs Thickness and Time from Launch for Effects on Short Circuit Current

Solar flare contribution is given as the flux at 1 AU with a required $1/r^2$ to $1/r^{2.5}$ scaling factor for other distances from the sun. The galactic cosmic ray (GCR) contribution is independent of the spacecraft location.

Probability of Large Solar Events**:** The probability of encountering a 90% to 99% magnitude solar flare, particularly during the comet flyby, is of interest for the spacecraft design team. The probabilities are estimated by D.R. Croley (JPL IOM 5052-96-304) using the model developed by Feynman et al. at JPL. The predicted mean times between flares of 90%, 95% and 99% magnitude are given in Table 2.3-6. The table also gives the derived probability of seeing these flares during the 12 hour period around the flyby.

Table 2.3-6 Probability of Large Solar Flares

Flare Magnitude	>90%	>95%	>99%
Mean time (*solar- max years)	~1.4	~2.8	~16.9
Probability of occurrence during the 12-hrs of the flyby	~1E-3	~5E-4	~8E-5

*Solar-max years=~7 years of ~11 year solar cycle. All of the 7-year STARDUST mission is in the solar-max years according to the model.

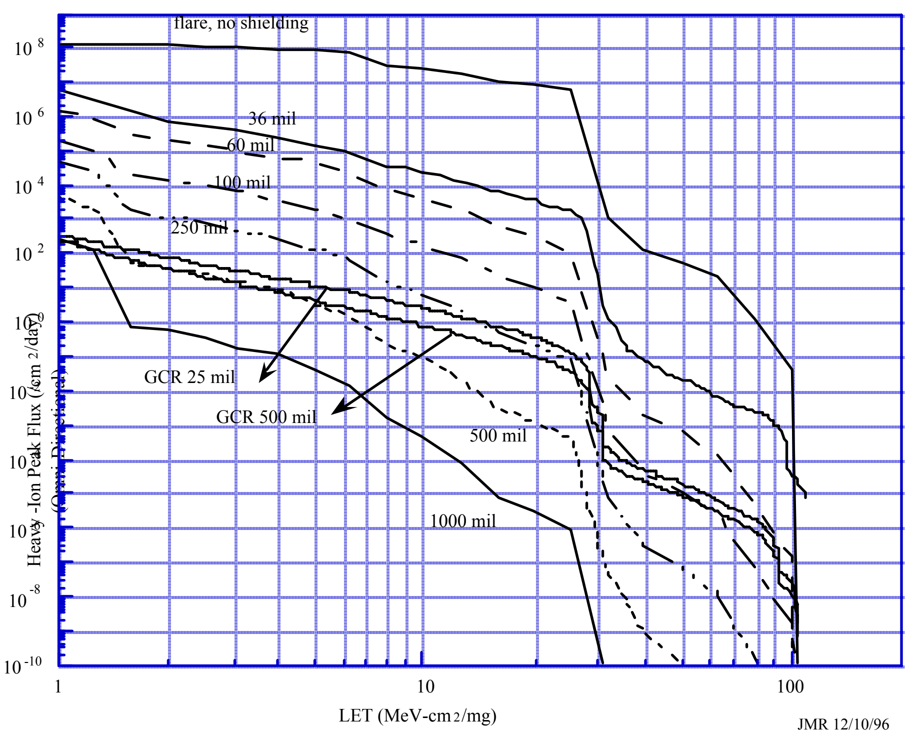


Figure 2.3-6.a Heavy-ion Flux from a 99% Solar Flare at 1 AU and for Adams' 90% Worst Case GCR

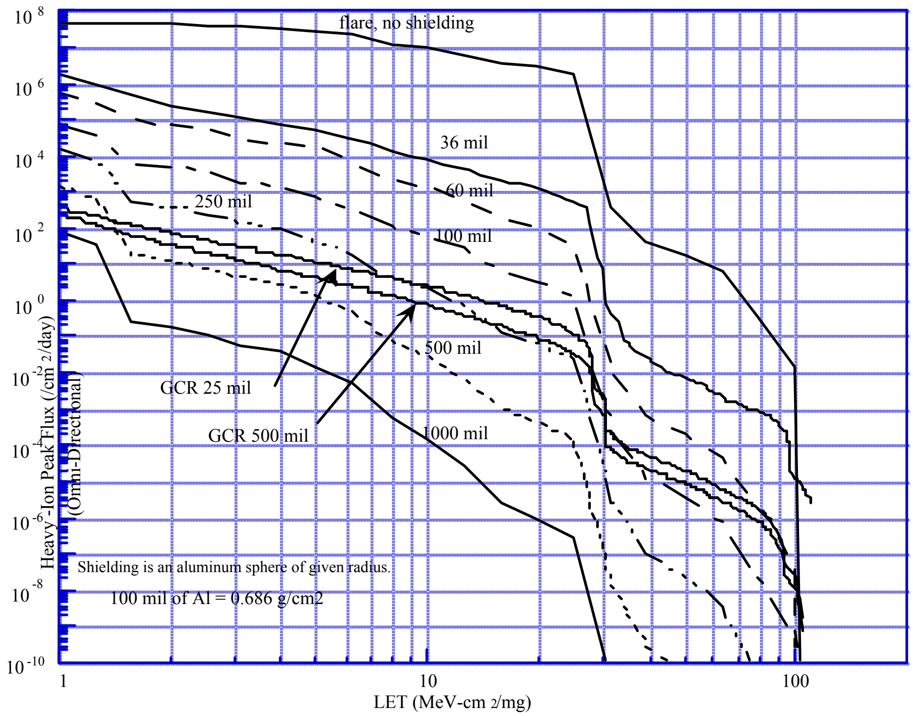


Figure 2.3-6b Heavy-ion Flux from a 95% Solar Flare at 1 AU and for Adams' 90% Worst Case GCR

2.3.3.3 Micrometeoroid

Cumulative micrometeoroid fluence levels as a function of time from Launch is shown in Table 2.3-7. These selected times correspond approximately to each of the three aphelions and to the end of mission. The integral fluence is provided as a function of particle mass. The numbers correspond to 1-sigma levels of the JPL micrometeoroid environmental model. The 1-sigma uncertainty of the model assumes log-normal distribution, thus the 2-sigma and 3-sigma levels are 3 and 9 times of the numbers shown.

Table 2.3-7 STARDUST Mission Micrometeoroid Environment

Time:	L+376.4 d	L+1188.7 d	L+2091.4 d	L+2533.6 d
MASS (grams)	FLUENCE (particles/m^2)			
3.16E-03	9.292E-04	2.340E-03	4.492E-03	4.790E-03
5.62E-03	4.545E-04	1.145E-03	2.198E-03	2.344E-03
1.00E-02	2.223E-04	5.605E-04	1.076E-03	1.147E-03
1.78E-02	1.039E-04	2.621E-04	5.031E-04	5.365E-04
3.16E-02	4.860E-05	1.226E-04	2.353E-04	2.509E-04
5.62E-02	2.273E-05	5.734E-05	1.100E-04	1.173E-04
1.00E-01	1.063E-05	2.682E-05	5.147E-05	5.489E-05
1.78E-01	4.940E-06	1.247E-05	2.393E-05	2.551E-05
3.16E-01	2.296E-06	5.796E-06	1.112E-05	1.186E-05

5.62E-01	1.067E-06	2.694E-06	5.170E-06	5.513E-06
1.00E+00	4.960E-07	1.252E-06	2.400E-06	2.563E-06
1.78E+00	2.306E-07	5.822E-07	1.117E-06	1.192E-06
3.16E+00	1.072E-07	2.707E-07	5.194E-07	5.539E-07
5.62E+00	4.983E-08	1.258E-07	2.414E-07	2.575E-07
Fluence units are -- # of particles for that mass and larger integrated over all velocities				

2.4 Science Investigation Descriptions

2.4.1 Science Investigation Requirements

The STARDUST science investigations have levied the following requirements on the design of the mission:

Primary
- Collect 1000 cometary particles of sizes greater than 15 μm in diameter at an encounter velocity of less than 6.5 km/s and return them to Earth.

Secondary
- Collect interstellar particles for 150 days minimum.
- Provide greater than 65 images of Wild-2, having a resolution of at least 67 μradians per pixel, taken within 2000 km of the comet nucleus through selected filters.
- Provide in-situ particle analysis during comet coma flythrough for resolving abundant elements in cometary solids.

Tertiary
- Provide in-situ particle analysis for interstellar dust.
- Collect comet coma molecules and return them to Earth.
- Conduct dynamic science to measure dust mass fluence, large particles and comet mass upper limit.
- Provide dust flux measurements of 10^{-9}g to 1g particles.

To further understand how these requirements will be met, the following sections describe in more detail the science environments experienced during the mission.

2.4.2 Comet Wild 2

2.4.2.1 Orbit

The orbit of comet Wild-2 was drastically altered in 1974 by Jupiter when it came to within 13 Jupiter radii of the planet. As a consequence, its perihelion distance has been decreased from 5.0 to 1.6 AU. The current ephemeris of Wild-2 is based on 709 observations during the 1983-1977 interval. The current best estimate of the orbital elements of Wild-2 and the position uncertainty (1-σ) near the STARDUST spacecraft encounter time (taking into consideration future ground based observations) are summarized in Tables 2.4-1 and 2.4-2 [source: Orbit Update and Ephemeris Files for Comet 81P/Wild-2, Yeomans, et. al., JPL-IOM 312.F-98-045, July 31, 1998].

Table 2.4-1 Current Best Estimate of Wild-2 Orbital Elements

Orbital Element(1)	Value
Perihelion Date, Tp	26 September 2003
Orbital Period	6.38455254 years
Eccentricity, e	0.540111700
Inclination, i	3.2426206°
Longitude of the Ascending Node, Ω	136.1556471°
Argument of Perihelion, ω	41.7735089°

(1) Earth Ecliptic and Equinox of J2000

Table 2.4-2 Projected Position Uncertainty of Comet Wild-2 at Encounter

Component	Value (km, 1-σ)
δR	1055
δT	65
δS	1093
where: R - position along sun-comet line, T - position normal to comet orbit plane S - perpendicular to R and T in comet orbit plane	

2.4.2.2 Nucleus and Coma

Empirical fit to the light curve of comet Wild-2 in 1978 and 1984 gives the following power law:

$$M_v = 6.7 + 5*\log(\Delta) + 14.62*\log(R)$$

where: M_v is visual magnitude
Δ is S/C - comet range (AU)
R is sun - comet range (AU)

In anticipation of a less bright appearance of Wild-2 in 2003, a modified power law fit, given below, is used for planning the mission:

$$M_v = 7.5 + 5*\log(\Delta) + 15*\log(R)$$

The physical characteristics (size/shape/rotation) of the comet are not well known. For the purposes of mission planning, a nucleus radius of 2.0 km and a coma radius of 100,000 km are assumed.

The proposed 2 km nucleus radius is based on the yet to be published, eight years of data on P/Wild-2 (provided by Dr. Karen Meech) which was gathered using telescopes up and including the world's largest, the 10m Keck reflector. These data easily show that Wild-2 is active out to 4.5 AU both pre- and post-perihelion. There are 13 first quality points (positive identification, no evidence of clouds, proper subtraction of other stars in the reduction aperture, etc.) taken at heliocentric distances greater than 4.5 AU. Ray Newburn has reduced these to a radius by using a geometric albedo of 0.04 and a phase function of 0.035 mag/deg. By grouping the data points (averaging points taken within 30 minutes of each other), he finds the following:

Table 2.4-3 P/Wild-2 Nucleus Radius Observation Reduction

Heliocentric Distance (AU)	No. of points	Mean Radius (km)
4.688	1	2.384
4.764	2	2.009
4.769	4	2.117
4.974	3	1.898
5.025	3	2.037

Source: Private communication from R. Newburn

Note that the single point nearest to the sun, at 4.688 AU, results in the largest radius. This could be a rotational or statistical effect, but it may also indicate residual activity. In any case, the average of the remaining 12 points is 2.015 km. The variation from 1.900 to 2.100 km is probably a rotational effect.

It is anticipated that there will be a separation between the center-of-brightness and the center-of-mass of the comet. An 800 km separation was seen for Halley at 1 AU, but for an order of magnitude less active comet such as Wild-2, much less separation (~100 km or less) is suspected. However, photometric model data appears to indicate that the difficulty for navigation or imaging may be removed at about 10 million km, by imaging the comet in continuum.

2.4.2.3 Dust Environment

The current best estimates of the dust flux at comet closest approach and the dust fluence referred to a solar distance of 1.86 AU at TP+98.5 days are shown in Table 2.4-4. For comparison, the table also contains the dust model documented in the Flight Systems Requirements Document. The FRSD model was used early during the development phase design of the spacecraft whipple shields.
The current dust model incorporates information obtained from observations of Wild-2 taken during 1997. It is an extrapolation from Halley comet data with the following model parameter assumptions:

- Particle size distribution = McDonnell Four slope particle size distribution = -3.65
- Nucleus Radius = 2.0 km, with 40% surface activity

- Dust density = Nucleus density = 1000 kg-cm^{-3}
- Mean dust albedo = 0.04
- Water production = 8.37x10^{27} mol/s
- Total gas production = Additional 20% of mass 44
- Interpolated Continuum Strength Ap(λ)/s = 5.75 meters

The data that is shown in Table 2.4-4 can be extrapolated to different closest approach distances by assuming a spherical $1/r^2$ particle distribution. It can be readily shown that the fluence is proportional to 1/D, where D is the closest approach distance.

The table shows that for the nominal closest approach of 150 km the total number of comet dust particles (diameter > 15 µm) collected will be about 2,700 given the collector area of 0.104 m^2. Recall the science requirement for collection of 1000 particles of sizes greater than 15 µm in diameter. The size requirement enables analysis of the particles by a variety of sophisticated techniques available in laboratories from a broad spectrum of the science community. The quantity requirement provides a sufficient number of samples for a statistically valid sampling of the various particle types, plus sufficient material to allow for handling and destructive analysis losses.

Table 2.4-4 Wild-2 Dust Model (assuming 150 km flyby @ 6.1 km/s)

Science Model (Phase D #2)		
Size Range (Radius)	Flux @ closet approach (#/m^2 /s)	Fluence (#/m^2)
0.1 - 0.4 µm	1.27E6	9.83E7
0.4 - 0.7 µm	2.24E5	1.73E7
0.7 - 1.0 µm	9.79E4	7.56E6
1.0 - 2.0 µm	7.97E4	6.16E6
2.0 - 7.5 µm	1.13E4	8.73E5
7.5 - 10 µm	1.25E2	9.65E3
10 - 20 µm	7.94E1	6.13E3
20 - 50 µm	1.05E1	8.14E2
50 - 100 µm	9.41E-1	7.27E1
0.1 - 0.2 mm	6.37E-1	4.92E1
0.2 - 0.5 mm	5.32E-1	4.11E1
0.5 - 1.0 mm	8.78E-2	6.78
1.0 - 2.0 mm	1.40E-2	1.08
2.0 - 5.0 mm	2.42E-3	1.87E-1
5.0 - 10.0 mm	1.97E-4	1.52E-2
10 - 48 mm	3.67E-5	2.83E-3
	Total	1.302E8

FSRD Model	
Size Range (Radius)	Fluence (#/m^2)
0.1 - 0.4 µm	1.84E9
0.4 - 1.0 µm	1.62E8
1.0 - 2.0 µm	3.08E7
2.0 - 5.0 µm	5.81E6
5.0 - 10 µm	3.21E5
10 - 15 µm	3.05E4
15 - 20 µm	7.19E3
20 - 50 µm	4.72E3
50 - 100 µm	2.68E2
0.1 - 0.2 mm	6.34E1
0.2 - 0.5 mm	2.31E1
0.5 - 1.0 mm	4.03E0
1.0 - 2.0 mm	5.50E-1
2.0 - 5.0 mm	6.90E-2
5.0 - 10.0 mm	3.80E-3
10 - 20 mm	4.50E-4
20 - 50 mm	5.61E-5
50 - 104 mm	3.15E-6
Total	2.04E9

The dust shield, with a total area of approximately 2.05 m^2, is designed to stop a 1 cm diameter (1 g) particle at the encounter velocity. Using the data in the table, it is determined that the risk of spacecraft puncture due to particles greater than 1 cm is less than 5.8E-3.

The particle size and number distribution of the current science model shown in Table 2.4-4 incorporates the observations made during the appearance of Wild-2 in 1997. However, the hazard predictions based on this model is still considered to be speculative. The mission plan includes a real time hazard assessment, on approach to the comet, and an adjustment of the flyby distance at E-2 days, if necessary.

2.4.3 Interstellar Dust Particle (ISP) Sizes, Impact Velocity and Direction

Reports made from 1993 to 1995 by the Ulysses and Galileo dust experiment team suggested that the upstream speed and direction of interstellar dust particles in ecliptic latitude and longitude were within a range of (26 km/s, 2.5° ±6°, 252° ±6) to (30 km/s,10°±10°, 280°±30°). The former, an earlier conjecture, indicated the dust stream to be in the general direction of the interstellar helium gas flow but the latter, a report by Baguhl, et. al., 1995, suggested a different direction for the dust stream. The STARDUST project has used both values in the past, but based on a more recent communications with M. Landgraf (7 Feb 1997), we have adopted a magnitude of 26 km/s and an upstream direction of 7.7° ecliptic latitude and 259° ecliptic longitude. It does not matter too much which value we adopt because of the magnitude of the uncertainty. However, it is very important that the ISP collection experiment be designed in such a manner that the directional information of the collected particles, a key factor in tracing the particle's origin, is retained to the extent possible.

The flight paths of ISP's are modified by the gravity of the sun, the solar pressure and various other complex processes not well or easily formulated. If one considers only the simple effects of solar gravity and solar pressure, the velocities of ISP's of various sizes can be calculated easily as a function of β, where β is the ratio of the solar pressure to solar gravity. High β particles (greater than 1) are low density, fluffy ones while low β particles (less than 1) are dense dark ones.

One to one correspondence between the β group and the particle size cannot be made without knowledge of individual particle density, shape and radiative parameters. If some assumptions regarding these parameters are made, it is possible to estimate the possible range of particle sizes as summarized in Table 2.4-5.

Table 2.4-5 Particle Size Estimate

β	Particle Size (μm)	β	Particle Size (μm)
0.6	0.1 - 0.7	1.4	0.2 - 1.2
1.0	0.1 - 0.9	1.8	0.3 - 2.0
Assumptions: Density = 1-3 g/cc, Reflectivity = 0 - 1			

2.4.4 Interstellar Dust Science Planning Constraints

The definition of the interstellar particle collection periods and CIDA experiment periods is deferred to Section 4.2 Interstellar Dust Science. However, it is important to note the following planning constraints:

- Larger particles are preferred for laboratory analysis. As such, the best orientation for the collection of interstellar particles is one that tracks the β=1 particle.
- The collector pointing strategy should be consistent. If so, it is expected that the tracks left in the aerogel will reveal inertial direction information.
- Low impact velocities (less than 25 km/s) are required to assure higher chance of successful capture of the particles.
- Collection of solar beta population particles is to be avoided to prevent corruption of the interstellar dust sample. Solar beta particles are assumed to have a velocity of 50 km/s [Martha Hanner] and to be traveling radially outward from the sun. Violation is this constraint is allowed for communications, TCMs, and spacecraft deadbanding.
- Contamination of the interstellar sample by plume impingement is to be kept to a minimum. As such, no collection is permitted during DSMs (or TCMs > 20 m/s), but allowed during other TCMs.
- Collection is allowed with as much as half of the collector grid in the SRC backshell shadow if required to lengthen the collection periods.
- The CIDA experiment should be discontinued when less than 25% of the total CIDA field-of-view is exposed to the ISP stream.

3.0 Launch Phase (L+0 to L+30 days)

3.1 Overview

The launch phase begins at the launch vehicle lift-off and ends with the completion of the activation and checkout of most of the spacecraft subsystems. Included in this phase are spacecraft separation from the launch vehicle, establishment of attitude and communications, tracking of the spacecraft and the execution of the first trajectory correction maneuver (TCM-1) to correct the injection error. The duration of this phase is 30 days.

The spacecraft trajectory for this phase is shown in Figure 3.1-1. This plot shows the path of the spacecraft in an Earth-sun fixed coordinate system for the first day of the baseline launch period. Subphases are defined in Table 3.1-1. A trajectory data set containing the following parameters can be found in Section 9.2:

Earth-Probe Range	Moon-Probe Range
Sun-Earth-Probe Angle	Sun-Moon-Probe Angle
Sun-Probe-Earth Angle	Sun-Probe-Moon Angle

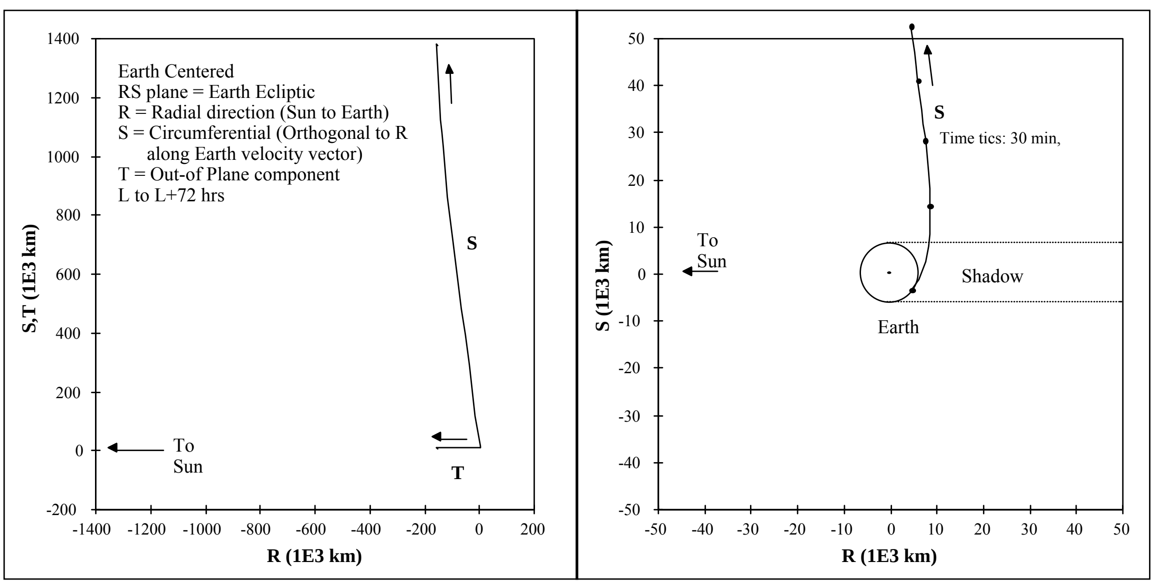


Figure 3.1-1 Launch Phase Spacecraft Trajectory

Table 3.1-1 Launch Phase Subphase Definition

Mission Phase	Sub-Phases	Time (L+days)	Duration (days)

Launch		0 - 30	30
	Initial Acquisition	0 - 1	1
	TCM-1	15	-
	Activation and Checkout	1 - 30	29

3.2 Initial Acquisition Subphase

The initial acquisition subphase includes all activities from launch vehicle liftoff to completion of Deep Space Network (DSN) acquisition. Although one complete day is allocated for this activity, selection of the short coast launch option allows these activities to be completed within three hours of launch.

Prior to liftoff (L/O), the spacecraft is powered on via launch vehicle umbilical power at L/O-240 minutes. The spacecraft is transferred to internal battery power at L/O-4 minutes. At this time the spacecraft is electrically configured for initial cruise mode with the exception that solar panels are not deployed and the solid-state power amplifier (SSPA) is off.

The activities from liftoff to spacecraft separation are summarized in Table 3.2-1 and illustrated in Figure 3.2-1. It should be noted that the numbers presented are specific to a February 6 launch date, but are typical of other launch dates. However, the specific numbers are provided for illustrative purposes only and are subject to change as mission plans mature.

Table 3.2-1 Injection Activities

Event		L/O+(sec)	(min)	Comments
PRE-LAUNCH				
1	Spacecraft power ON	-86400.0	-1440.0	Latch Valves Closed & System Wet; EPS, C&DH, Rcvr, & DST powered
2	Switch to internal power	–240.0	-4.0	On batteries
3	Liftoff	0.0	0.0	
PRE-SEPARATION				
4	Power on Prop Heaters	241.0	4.0	1 lb thrusters, valve, line, tank
5	Main engine cutoff (MECO)	264.0	4.4	
6	Stage II ignition	277.7	4.6	
7	9.5 ft fairing separation	284.0	4.8	
8	First Stage II cutoff (SECO 1)	597.3	10.0	
9	Enter Solar Eclipse	902.0	15.0	02/06/99 launch
10	Restart Stage II	1309.8	21.8	
11	SECO 2	1414.0	23.6	
12	Stage II separation	1467.0	24.5	
13	Power on IMU	1485.0	24.8	sep - 2 min, earliest across LP
14	Stage III ignition	1504.0	25.1	
15	Stage III burnout	1569.3	26.2	
16	Spacecraft separation	1639.0	27.3	Assumes 69.7 seconds coast
17	Open Latch Valves	1640.0	27.3	sep + 1 sec
18	Deploy LV Stage III Yo	1642.0	27.4	
DESPIN				

19	Start S/C despin	1643.0	27.4	delayed to gain sep distance
20	Complete despin	1764.0	29.4	rates < 0.2 deg/s
21	Power on Star Camera	1764.0	29.4	
22	Begin attitude acquisition	1764.0	29.4	
23	Primary string to 1 lb thrusters	1883.0	31.4	
24	Disarm thrusters	1884.0	31.4	No torques during SA deploy

Table 3.2-1 Injection Activities (cont.)

Event		L/O+ (sec)	(min)	Comments
SOLAR ARRAY DEPLOY				
25	Start Solar Array Deploy	1885.0	31.4	
26	End Solar Eclipse	2231.0	37.2	02/06/99 launch
27	Complete Solar Array Deploy	2785.0	46.4	15 min alloc, <10 min est
28	Begin turn to DSN acq. attitude	2786.0	46.4	after re-arming thrusters
DSN ACQUISITION				
29	Begin DSN Acquisition	3385.0	56.4	power on SSPA, begin Xmit
30	Worst case end turn to DSN acq. att.	3386.0	56.4	contingency use of sun sensors
31	Transition to 0.2 lb thrusters	6086.0	101.4	45 min after panels on sun
32	Complete DSN Acquisition	10587.0	176.5	
33	End Launch Activities	10587.0	176.5	

When the spacecraft separates from the third stage of the launch vehicle, push off springs in the launch vehicle adapter provide about 1.5 ft/s separation velocity. At separation, the spacecraft is spinning at approximately 60 (±10%) RPM.

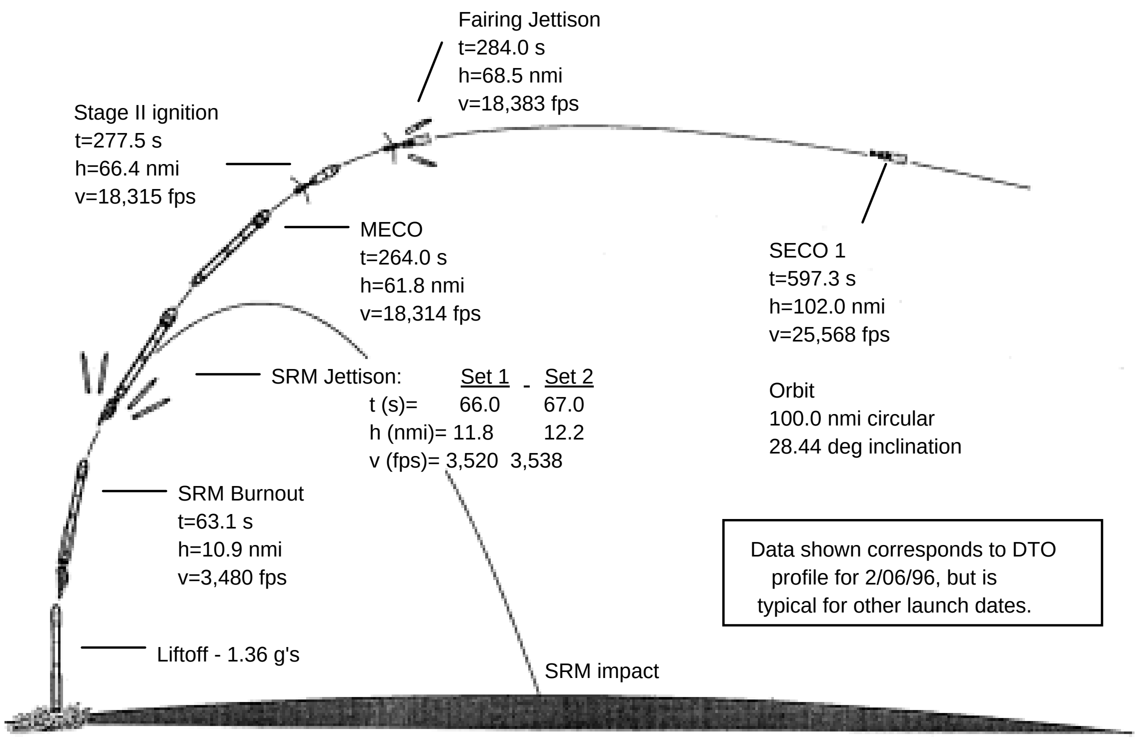


Figure 3.2-1.a Launch Vehicle Boost Profile

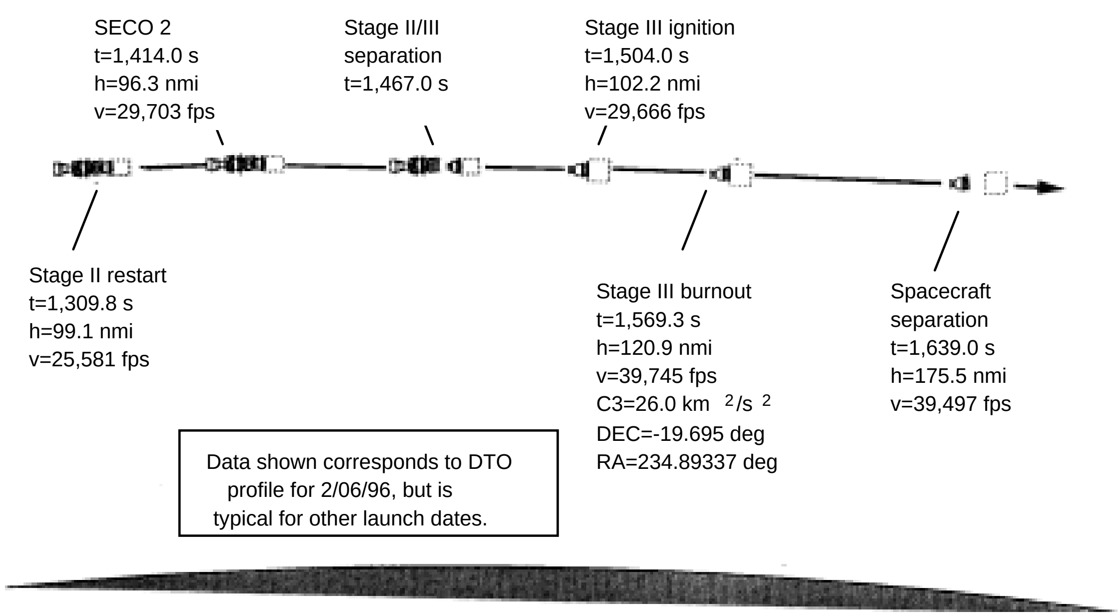


Figure 3.2-1.b Spacecraft Orbit Injection Profile

3.3 Activation and Checkout Subphase

After completion of the initial acquisition subphase, the spacecraft is essentially at a known attitude with communications having been established. At this point the flight team begins a characterization and calibration period of the majority of the spacecraft subsystems. In addition, attitude control maneuvers will commence to maintain the desired attitude. Communication during this period is near continuous.

Key subsystem performance tests will be conducted early in the checkout phase. Table 3.3-1 provides a summary of the subsystem checkout plan. Again it is noted that specific numbers are provided for illustrative purposes only and are subject to change.

Table 3.3-1 Subsystem Checkout Plan

Subsystem	Activity	Time	Risk / Impact	Data Return
ACS	Determine if Star Camera performance can maintain 15° deadband	L to L+14 d	Reliance on IMU for attitude knowledge. Impacts power at aphelion	Star Camera images, attitude knowledge information
Telecom	Verify HGA performance	L to L+90 d	Less data return thru use of MGA.	Nominal telemetry
Navigation Camera (see below)	Perform series of calibrations, includes Scan Mirror	L+4 d to L+18 d	Unable to obtain calibrated optical navigation data	Nav Camera images (window & compress)
CIDA	Verify CIDA is functional	L+5 d	Unable to collect CIDA data	CIDA data
DFMI	Verify DFMI is operational	L+18 d	Unable to collect DFMI data	DFMI data
SRC	Verify SRC latches are operational	L+90 d	Minimal probability SRC fails to open at first ISP collection	Latch telemetry indicating open

The first trajectory correction maneuver (TCM-1) is performed at L+15 days to correct injection errors. At completion of this maneuver, the spacecraft will be ready for the long cruise period that lies ahead.

Within the Activation and Checkout subphase, it is desirable to verify the performance of the Navigation Camera, the Star Cameras, the pointing mirror, the periscope, the Attitude Control System (ACS) and the navigation flight software algorithms of centroiding, windowing and compression, all of which will be heavily used during encounter operations. Table 3.3-2 provides a summary of the current imaging plans for the launch phase.

Table 3.3-2 Launch Phase Imaging Plan

Time	Image Description	no. of images	bits per pixel	no. of filters	Comments
L+4 days	Moon Color	3	16	4	PIO-windowed, best efforts basis depending on launch activities
L+18 days	Mirror pointing, alignment & sensitivity calibration	20	16	1 (nav)	Pattern matched, windowed (10x10), nominal attitude, tight deadband

Special 'coming-off-the-periscope' calibration	10	16	1 (nav)	- same as previous -

3.4 Mission Operations

STARDUST mission operations during the launch phase is comprised mainly of the checkout and activation of spacecraft subsystems, as well as the first orbit determination of the spacecraft trajectory in preparation for TCM-1.

Initial tracking of the launch vehicle through spacecraft separation will be handled by various ground tracking stations operated by the Air Force as well as by Advanced Range Instrumentation Aircraft (ARIA). A NASA requirement calls for tracking of all powered launch vehicle flight activities, so ARIA tracking is required through out the injection burns. Within 30 minutes of separation, Boeing will supply JPL with an injection state based on tracking and telemetered data from the launch vehicle during the launch sequence. After separation, tracking will be taken over by the Deep Space Network's 34M HEF net. Table 3.4-1 summarizes the general mission operations requirements and activities.

Table 3.4-1 Launch Phase Mission Operations

Mission Operation	Description				
Communications	L+0 to 16 d: 24 hr/d, antenna: LGA L+16 to 30 d: 8 hr/d, antenna: LGA				
Navigation	L+15 d: TCM 1				
Spacecraft Attitude	Time	Description	angz (°)	angy (°)	db (°)
	L+0 to 30 d	constant off-sun	-45	180	15
DSN Profile All 34-m	L+0 to +16 d: 24 h/d L+16 to +30 d: 2*4 h/d				

1. See section 10 for attitude mode definitions.
2. DSN Coverage should alternate between Northern Hemisphere and Southern Hemisphere DSN sites.
3. A*B = A number of tracks at B frequency

4.0 Cruise Phases

4.1 Overview

The STARDUST mission has nearly six years of relatively low activity cruise. The cruise phases are subdivided into Cruise 1 (Earth-Earth), Cruise 2 (Earth-Wild-2), and Cruise 3 (Wild-2-Earth). Within these phase are embedded the following subphases: ISP collection, Deep Space Maneuvers (DSM), and Trajectory Correction Maneuvers (TCM). Other activities that occur during the cruise phases but do not have specific subphases associated with them are the CIDA and DFMI experiments.

The spacecraft trajectory for this phase is the same as shown in Figure 2.3-1. Cruise phases and subphases are defined in Table 4.1-1. The Cruise phase data set is considered the same as the Mission data set and can be found in Section 9.1.

Table 4.1-1 Cruise Phase Subphase Definition

Cruise Phase	Sub-Phases	Time (L+days)	Duration (days)
Cruise 1 (Earth-Earth)		30 - 649	619
	DSM-1 (TCM 2)	398 - 402	5
	ISP Collection	403 - 469	66
	TCM 3 (DSM-1 + 30 d)	432	-
Cruise 2 (Earth-Wild-2)		739 - 1691	952
	ISP Collection	1267 - 1402	135
	DSM-2 (TCM 7)	1130	1
	DSM-3 (TCM 8)	1609 - 1611	3
	TCM 9 (DSM-3 + 7 d)	1618	-
Cruise 3 (Wild-2-Earth)		1841 - 2445	604
	TCM 16 (3rd aphelion)	2063	-

4.2 Interstellar Dust Science

Interstellar dust collection is concentrated in the part of the trajectory where the Interstellar dust impact velocity is relatively low (inbound trajectory legs). Collection is performed only during the first two loops resulting in 201 days of total collection time. Collection is not performed on the third loop to avoid contamination of the cometary samples collected during the encounter with Wild-2. CIDA and DFMI operations are nearly continuous, essentially whenever there is sufficient power to turn the instruments on. However, prime CIDA periods can be defined as those during which the interstellar dust stream is made to fall within the field-of-view of the CIDA instrument, while not violating power availability or conflicting with other important mission activities.

With passive experiments and without the need for stringent attitude control (the uncertainty in the radiant direction of the interstellar dust could be as large as 30°), these

phases are very similar to the standard cruise mode (sun-pointed and maintained to ± 15°). The only exception, however, is that in order to maximize the opportunity to collect interstellar particles and conduct the CIDA experiment, certain periods of off-sun pointing are allowed. Also recall that these science opportunities are planned for the β=1 (or reference) particle. These particles are those for which solar pressure and solar gravity are balanced.
In addition to the science constraints described in Section 2.4.3, a number of spacecraft constraints are imposed for the planning of interstellar dust science. The following spacecraft guidelines apply to the design of these experiments:

- Off-sun angles of +z-axis are limited to 15° (absolute) when pointing the +x-axis (whipple shields) toward the sun and 35° (absolute) when pointing the -x-axis (SRC) toward the sun. Assume 15° deadbands during ISP collection and CIDA periods, such that, maximum 'center-of-deadband' off-sun limits are 0° and 20°, respectively.
- Off-Earth angles are limited such that Earth must always be kept within one of the low gain antenna fields-of-view.
- The aerogel grid is to be deployed only once per ISP collection period.
- Science periods should avoid conflicts with other mission phases (Launch, EGA, Encounter) and key geometrical events (solar conjunction).

4.2.1 Interstellar Particle Collection Subphases

Capture of ISP's is accomplished via a passive aerogel collector that is maintained inside the SRC and deployed only during the Wild-2 encounter and these collection subphases. As previously stated, the collection subphases are defined via a number of constraints. The off-sun angle and beta meteoroid constraints in conjunction with the aerogel collector deployment geometry are the primary geometric factors that define the start and end of each collection period. In addition, a combination of spacecraft and science constraints have led to a plan that does not start ISP-1 until after DSM-1 has been completed (see section 4.2.3 for more detail).

Each ISP collection period is constructed from the implementation of two different strategies for tracking the spacecraft relative ISP velocity vector. The first strategy is implemented during the first part of each collection period and involves taking advantage of the deployment motion (about the wrist joint) of the aerogel grid to track the motion of the ISP stream in the spacecraft x-z axis plane. The out-of-plane component of the ISP stream is tracked by yawing (yaw is a rotation about the z-axis) the spacecraft sufficiently to place the s/c relative ISP stream in the x-z axis plane. The +z-axis of the spacecraft, and as a result the solar panels, remain oriented toward the sun.

Once the aerogel grid wrist is fully extended it can no longer be used to track the ISP stream and the second strategy is invoked. The second strategy involves pointing the spacecraft -x-axis toward the incoming ISP stream. With the grid wrist fully extended, the vector normal to the grid surface is parallel to the spacecraft x-axis. The strategy is implemented until the off-sun angle is such that the beta meteoriod constraint is violated, which typically occurs prior to reaching power related off-sun angle constraints.

The ISP schedule is summarized in Table 4.2-1.a. The collection geometry for the first trajectory loop is illustrated in Figure 4.2-1.

Table 4.2-1.a Interstellar Particle Collection Subphases

Period	Start (L+days)	End (L+days)	Duration (days)	Equivalent Full Grid Duration (days)
1	403	469	66	66
2	1267	1402	135	127
Total	-	-	201	193

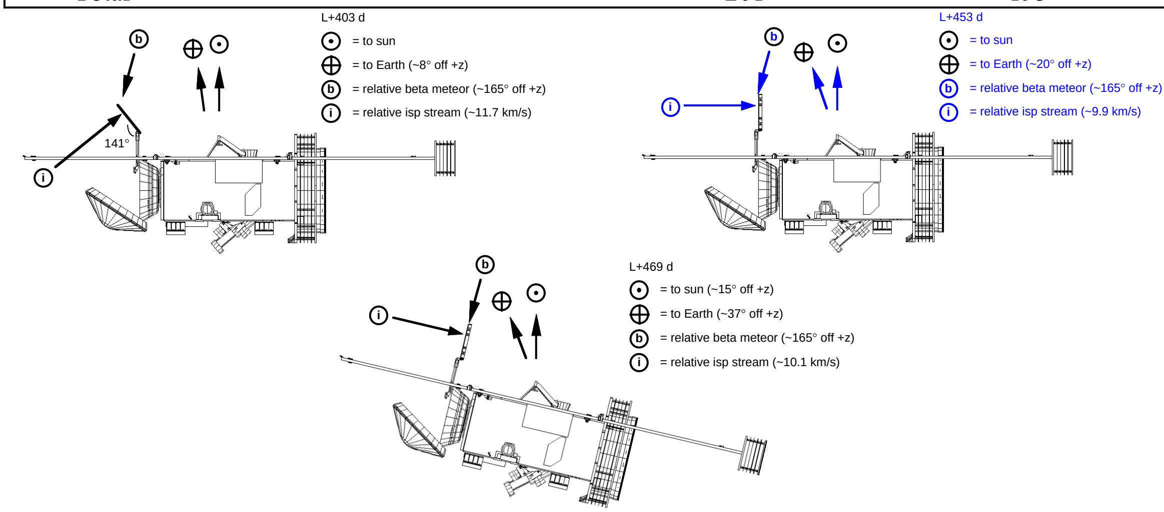


Figure 4.2-1 Profile of ISP Collection Experiment - Loop 1

Based on a flux model of 13 interstellar particles per meter squared per day, a 0.1 m^2 collection area and 193 days of "full grid" collection time, this schedule provides for the collection of about 250 interstellar dust particles. However, thus far we have stressed the collector pointing strategy in terms of the reference ISP's (β=1), in reality ISP's of different dynamic characteristics will impact the aerogel with various speeds and directions.

Both of these strategies are consistent with the above stated off-sun angle limits. As previously stated, the maximum allowable 'center-of-deadband' off-sun angles, given 15° deadbands, are 0° and 20°, respectively. The aerogel grid deployment geometry allows collection to start much earlier than would be possible by a simple off-sun pointing strategy, especially in light of the 0° +x-axis-to-sun off-sun angle constraint.

To illustrate the characteristics of these collection periods, Figures 4.2-2 through -4 provide the history of impact velocity of the ISP's during the collection periods, spacecraft off-sun and off-Earth angles, spacecraft yaw angle, collector deployment angle, grid exposure, and beta meteoriod impact angle. These same characteristics are presented in tables contained in Appendix D. The spacecraft attitude consistent with the ISP plan are also listed in Appendix D. The attitude characteristics of these phases of the mission are summarized with respect to attitude reference planes defined in Table 4.2-1.b.

Table 4.2-1.b Reference Plane Definitions

Item	Definition
SPE Reference Plane	+z axis // r = unit vector from spacecraft to sun +y axis // n = unit vector of cross product of vector to sun and vector to Earth, corrected such that ecliptic-z component is positive +x axis // t = completes the triad
Orbital Reference Plane	+z axis // r = unit vector from spacecraft to sun +y axis // n = unit vector of cross product of heliocentric position and velocity vectors, i.e. orbit angular momentum vector +x axis // t = completes the triad

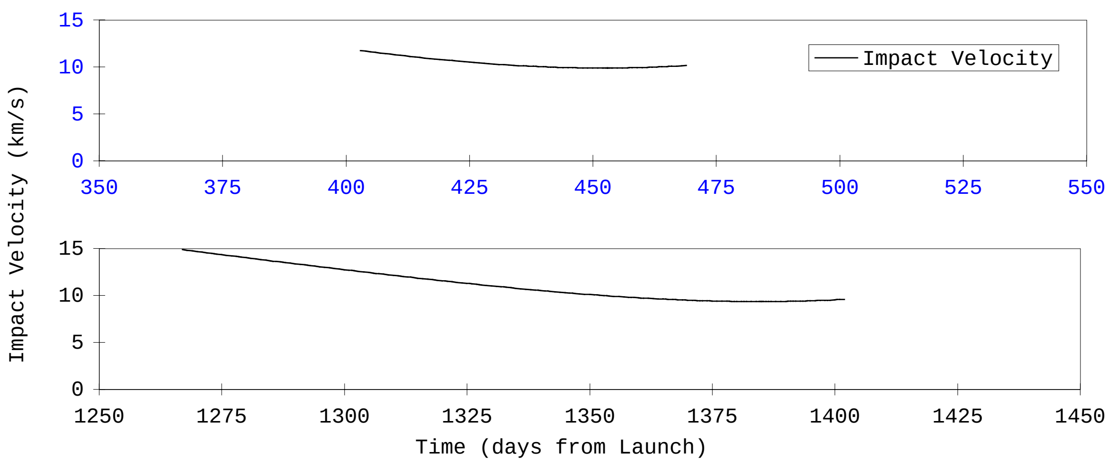


Figure 4.2-2 ISP Impact Velocity History (β=1 particle)

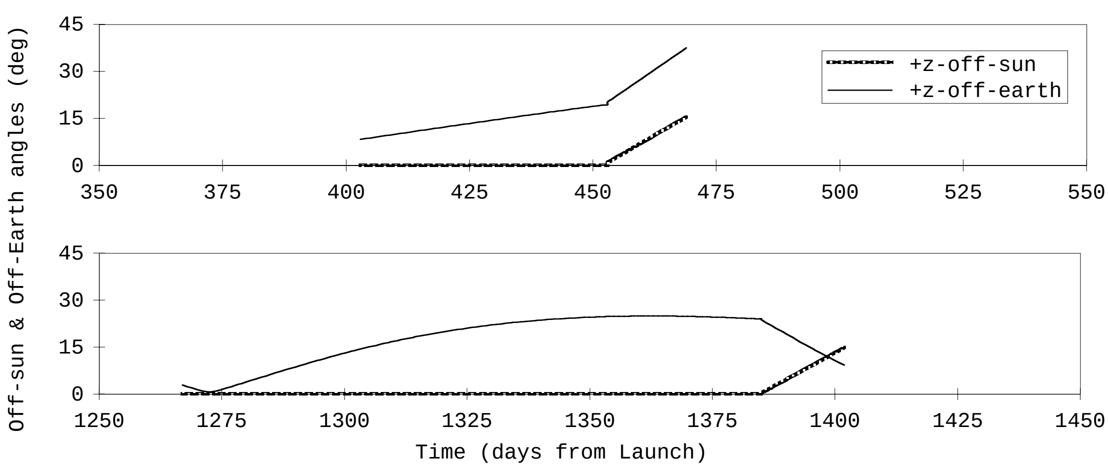


Figure 4.2-3.a. Spacecraft +z-axis Off-sun and Off-Earth Angle History

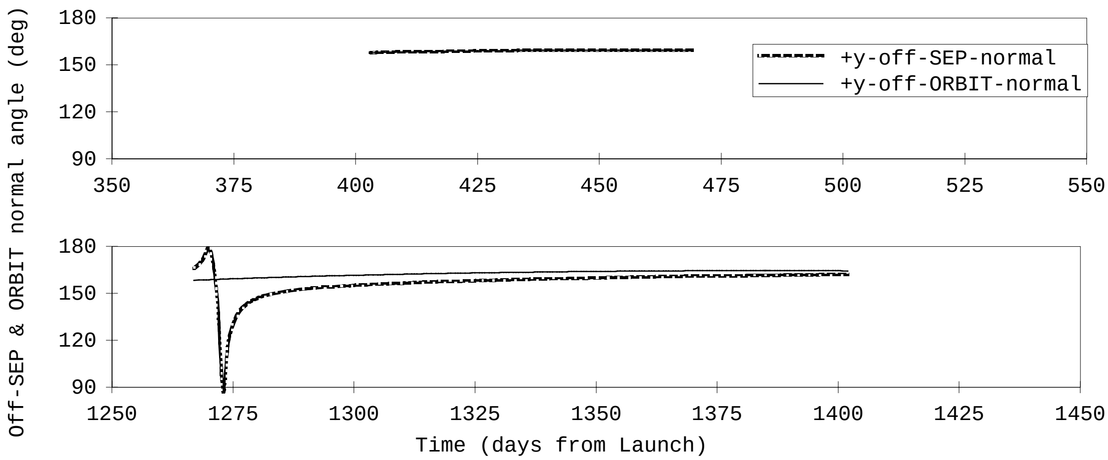


Figure 4.2-3.b. Spacecraft +y-axis Yaw Angle History

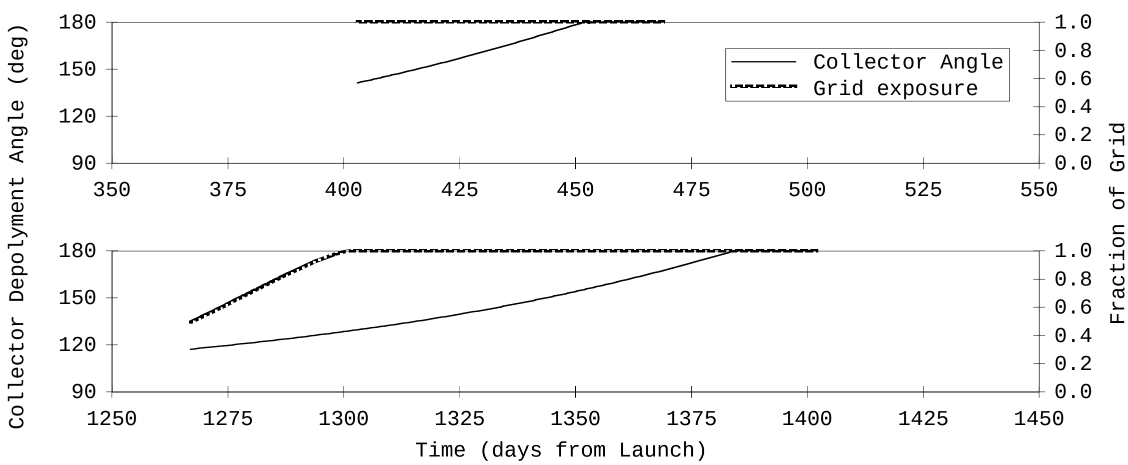


Figure 4.2-4.a. Collector Deployment Angle and Grid Exposure History

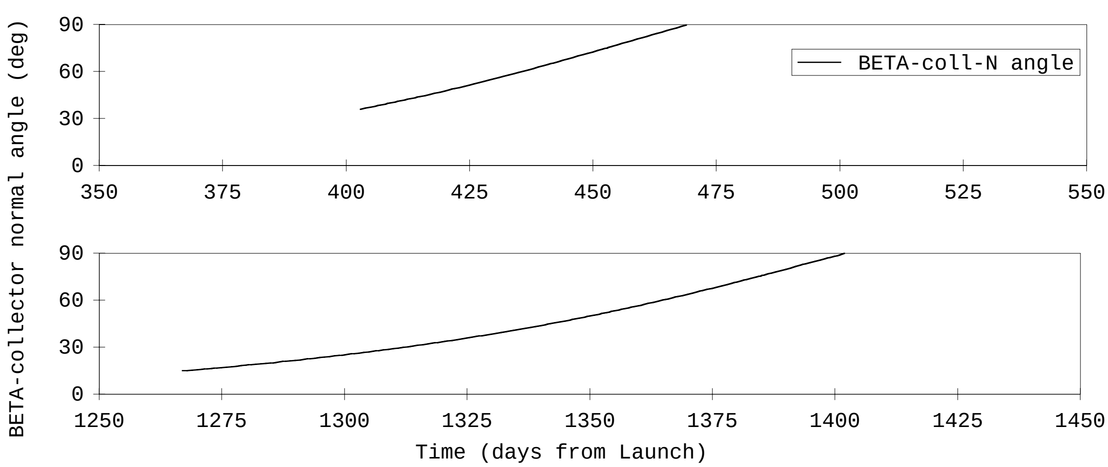


Figure 4.2-4.b. Beta Meteoriod Impact Angle

4.2.2 CIDA Experiment

The Cometary and Interstellar Dust Analyzer (CIDA) is planned to be operated anytime permissible. The main restrictions on CIDA experiment periods are off-sun angle constraints and other mission phases. The CIDA instrument is body fixed and its field-of-view is pointing toward the spacecraft +x-axis. The prime CIDA periods are defined as those portions of the mission during which the interstellar dust stream can be made to fall in the instrument field-of-view (refer back to Section 2.2.2.4).

Similar to the ISP collection periods, the CIDA experiment periods are built from the implementation of two different strategies for tracking the spacecraft relative ISP velocity vector. The initial tracking strategy involves pointing the spacecraft +x-axis toward the incoming ISP stream. The same deadbands (15°) and maximum 'center-of-deadband' off-sun angles, 0° and 20°, as the ISP collection period analysis apply. The start of the CIDA period is determined by when the ISP stream aligns itself with the +x-axis of a sunpointed spacecraft. The spacecraft off-sun angle is increased as the +x-axis is kept aligned with the drifting spacecraft relative ISP stream. This continues until the maximum 'center-of-deadband' off-sun angle, 20°, is achieved. At this point, the second strategy is invoked, which involves maintaining the maximum off-sun angle and allowing the ISP stream to drift through the CIDA field-of-view. The experiment is terminated when less than a quarter of the CIDA target is exposed to the ISP stream. The out-of-plane component of the ISP stream is once again tracked via a spacecraft yaw.

The geometrically defined CIDA experiment periods are reduced by other mission activities. The CIDA 1 and CIDA 2 periods currently allow for some quiet time between the end of important mission phases and the start of CIDA activity (see section 4.2.3 for more detail). The CIDA 3 period is technically scheduled during the encounter phase, but is described here for convenience. The start of CIDA 3 is determined by when the spacecraft is able to establish communications upon exit of the pre-encounter solar conjunction. Options for starting CIDA 3 during solar conjunction are discussed in section 4.2.3. The end of CIDA 3 comes when the communications frequency is increased to 1 track per day in support of the first encounter trajectory correction maneuver.

The CIDA experiment plan is summarized in Table 4.2-2. The experiment geometry for the first trajectory loop is illustrated in Figure 4.2-5. An illustration of the characteristics of these experiment periods are provided in Figures 4.2-6 through 4.2-7. These same characteristics are presented in tables contained in Appendix D. The spacecraft attitude consistent with the CIDA plan are also listed in Appendix D.

Table 4.2-2 Interstellar Particle Related CIDA Experiment Periods

	Start	End	Duration	Equivalent Full Target

Period	(L+days)	(L+days)	(days)	Duration (days)
1	45	144	99	52
2	769	914	145	74
3	1703	1747	44	28
Total	-	-	288	154

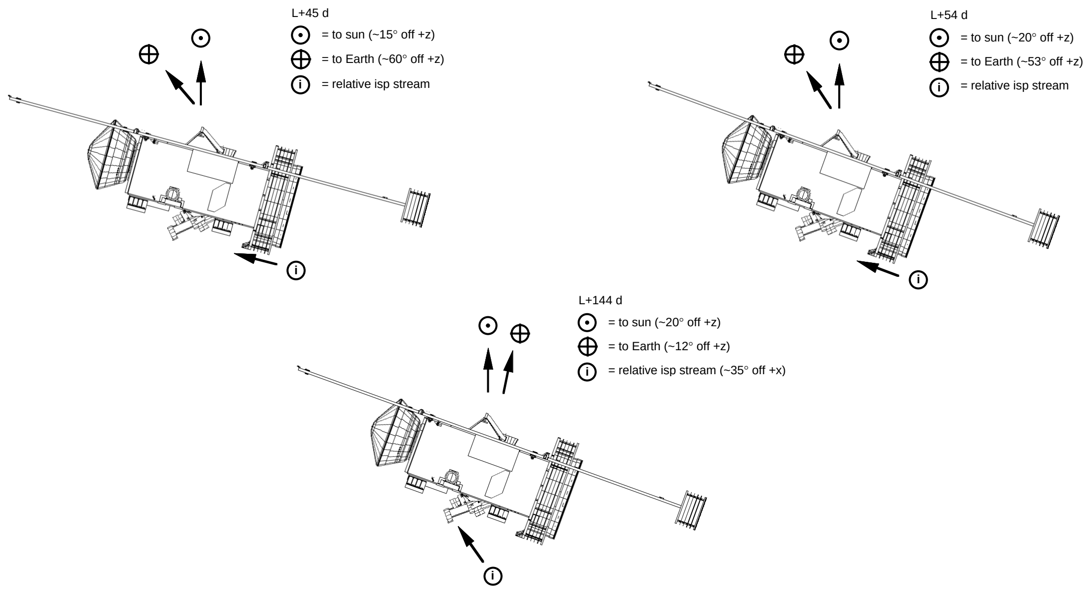


Figure 4.2-5 Profile of CIDA Experiment - Loop 1

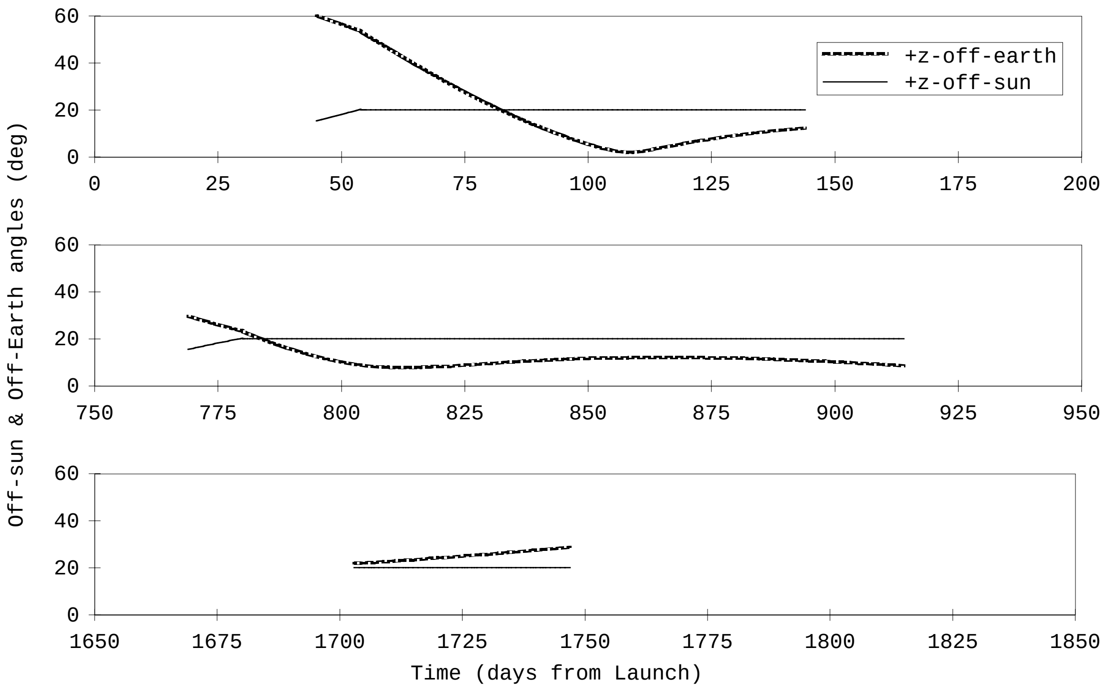


Figure 4.2-6.a. Spacecraft +z-axis Off-sun and Off-Earth Angle History

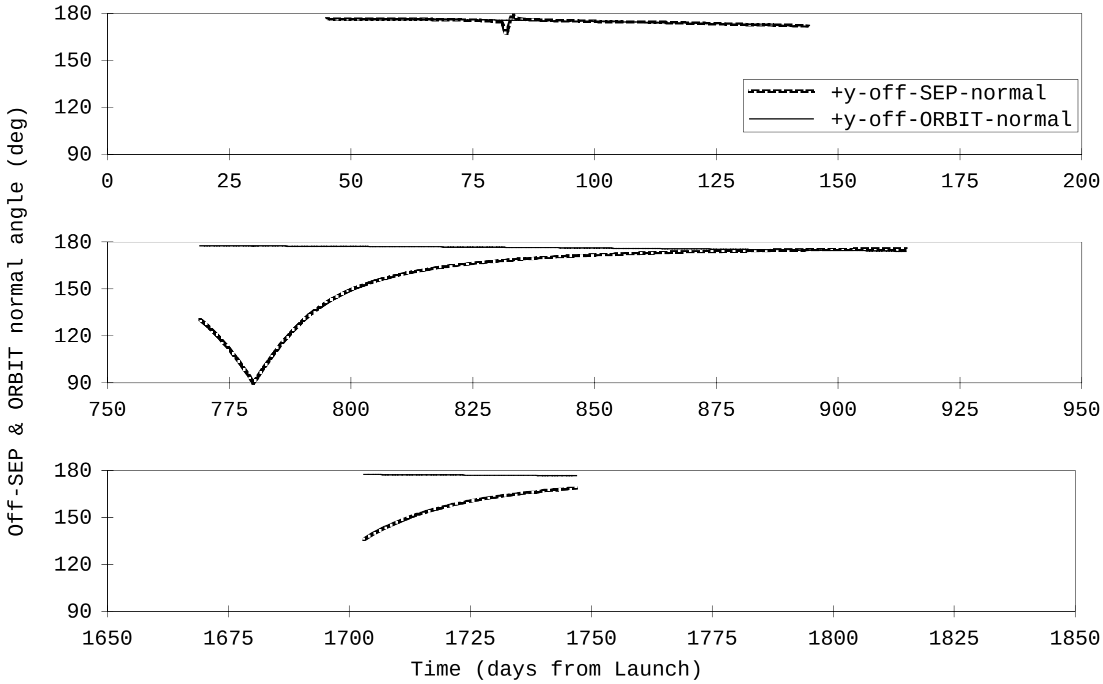


Figure 4.2-6.b. Spacecraft +y-axis Yaw Angle History

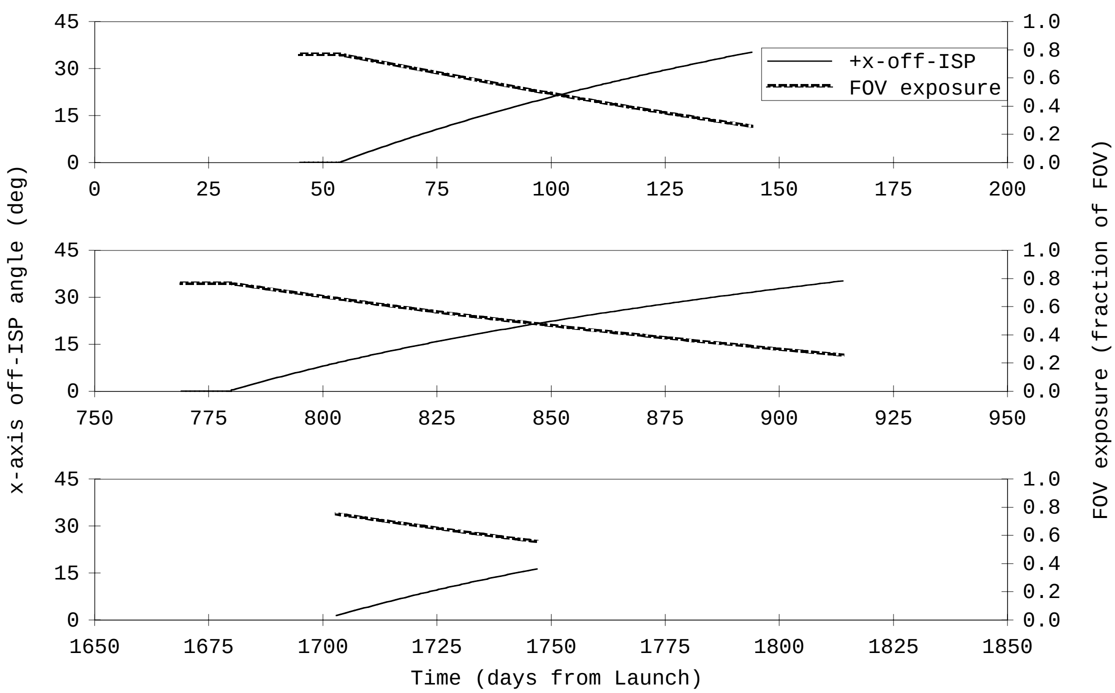


Figure 4.2-7. ISP off +x-axis Angle and Field-of-View Exposure History

4.2.3 Expansion Opportunities for ISP Experiments

The ISP collection and CIDA experiment plans are currently defined to allow easier mission operations and pre-launch mission design. These allowances, based on rigid ground rules, result in less than optimal collection durations. If desired, these constraints may be relaxed, but doing so may add operational and mission plan complexity.

ISP Collection #1

The geometrical conditions suitable for starting ISP 1 can be achieved as early as L+355 days, but DSM-1 would interfere with the collection period. A combination of spacecraft and science constraints have led to the current plan that does not start ISP 1 until after DSM 1 has been completed.

The location of DSM 1 is dictated, after all trajectory design considerations, by the need to allow sufficient radiometric tracking to support the implementation of DSM 1. Radiometric tracking is affected here by a period of solar conjunction that occurs a few weeks prior to the DSM. Based on the NEAR spacecraft solar conjunction experience, DSM 1 has been placed at 14 days after the spacecraft has reached a Sun-Earth-Probe angle of 4 degrees (increasing). For the mission scenario resulting from a launch on the first day of the launch period, DSM 1 could be scheduled such that ISP 1 would start on L+395 days. However, to ease pre-launch trajectory development, DSM 1 has been scheduled to support the latest SEP=4 degree occurrence across the launch period and ISP 1 is set to start at L+403 days. The possible variation of ISP 1 as a function of launch date is illustrated in Figure 4.2-8. Notice that not only does the start of the period change, but so also does the end of the period. The end of the period is constrained by the beta meteoriod avoidance constraint. After launch, it should be possible, if required, to adjust the location of DSM 1 according to the actual launch date and flight trajectory and obtain an earlier start to ISP 1.

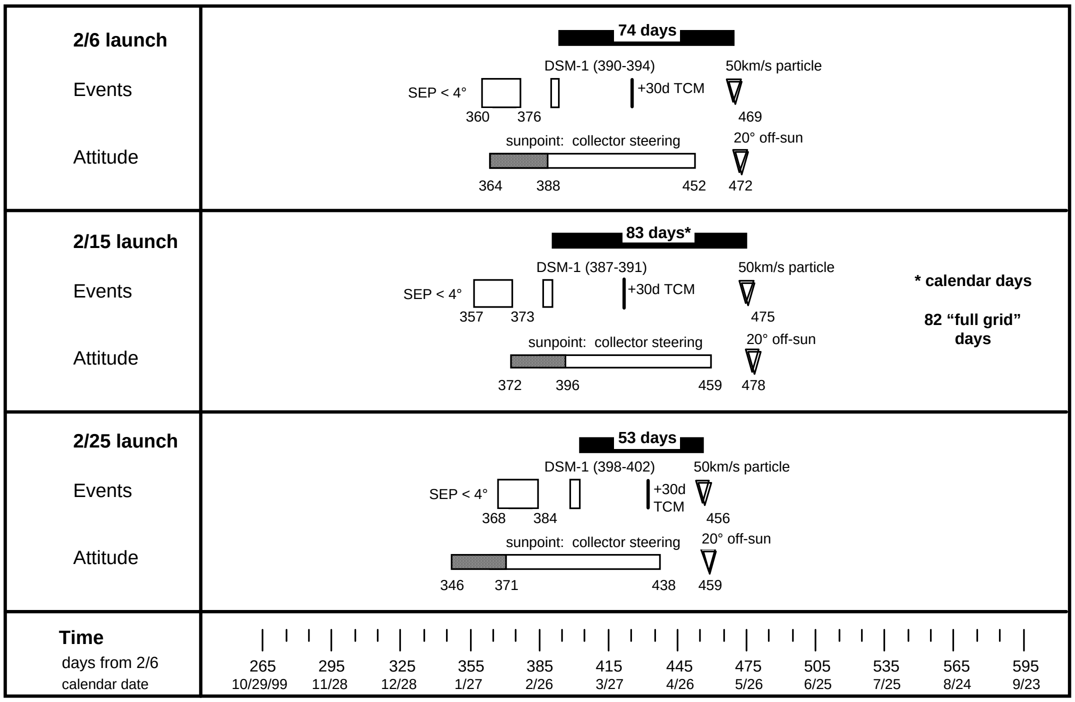


Figure 4.2-8 ISP 1 Variability Across the Launch Period

CIDA Experiment

The CIDA 1 and 2 periods currently allow for some quiet time between the end of important mission phases, Launch and EGA, respectively, and the start of CIDA activity. Geometrically, these periods could start as early as L+20 days (vs. +45 days) and L+740 days (vs. +769 days), respectively. However, operationally, these periods are solidly restricted by the end of the Launch (L+30 days) and EGA (L+739 days) phases.

The baseline CIDA 3 plan does not provide for off-sun attitudes during the pre-encounter solar conjunction period (SEP < 3° for 75 days). However, without a specific spacecraft attitude plan, this portion of the CIDA period will be very inefficient due to the attitude reference to the Sun-Earth-Probe plane (which will be slowly rotating 180° as the spacecraft passes through solar conjunction). A plan can be developed that includes sequenced attitude updates during solar conjunction for more efficient tracking of the ISP stream. The experiment characteristics and associated spacecraft attitudes for implementation of standard CIDA experiment strategies (+x-axis alignment with ISP stream, ISP stream within FOV) during this period are presented in Appendix D.

Finally, the start of off-sun attitudes for CIDA 3 is dictated by the spacecraft exit from the pre-encounter solar conjunction. For planning purposes, 'exit' has been defined as a Sun-Earth-Probe angle of 3 degrees. If operational experience shows that communications are possible at smaller SEP angles, the CIDA 3 off-sun period could be initiated earlier than currently scheduled, L+1703 days. To provide some perspective, in the current trajectory, a Sun-Earth-Probe angle of 2 degrees is achieved at L+1693 days.

4.2.4 Mission Operations Considerations

Current mission operations plan to issue a minimum of weekly updates to the spacecraft attitude and aerogel grid collector angle during ISP collection, and spacecraft attitude during the CIDA experiment. An intentional lead-lag strategy should be established for most efficient tracking of the ISP stream. However, the final spacecraft attitude and collector angle update schedules can be established only after the post launch final uplink schedule is known. JPL will provide a list of daily spacecraft attitudes and collector angles (see section 12) from which LMA will build the required lead-lag update schedule.

4.3 Mission Operations

Mission operations during the Cruise phases are summarized in Tables 4.3-1.a-c. The operations during these phases drop to the lowest level of the mission. Activities required are essentially to maintain the spacecraft attitude profile to ensure adequate reception of solar power, communication with Earth at the scheduled times and tracking of ISP's during the collection and CIDA periods. In addition, the spacecraft gathers and transmits information on spacecraft health as well as the sporadic science data. Imaging plans during cruise are limited to calibrations and standard camera maintenance. These plans are described in Table 4.3-2.

Primary activities on the ground are spacecraft subsystem analysis and maintenance, and the generation of uplink commands. DSN tracking continues using the 34-m HEF network. Medium Gain Antenna (MGA) tracking is performed to obtain radiometric data for orbit determination and DSM/TCM formulation. This radiometric data is comprised of both ranging data and two-way Doppler data (See the Navigation Plan for more details). Spacecraft mode tracking is performed for telemetry and command. An uplink frequency of once per month is anticipated, however, commanding will increase during ISP collection and CIDA periods to allow tracking of the reference particle.

The current request for DSN tracking in support of DSM-1 and its cleanup maneuver, TCM-3, is reduced from the baseline for TCMs. The power constraint to avoid casting shadows on the solar arrays with the whipple shields, and sun-Earth geometry during this phase of the mission would drive a need for large yaw slews (rotation about the z-axis), 160° over 4 hrs, between the ISP collection attitude and the MGA communications attitude. Given this slew scenario, the daily communication requirement surrounding TCMs reduces the amount of time available for ISP collection. Two action are taken to reduce the impact of NAV tracking on spacecraft slewing and on ISP collection time. The first is to schedule use of the HGA instead of the MGA. The HGA's tighter deadband, together with small SPE angles (also coincident with this phase of the mission), allows the spacecraft to communicate with the Earth without performing a large yaw, while continuing to meet solar array shadow constraints. The second strategy is a reduction to the amount of daily tracking required to support these maneuvers. Post-DSM-1 and pre- and post-TCM-3, daily tracking is reduced from 2 weeks to 1 week.

Mission operations are slightly more complex during actual execution of DSM's and TCM's. During the maneuvers, the attitude of the spacecraft is such that solar power and telemetry will most likely not be available. The rechargeable battery will be the source of power. The two large DSM's (1 and 3) cannot be executed in a single burn due to insufficient battery capacity. The current plan is to implement DSM-1 in three segments and DSM-3 in two. Each burn is separated by two days to provide sufficient time for battery recharging. No ΔV updates between each cluster of burns is planned. However, receipt of telemetry and radiometric data (>1 hr) for burn reconstruction may be possible during battery recharging.

At solar ranges beyond 2.5 AU, second (L+1014 to 1320) and third (L+1942 to 2219) aphelion, the spacecraft operational capabilities are power limited such that a full 4 hour pass may not be supportable. The duration of tracking passes at these solar ranges will be reduced from 4 hours to the maximum allowable, down to a minimum of 2 hours (if required) at aphelion. The second DSM and a TCM are scheduled during second and third aphelion, respectively. A reduced tracking frequency and track duration is imposed in support of these maneuvers.

Three TCM's are planned during the cruise phase. Two of them are performed 30 and 7 days after DSM-1 and -3, respectively, to correct execution errors. The third is performed at third aphelion and provides an opportunity for early targeting of the return trajectory.

Table 4.3-1.a Cruise Phase Mission Operations

Mission Operation	Description	
Communications	4[1] hrs / week, antenna: MGA 4[1] hrs / month, antenna: HGA, can replace navigation tracking TCM/DSMs (<u>overlay</u> changes for DSM 1,2 / TCM 3,16 below)- Two - 4 hr pass/week - MGA Comm, -14 to -28, +14 to +28d 4 hrs /day - MGA Comm, ± 14 d of first/last segments 1 hr / between seg. - HGA Comm, DSMs only - if possible DSM 1 / TCM 3 (overlap with ISP-1) - overlay changes: 4 hrs /day - HGA Comm, 0 to +7 d, DSM-1 Two - 4 hr pass/week - HGA Comm, +7 d DSM-1 to -7 d TCM 3 4 hrs /day - HGA Comm, -7 to 0 d, TCM 3 Two - 4 hr passes/week - MGA Comm, +7 to +28 d, TCM 3 DSM 2 / TCM 16 (aphelion maneuvers) - overlay changes: 4[1] hrs / every other day - MGA Comm, ± 14 d	
Navigation	L+398-402 d: DSM-1 (TCM 2) L+432 d: TCM 3 L+1130 d: DSM-2 (TCM 7)	L+1609-1611 d: DSM-3 (TCM 8) L+1618 d: TCM 9 L+2063 d: TCM 16

1. Or maximum allowable at solar ranges greater than 2.5 AU Minimum of 2 hours for radiometric tracking.

Table 4.3-1.b Cruise Phase Mission Operations - DSN Profile

Antennas:	All 34-m(4)	
L+30 to +43d: 2*4 h/w L+43 to +370d: 4 h/w L+370 to +384d: 2*4 h/w L+384 to +409d: 4 h/d L+409 to +425d: 2*4 h/w L+425 to +439d: 4 h/d L+439 to +460d: 2*4 h/w L+460 to +621d: 4 h/w L+621 to +635d: 2*4 h/w L+635 to +649d: 4 h/d L+649 to +739d: EGA	L+739 to +753d: 4 h/d L+753 to +767d: 2*4 h/w L+767 to L+1014: 4 h/w L+1014 to +1102d: 4(1) h/w L+1102 to +1116d: 2*4(1) h/w L+1116 to +1144d: 4(1) h/ 2d L+1144 to +1158d: 2*4(1) h/w L+1158 to +1320d: 4(1) h/w L+1320 to +1581d: 4 h/w L+1581 to +1595d: 2*4 h/w L+1595 to +1632d: 4 h/d	L+1632 to +1646d: 2*4 h/w L+1646 to +1691d: 4 h/w L+1691 to +1841d: Encounter L+1841 to +1942d: 4 h/w L+1942 to +2035d: 4(1) h/w L+2035 to +2049d: 2*4(1) h/w L+2049 to +2077d: 4(1) h/ 2d L+2077 to +2091d: 2*4(1) h/w L+2091 to +2219d: 4(1) h/w L+2219 to +2445d: 4 h/w L+2445 to +2536d: Return

1. Or maximum allowable at solar ranges greater than 2.5 AU Minimum of 2 hours for radiometric tracking.
2. DSN Coverage should alternate between Northern Hemisphere and Southern Hemisphere DSN sites.
3. A*B = A number of tracks at B frequency

Table 4.3-1.c Cruise Phase Mission Operations - Spacecraft Attitude

Time (days)	Description	angz (°)	angy (°)	db (°)
L+0 to 30	Launch Phase			
L+30 to 45	constant off-sun	22	180	15
L+45 to 54	CIDA tracking	-	-	15
L+54 to 144	CIDA constant off-sun	-20	-	15
L+144 to 369	constant off-sun	0	180	15
L+369 to 403	constant off-sun	0	0	15
L+403 to 453	ISP collector steering	-	-	15
L+453 to 469	ISP tracking	-	-	15
L+469 to 649	constant off-sun	0	0	15
L+649 to 739	EGA Phase			
L+739 to 744	constant off-sun	20	0	15
L+744 to 769	constant off-sun	0	0	15
L+769 to 780	CIDA tracking	-	-	15
L+780 to 914	CIDA constant off-sun	-20	-	15
L+914 to 1053	constant off-sun	0	180	15
L+1053 to 1267	constant off-sun	0	0	15
L+1267 to 1385	ISP collector steering	-	-	15
L+1385 to 1402	ISP tracking	-	-	15
L+1402 to 1523	constant off-sun	0	180	15
L+1523 to 1658	constant off-sun	0	0	15
L+1658 to 1691	constant off-sun	0	180	15
L+1691 to 1841	Encounter Phase			
L+1841 to 1965	constant off-sun	0	0	15
L+1965 to 2185	constant off-sun	0	180	15
L+2185 to 2445	constant off-sun	0	0	15
L+2445 to 2536	Return Phase			
MGA communications: 7° off +z-axis to Earth				6
HGA communications: +z-axis to Earth				2

1. See section 10 for attitude mode definitions.

Table 4.3-2 Cruise Phases Imaging Plan

Approx	no. of	bits per	no. of

Time	Image Description	images	pixel	filters	Comments
L+150 days	Standard star in Hyades - solar analog	28	16	7	4 exp / 7 filters, windowed (15x15), yaw turn, mirror, tight deadband
	Zero exposure	3	16	1	windowed (20x20), determine camera bias (~400 DN)
	Photocal w/ lamp on	21	16	7	3 exp / image, same attitude and windows as 'standard star'
L+200 days	Stray light test at encounter conditions	6	16	1 (hi-res)	@ max exposure, 3 @ 0,1 @ 10, 20, 30 degree mirror angle, no ISP conflict, full frame, SPE same as encounter (~17 deg).
L+410, days	Standard Maintenance Sequence	10 /ea	16 (8?)	1 (nav)	pattern matched, windowed (10x10), nominal background attitude, tight deadband
	* repeat L+590, 920, 1100, 1410, 1510 days				

5.0 Earth Gravity Assist Phase (EGA-60 to EGA+30 days)

5.1 Overview

The Earth flyby is performed to provide a gravity assist to the STARDUST spacecraft and reduce the ΔV requirements of the mission. The flyby changes the orbital period from 2 years to about 2.5 years. The spacecraft approaches Earth with a velocity of 6.5 km/s from the dark side and recedes back into the dark side having flown by the sunward side. At closest approach, the altitude, for a 02/06/99 launch, will be 5965 km, but could be as low as 1649 km depending on the actual launch date of the mission. During the flyby the Sun-Earth-Probe angle cycles from ~130° to 28° at closest approach to a minimum of 19° (8 minutes after closest approach) and back up to ~90° toward the end of the EGA phase. The Earth flyby time is also dependent on the actual launch date. For planning purposes, the first launch date is assumed which results in a flyby date and time of 15 January 2001 11:01:24 (ET), or L+708.5 days.

Three special activities are planned for the Earth Gravity Assist (EGA) phase. The first is a rehearsal or demonstration of the navigation processes required during return to Earth. This activity is envisioned to be a ground activity only and will not involve the spacecraft or require any increase in DSN resources. The second is an opportunity to take Earth-Moon images. The third and final activity is a Dust Flux Monitor Instrument experiment. Its objective is to collect data on dust particles near Earth perigee, within the near-Earth magnetosphere. Support of this activity will require the DFMI to be turned on and for the spacecraft +x-axis to be oriented parallel to the spacecraft velocity vector as the spacecraft flys through perigee.

As previously mentioned, the Earth flyby contributes substantially to the reduction of ΔV requirements for STARDUST. As such, an accurate execution of this event is important. The JPL navigation team has successfully navigated Earth flybys twice for the GALILEO project and will have done it again for the CASSINI project. No difficulties are anticipated.

The spacecraft trajectory, again for a 02/06/99 launch, in Earth-sun fixed coordinates for this phase is shown in Figure 5.1-1. Subphases are defined in Table 5.1-1. A trajectory data set containing the following parameters can be found in Section 9.3:

Earth-Probe Range
Sun-Earth-Probe Angle
Sun-Probe-Earth Angle
Moon-Probe Range
Sun-Moon-Probe Angle
Sun-Probe-Moon Angle

Table 5.1-1 Earth Gravity Assist Phase Subphase Definition

Mission Phase	Subphases	Time (L+days)	Duration (days)
Earth Gravity Assist		649 - 739	90

(EGA-60d to +30d)	TCM 4 (EGA-60 d) TCM 5 (EGA-10 d) TCM 6 (EGA+30 d)	649 698 739	- - -

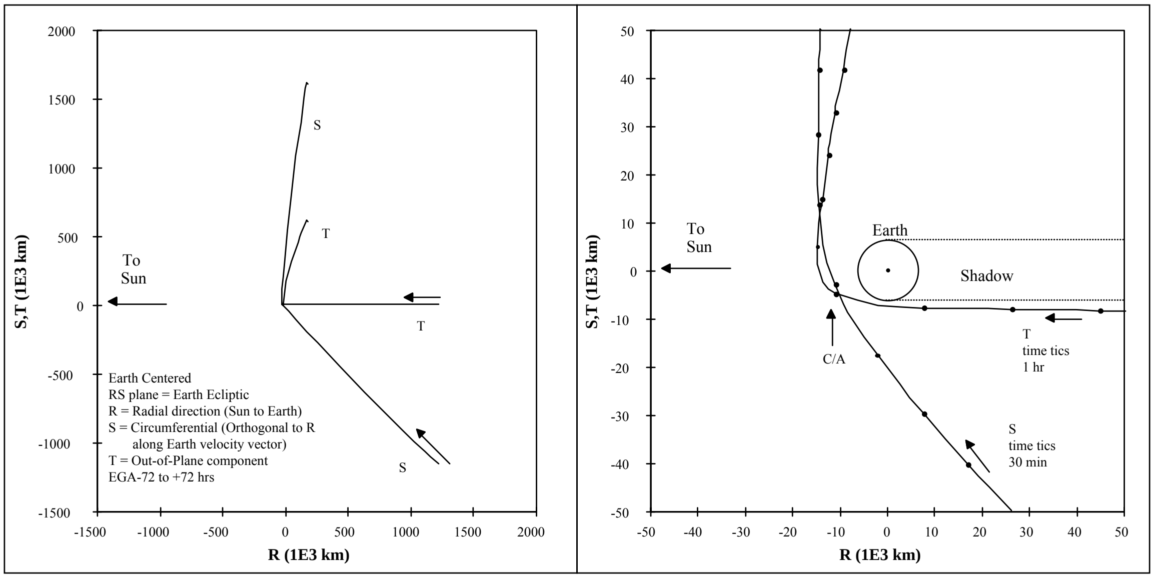


Figure 5.1-1 Earth Gravity Assist Phase Spacecraft Trajectory

5.2 Mission Operations

Mission operations during the EGA phase is summarized in Table 5.2-1. Support requirements for the special activities of the EGA phase will be developed post-launch, if required. However, they are expected to fit within the allocated resources. As before, ground activities are increased during the TCM periods to process radiometric data and generate the TCM commands. The delivery accuracy for the -10 day TCM is expected to be 10 km (1-σ). Two other TCM's are performed during this phase at closest approach - 60 days and +30 days.

Table 5.2-1 Earth Gravity Assist Phase Mission Operations

Mission Operation	Description				
Communications All MGA, except LGA: L+708-728	EGA - 8 hrs /day, within ±14 days TCMs - Two - 4 hr passes week, -14 to -28, +14 to +28d 4 hrs / day, within ± 14 days				
Navigation	L+649 (EGA-60 d): TCM 4 L+699 (EGA-10 d): TCM 5		L+739 (EGA+30 d): TCM 6		
Spacecraft Attitude	Time	Description	angz (°)	angy (°)	db (°)

(see section 10 for attitude mode definitions)	L+649 to 668 d	constant off-sun	0	0	15
	L+668 to 704 d	constant off-sun	0	180	15
	L+704 to 708 d	constant off-sun	-17	180	15
	L+708 to 709 d	constant off-sun	-45	0	15
	L+709 to 728 d	constant off-sun	-45	180	15
	L+728 to 739 d	constant off-sun	20	0	15
	MGA communications: 7° off +z-axis to Earth				6
DSN Profile All 34-m	L+649 to +663d: 4 h/d L+663 to +685d: 2*4 h/w L+685 to +695d: 4 h/d		L+695 to +723d: 8 h/d L+723 to +739d: 4 h/d		

1. DSN Coverage should alternate between Northern Hemisphere and Southern Hemisphere DSN sites.
2. A*B = A number of tracks at B frequency

6.0 Wild-2 Encounter Phase (E-100 to E+50 days)

6.1 Overview

The most important phase of the STARDUST mission nominally starts 100 days prior to and ends 50 days after comet encounter (L+1790.9 days). DSM-3, completed during the Cruise-2 (Earth-Wild 2) phase, at encounter minus 180 days (E-180 d), is the first aim at Wild-2. Knowledge of the orbital state of Wild-2 at this time will still be based on ground observations which will have an estimated position uncertainty of about 1520 km (1-σ). A better estimate of the comet ephemeris is expected at about E-50 d after optical navigation (OPNAV) has been in operation for some time. (See Navigation Plan document, SD-76000-100, for more details). Independent of launch date, encounter with the comet Wild-2 occurs at a reference time of 02 January 2004 19:20:00 ET.

The primary goal of obtaining comet coma samples during the encounter flyby is accomplished by a navigation plan that delivers the spacecraft with the required accuracy. It is also necessary to assure the survival of the spacecraft at a reasonable level of confidence. The spacecraft encounters Wild-2 at 98.5 days past perihelion. At this point of its orbit, Wild-2 is far from its "peak" active period and it should be relatively safe for a 150 km closest approach. A risk analysis based on a probabilistic model of the Wild-2 dust environment is required, however, this exercise is regarded as preliminary until a time when a better model may be constructed upon approach to the comet. The current model is based on best estimates. Adjustment of the encounter parameters (flyby date and distance) is possible if required by mission risk issues. Given the current dust models, these adjustments are possible without penalizing mission performance.

This mission phase proceeds from an initially slow pace (scale of days) and progresses gradually to an extremely fast pace (minutes/seconds) centered around the closest encounter. In order to organize this mission phase in a more orderly way, it is divided into four subphases: Far Encounter, Near Encounter, Close Encounter and Post Encounter. The Far Encounter subphase focuses on acquisition of comet and coma science data. The Near Encounter subphase emphasizes terminal navigation and high resolution coma and nucleus activities. The Close Encounter subphase is the core science period of STARDUST. It contains comet dust sample collection and high resolution nucleus imaging. Finally, the Post Encounter subphase is dedicated to mission performance assessment and return of stored science data. Five TCM's are performed on approach to the comet. The final TCM before encounter is performed at 6 hours from closest approach and is expected to be implemented only in case of a contingency. These subphases are further defined in Table 6.1-1.

Encounter activity is not scheduled to start until the spacecraft exits from the pre-encounter solar conjunction. For planning purposes, 'exit' has been defined as when the Sun-Earth-Probe angle reaches 3 degrees (increasing). On the current trajectory, this occurs 88 days prior to closest approach. The encounter phase definition, however, is left at E-100 days as operational experience may allow a reduction of the 3 degree SEP angle planning value. The end of the encounter phase, E+50 days, is defined to encompass all possible data return scenarios, and to adequately cover all post-encounter TCM activity.

Table 6.1-1 Wild-2 Encounter Phase Subphase Definition

Mission Phase	Sub-Phases	Time	Duration
Wild-2 Encounter		L+1691 - 1841d	150 d
(E-100d to +50d)	Far Encounter	E-100 to -1d	99 d
	Near Encounter	E-1d to -5h	19 h
	Close Encounter	E-5 to +5h	10 h
	Closest Encounter	E-5 to +5 m	10 min
	Post Encounter	E+5h to +50d	50 d
	TCM 10 (E-30 d)	L+1761 d	-
	TCM 11 (E-10 d)	L+1781 d	-
	TCM 12 (E-2 d)	L+1789 d	-
	TCM 13 (E-18 h)	L+1790 d	-
	TCM 14 (E-6 h)	L+1791 d	-
	DSM 4 (TCM 15) (E+30 d)	L+1821 d	-

An abbreviated CIDA 3, described in section 4, is scheduled for the first half of the encounter phase where imaging and communications activity is minimal. The spacecraft attitude required to support the CIDA experiment is significantly different from the desirable communications attitude. As a result, the CIDA experiment is abandoned (E-44 days) once daily navigation tracking (MGA comm) is initiated in support of the first approach TCM.

The spacecraft trajectory in a Wild-2-sun fixed system for this phase is shown in Figure 6.1-1. Notice that the small out-of-plane component of the spacecraft path indicates that it is nearly in the comet's orbital plane. The spacecraft approaches Wild-2 from above and recedes under the comet orbit plane. The Sun-Wild-2-Probe angle starts at 73° which is favorable for pre-encounter comet viewing. This phase angle reaches a minimum approaching 0° near closest approach and rises back up to 107° toward the end of the encounter phase. The flyby speed is 6.1 km/s and the nominal flyby distance is 150 km on the sunward side. The 3-sigma minimum flyby distance is 120 km when considering navigation delivery errors. The spacecraft is presented with the dark side of Wild-2 as it recedes from the comet.

Near the closest encounter, the spacecraft +x-axis is pointed in the spacecraft-Wild-2 relative velocity direction such that the dust shield protects the spacecraft bus and solar panels. In this flyby configuration, the Earth is located in the direction of the spacecraft +z-axis (also HGA direction). The selection of TP+98.5d as the encounter date has been dictated by this encounter geometry which translates into simplicity and mass savings in the installation of the HGA. The sun is 17° off the +z-axis near the encounter which results in a slight cosine power loss.

Independent of launch date, the comet closest approach time has been established to be 02 January 2004, 19:20 ET, under near-identical sun, Earth, comet and spacecraft geometries. This time was chosen to allow for scheduling of the comet flyby during the Goldstone-Canberra DSN viewperiod overlap. The elevation angles for this period of the mission are illustrated in Figure 6.1-2. An encounter phase overview is provided in Figure 6.1-3.

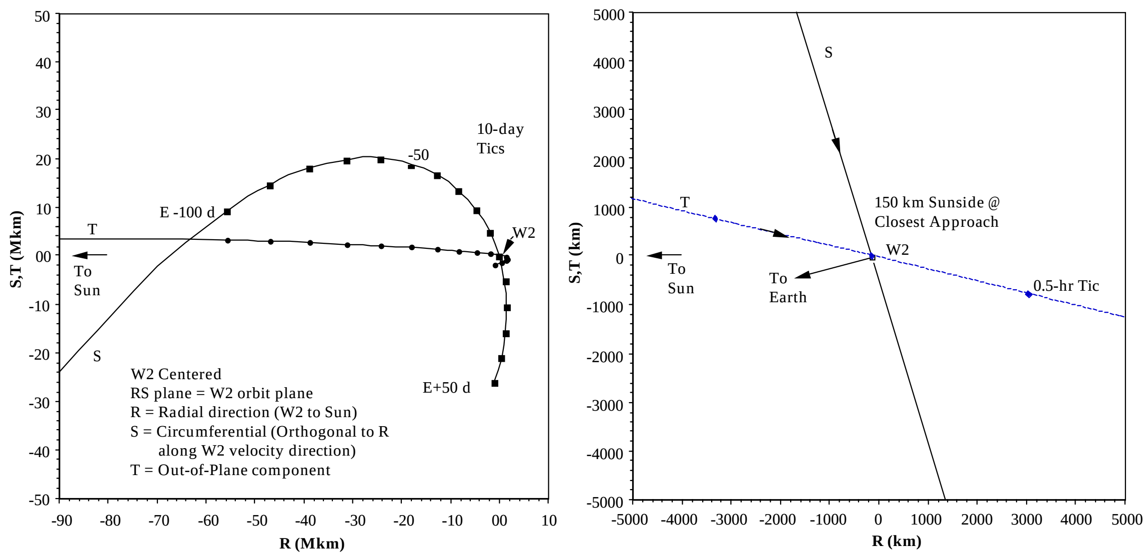


Figure 6.1-1 Encounter Phase Spacecraft Trajectory

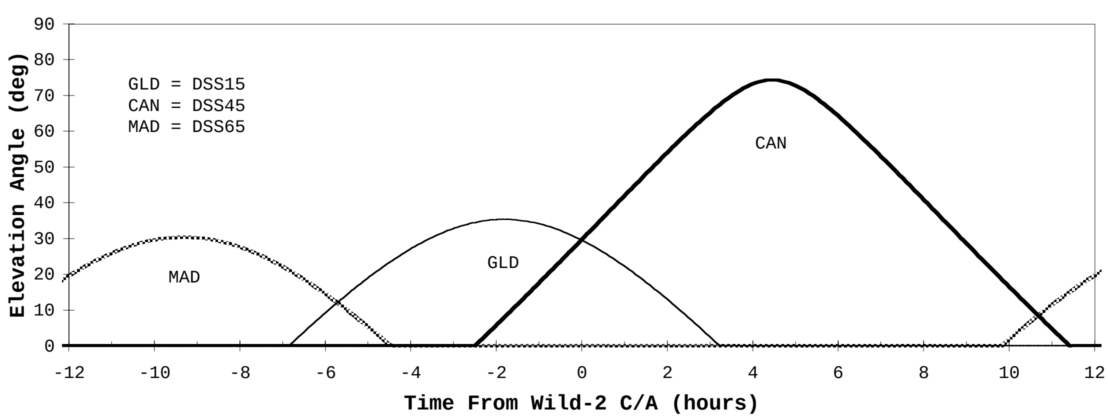


Figure 6.1-2 Encounter Elevation Angle Profile

A trajectory data set containing the following parameters can be found in Appendix 9.4:

Earth-Probe Range
Sun-Earth-Probe Angle
Sun-Probe-Earth Angle
Earth-Probe-Wild-2 Angle
Earth Cone and Clock Angles
Sun Cone and Clock Angles

Wild-2-Probe Range
Sun-Wild-2-Probe Angle
Sun-Probe-Wild-2 Angle
Comet Cone and Clock Angles
Comet Cone and Clock Angular Rate

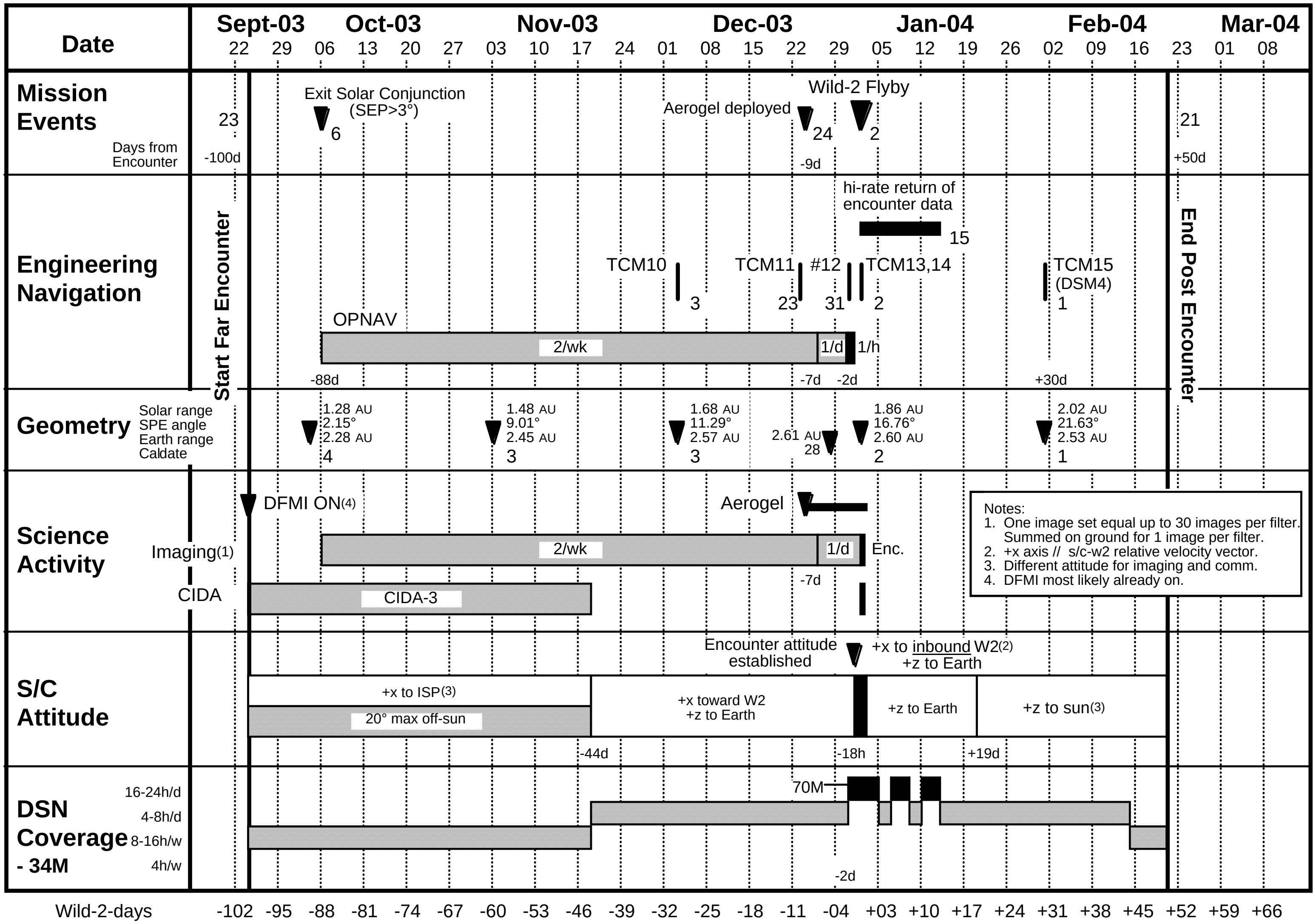


Figure 6.1-3 Wild-2 Encounter Phase Overview (Far and Post Sub-phases)

6.2 Science Operations

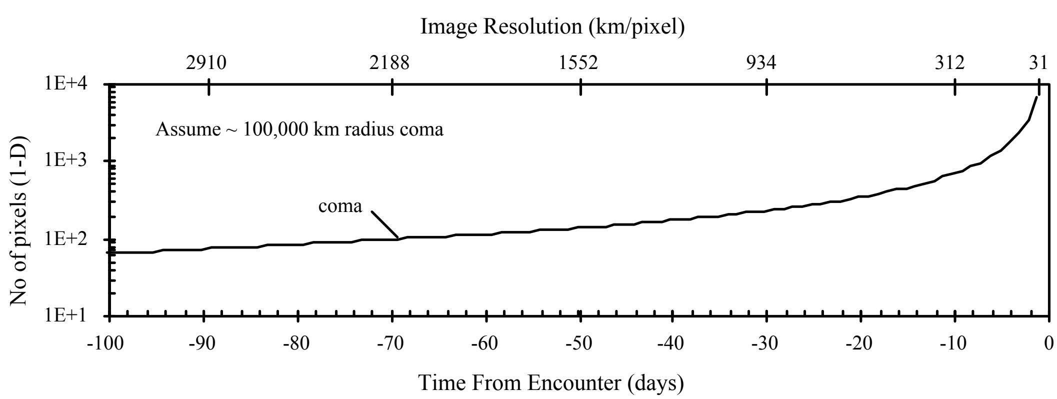
6.2.1 Aerogel Collection of Cometary Dust

Although the collection of cometary dust samples is the primary goal of the mission, it is totally passive. Occurring mostly during the Closest Encounter sub-subphase of the mission, it is enabled by deployment of the aerogel collector and the setting of the spacecraft / collector attitude perpendicular to the dust stream. Collector deployment is currently planned approximately 9 days prior to encounter, and the encounter spacecraft attitude will be established after the last nominal pre-encounter TCM performed at E-18 hours. The collector is planned to stay deployed until E+5 hours which is approximately when the spacecraft exits the comet coma.

6.2.2 Comet Coma and Nucleus Imaging

All images (and other data for that matter) taken before E-4 minutes will be sent to Earth in real-time as the tracking schedule permits. All images taken within E±4 minutes will be stored on-board for delayed transmission. The data rate and storage capabilities of the spacecraft are such that a substantial number of images should be possible.

Imaging plans are heavily related to the comet image profile. This profile is defined as a function of image resolution and size (number of pixels) of the coma and nucleus in the camera field-of-view. Figures 6.2-1.a-c define these parameters as a function of time and Wild-2 encounter subphase.

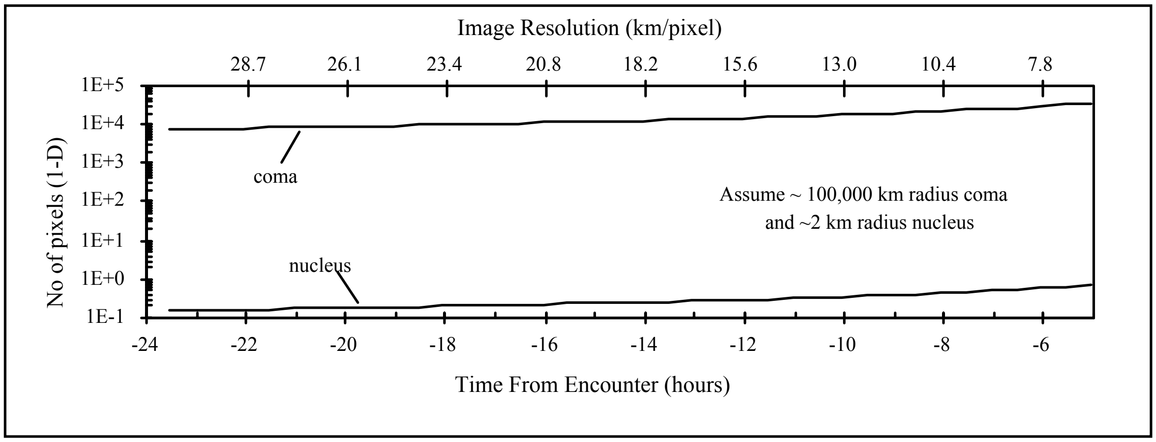


a. Far Encounter

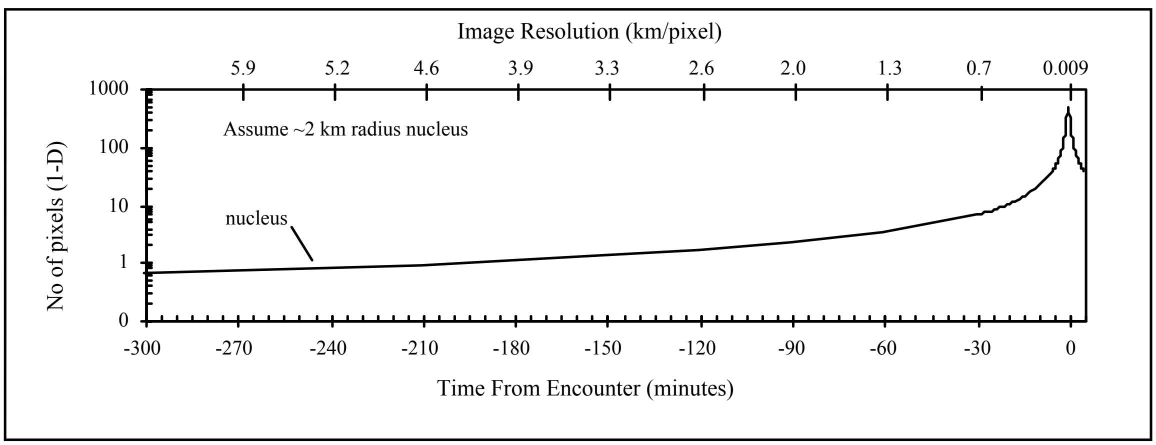
Figure 6.2-1 Wild-2 Encounter Comet Profile

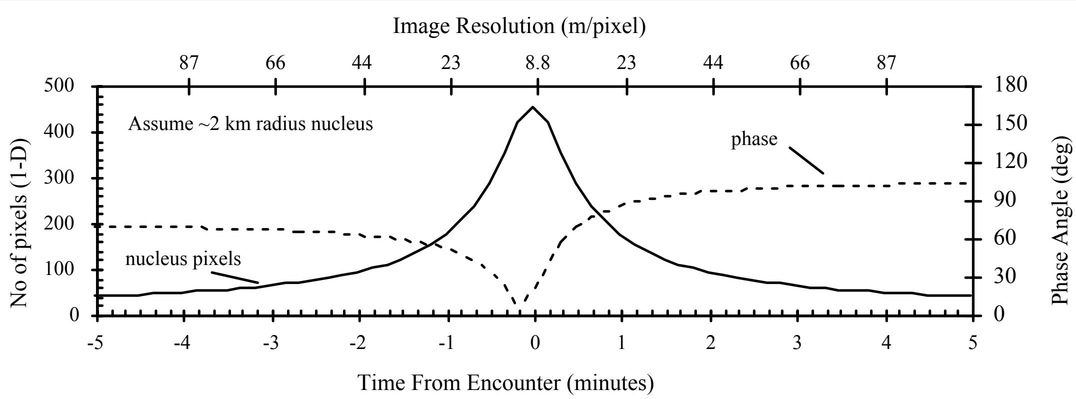
6.2.2.1 Coma Images

Coma images will be acquired primarily during the Far Encounter subphase of the mission. Images obtained during this subphase will have resolutions of 31 to 3000 km per pixel. Seven filters will be used at each science imaging episode and will be sent down at the designated communication times. Approximately 210 images (30 per filter, which allows



b. Near Encounter





c. Close Encounter

Figure 6.2-1 Wild-2 Encounter Comet Profile image summing on the ground to correct for spacecraft stability during imaging) will be acquired twice per week until E-7 d. At E-7 d, this level of imaging increases to 1 set per day. This schedule offers the opportunity to develop full color movies of the evolving coma and make any corrections to the comet dust flux model. From E-100d to E-1d, the size of the coma images will vary from several pixels to virtually filling the camera FOV.

The detailed strategy for compression and windowing for science images will be image dependent and described in image request files, but based on a data rate capability of 500 bps (science allocation) and the telemetry schedule provided in Figure 6.1-2, STARDUST is expected to be able to transmit more than 40 full-frame image equivalents at 2:1 compression. This would far exceed the nominal imaging requirement. The images taken during the first part of the encounter phase may be used to assess the comet activity level. If deemed unsafe for the spacecraft, a large deflection maneuver (several hundred to 1000 km) may be incorporated in the TCM planned at E-2 d.

At E-1 d, within the Near Encounter subphase, the coma image is assumed to fill the camera field-of-view and, the nucleus becomes discernible (fraction of a pixel). Viewing of the coma near the nucleus for finer details now becomes possible. These images are expected to have resolutions ranging from 7 to 31 km/pixel. Imaging continues through to E-12 h. From E-12 h to E-5 h, there is no specific plan to acquire additional images so as to permit preparation and execution of the final pre-encounter TCM (E-6 h), if needed. Any additional images taken during this period may contribute to the final targeting and to risk avoidance.

6.2.2.2 Nucleus Images

Near-continuous imaging and real-time transmission of imaging data are planned from E-5 hours to E-5 min, within the Close Encounter Subphase. Assuming 8 images per set and 2:1 compression, Table 6.2-1 summarizes the image size that can be transmitted during these individual periods as a function of bits per pixel and number of sets.

Table 6.2-1 Allowable Near Encounter Image Size

Number of Sets	Number of Images	Image Size (pixels) 12 bits per pixel	Image Size (pixels) 8 bits per pixel
1	8	751 x 751	920 x 920
2	16	531 x 531	651 x 651
3	24	434 x 434	531 x 531
4	36	376 x 376	460 x 460

Two spacecraft functions that allow the nucleus images to remain in the camera field-of-view are initiated during this period of time. A one degree-of-freedom imaging mirror allows image motion compensation and protects the camera optics from the cometary dust hazard. Centroiding of the comet image is used in conjunction with the imaging mirror via a simple one dimension tracking algorithm. These functions become critical within ± 2 minutes of the encounter. An additional spacecraft function, a roll maneuver, is planned to allow accurate imaging during this time period. The interaction of these three functions is further discussed in Section 6.2.4, Nucleus Tracking.

At E-4 minutes, when the nucleus is expected to occupy 46 x 46 pixels, the last pre-encounter real-time image, a clear filter image of the comet (87 m/pixel resolution, 150 x 150 pixels, 2:1 compression) will be sent to Earth.

Other images taken between E±5 minutes, the Closest Encounter sub-subphase, will be stored on board the spacecraft. These images will be 8 bits/pixel which should allow for approximately 64 images. Of these 64 images, 16 of them are to be allocated to 4 color sets (4 images per set) taken prior to and after each roll maneuver when the phase angle of the comet is relatively constant. The remaining 48 images, to be taken within ±2 min (see Figure 6.2-1 c), will be black and white and taken a minimum of 5 seconds apart.

A total of 600 Mbits of storage space is allocated to imaging science. The images stored during the Closest Encounter sub-subphase are not currently expected to fill the memory allocation (see Figure 6.2-2). After the encounter, during the Post Encounter subphase, imaging will continue until the allocated memory is full.

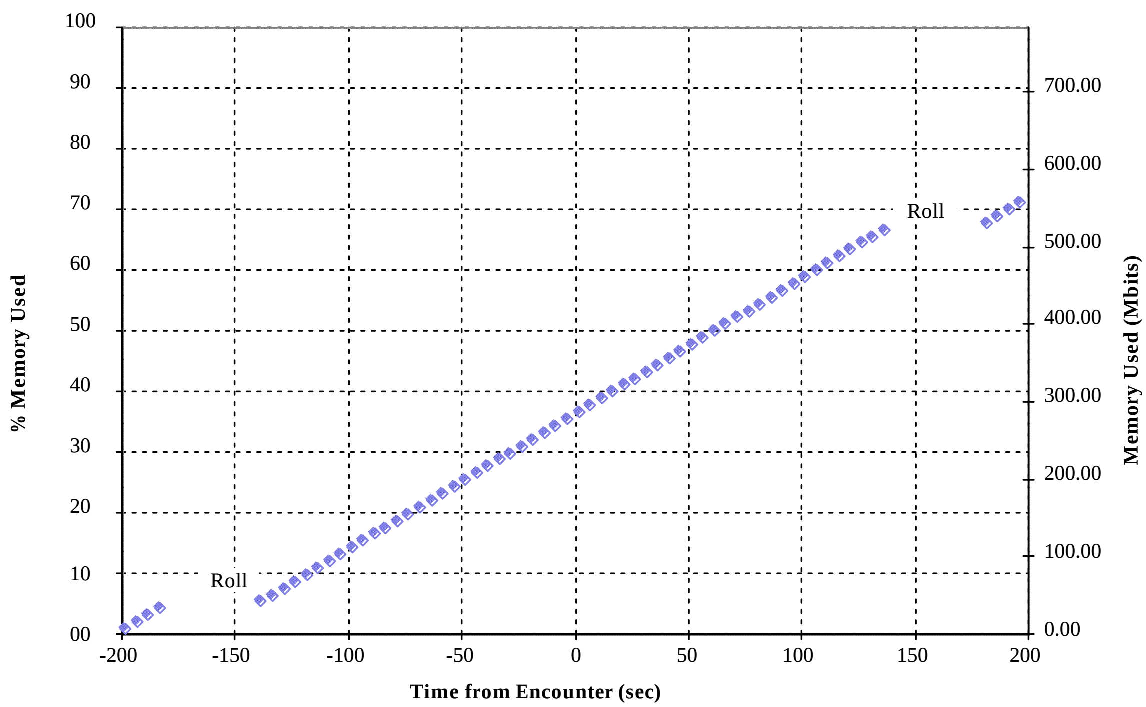


Figure 6.2-2 Image Memory Storage

6.2.2.3 Imaging Calibrations

Several imaging calibration activities will be performed on approach to the comet and after comet flyby. These activities are required to ensure proper performance from the camera and interpretability of the images acquired during encounter. Table 6.2-2 summarizes the required calibration activities during the encounter phase.

Table 6.2-2 Encounter Imaging Calibrations

Time (days)	Image Description	no. of images	bits / pixel	no. of filters	Comments
E-60	Mini cal sequence	7	16	7	windowed about center (100x100?)
	Mirror pointing, align & sensitivity cal	20	16	1 (nav)	pattern matched, windowed (10x10), nominal attitude, tight deadband
E ±30	1 Standard solar analog 1 Flux standard (star TBD)	28 /ea	16	7 /ea	4 exp / 7 filters, windowed (15x15), yaw turn, mirror, tight deadband
	Zero exposure	3	16	1	windowed (20x20), determine camera bias (~400 DN).
E-30, ±15	Photocal w/ lamp 'on'	21	16, 8	7	3 exposures / image, windowed

6.2.3 CIDA and DFMI Encounter Experiments

At E-5 hours, communications will be continuous and CIDA and DFMI data included in the telemetry to Earth. It is after this time, that most, if not all, dust related activity is expected to occur. This configuration will continue through to approximately E-3 minutes at which time the telemetry link is interrupted if the roll maneuver is required.

Data from CIDA events will be compressed and stored on board. Any free memory left from the encounter period will be used for imaging after the primary encounter period.

6.2.4 Delivery Accuracy and Science Implications

If navigation targeting is perfect, Wild-2 will be located at z=150 km, y=0 km and x=0 km in the spacecraft fixed coordinate system at the closest approach to the comet. Table 6.2-3, however, shows the potential delivery error after the E-18 h and E-6 h TCMs. Remember that the E-6 h TCM will be performed only in the event of an anomaly. However, the knowledge improvement will be used to initialize the nucleus tracking algorithm and to update the start of the encounter sequence block, if necessary, thus keeping the navigation delivery in line with the spacecraft and sequencing capabilities.

Table 6.2-3 Encounter Delivery Accuracy (1-sigma)

TCM	Cross-track (km)	Time-of-Flight (sec)
E-18 h	10	29
E-6 h	7	29

The cross track error corresponds to offset of the Wild-2 nucleus in the spacecraft z and y-axis, and the time-of-flight error to x-axis (also representing the error in the time of closest approach). Recall that the dust shield normal is along the spacecraft x-axis, perpendicular to the spacecraft y-z plane.

The impact of these potential errors on the quality and the quantity of the dust sample should be minor. Given a 3-sigma error of 30 km, applying the 1/D (where D is the flyby distance) scaling law for the fluence vs. D, the deviation from the nominal number of particles collected will be +25% or -17% (depending on whether the miss is toward or away from Wild-2, respectively). Given the preliminary estimates of a 150 km flyby producing ~2,700 particles of the desired size, a 3-sigma miss away from Wild-2 would still provide ~2,250 particles (for more information refer back to Section 2.4.2.3).

The impact of the delivery on imaging is shown in Figure 6.2-3. Immediately after to the last pre-encounter TCM (E-6 hrs), the comet nucleus (a pin point) would appear in the center of the camera field-of-view and the errors would not be discernible. As the time of closest approach approaches, the delivery error in the camera field-of-view will grow inversely proportional to the comet-spacecraft range. Figure 6.2-3 shows the growth of the 2-σ error ellipse of the location of the comet image in the camera field-of-view as a function of time. Based on an a priori set mirror and spacecraft attitude, set at E-6 hours, the comet nucleus images could be captured until about E-3 minutes with 2-sigma confidence. There would be a small chance that the capture of images after E-3 minutes would fail if no preventive action was taken, thus the need for applying a roll maneuver.

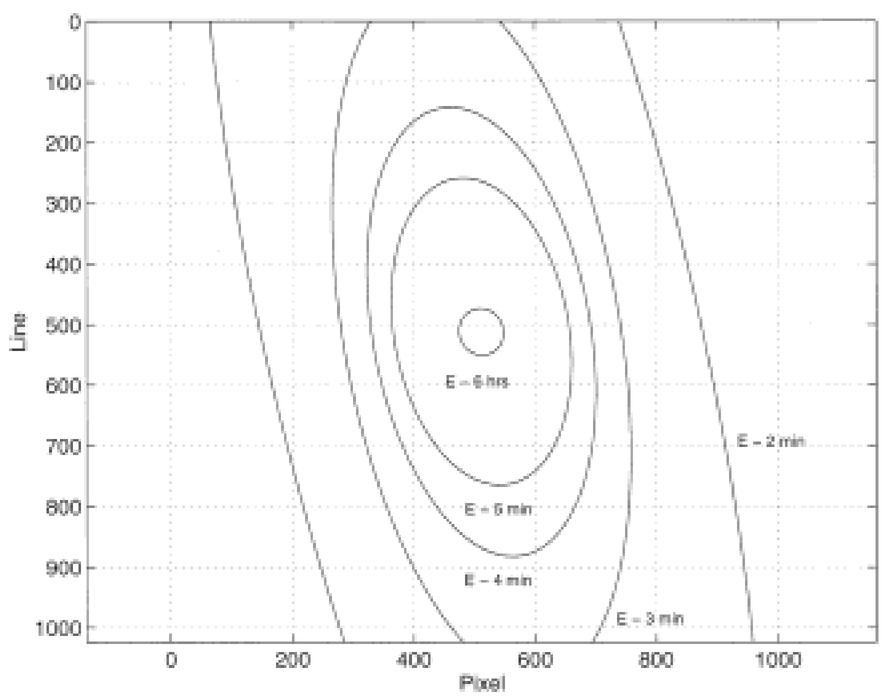


Figure 6.2-3 Delivery Error Growth: Nucleus Image Offset vs. Time

6.2.5 Nucleus Tracking

Given the delivery uncertainty and associated probabilities described in the previous section, imaging of Wild-2 could be accommodated adequately until E-3 minutes. However, in order to capture the highest resolution images, obtainable only after E-3 minutes, some action must be taken. As mentioned above, mirror control, centroiding and the roll maneuver are used to maintain the nucleus within the camera field-of-view.

Centroiding uses selected images (maximum of once every 10 seconds which is equivalent to every other image after E-4 minutes) and a 1-D algorithm to compute the mirror correction required to place the comet back into the center of the field-of-view of the camera. Designed to provide 180° in-plane tracking of Wild-2, this mirror slewing will compensate for the in-plane and time-of-flight delivery errors. Mirror control and centroiding are planned to start at E-50 minutes when the comet nucleus is about 3x3 pixels in size. Centroiding is planned to end at closest approach while mirror control is planned to end at E+20 minutes to support Post Encounter "fill memory" imaging.

To correct the out-of-plane delivery error, a correction must be made along the spacecraft y-axis. A roll maneuver about the x-axis is planned only once and implemented only if and when the nucleus image is expected to escape the camera field-of-view. In order to maintain a real-time telemetry link as long as possible into the encounter, it is desirable to have this maneuver not occur until absolutely necessary. Current estimates place the execution of this maneuver between E-4 to -3 minutes. The maneuver is expected to take no more than a minute to implement including time for attitude stabilization. Figure 6.2-4 shows the expected roll angle as a function of out-of-plane error and flyby distance. If a roll maneuver is performed, once the encounter is over, at about E+3 minutes, a subsequent roll maneuver is performed in order to re-establish communications as soon as possible.

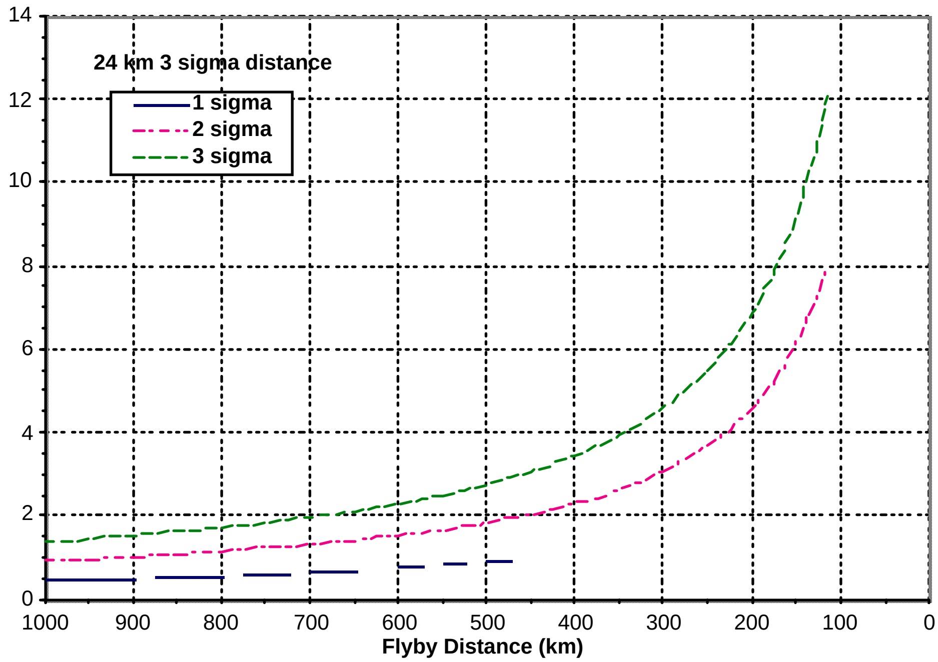


Figure 6.2-4 Roll Angle vs. Delivery Error and Flyby Distance

6.3 Mission Operations

A summary of the encounter phase operations profile is given in Table 6.3-1. Mission operations, in addition to the execution of science operations, concentrates on navigating the spacecraft to a successful encounter with comet Wild-2. Both radiometric data and optical navigation (OPNAV) are initiated at E-100 days and are carried out through E-12 hours. Approach TCM's are planned at E-30, -10 and -2 days, -18 hours, and -6 hours. The last TCM is planned to be implemented only in the event of a contingency. The round trip light time at encounter is approximately 40 minutes. This allows only about 5 hours after receipt of the last data, sent at E-12 h, to prepare and uplink the final TCM commands, if required.

OPNAV images will contain the comet and background stars. To reduce their data return requirement, they will be windowed and compressed on-board resulting in the equivalent of an image 200 x 200 pixel in size at 12 bits per pixel. As encounter approaches, the OPNAV rate is increased consistent with the increase in science imaging frequency. The OPNAV plan is summarized in Table 6.3-2.

The primary communications configuration during the encounter phase uses the HGA and 34-m HEF DSN stations. This configuration is changed with the use of 70-m DSN coverage at encounter and during the Post Encounter subphase to support transmission of stored data. After flyby, when the HGA link is reestablished at about E+3 min, orbit determination to pinpoint the spacecraft position and attitude during the flyby will resume. This is critical for the reconstruction of the flythrough conditions and contributes to the return of potentially viable and valuable dynamic science data. Tracking time ranges from 8 hours per week over the 34-m net to a maximum of 24 hours per day over the 70-m net at encounter.

The spacecraft attitude profile on approach to the comet starts with one that supports the third CIDA experiment (see section 4 for details). This attitude is abandoned at E-44 days when the communications frequency is scheduled to increase to one track per day in support of the first approach TCM (E-30 days). To minimize spacecraft slewing, the spacecraft attitude profile then becomes one where the MGA boresight tracks the Earth. This attitude continues until E-10 days when the attitude becomes one where the HGA boresight tracks the Earth. This is done to place the spacecraft in a near-Encounter attitude and to support the start of daily science and OPNAV events at E-7 days. Finally, after the E-18 h TCM, the spacecraft attitude is set for the final coma fly through. At the encounter attitude, the dust shield is oriented toward the comet-spacecraft relative velocity vector and the HGA boresight is pointed to the Earth. Attitude maintenance activity, required to maintain the HGA link as well as the dust shield protection, is expected to increase during the fly through due to disturbances caused by the comet dust. Attitude control will also include the execution of the roll maneuvers that surround the closest approach.

Table 6.3-1 Wild-2 Encounter Phase Mission Operations

<table>
<tr><td>Mission Operation</td><td colspan="5">Description</td></tr>
<tr><td>Communications</td><td colspan="5">8 hrs / wk - HGA Comm - E-100 to -7d, no s/c flip (small SEP)
8 hrs / day - HGA Comm - E-7 to E-1d
24 hrs / day - HGA Comm - E-2 to +3d, +5 to +8d, +10 to +13d
8 hrs / wk - HGA Comm - E+13 to E+50d
TCMs -
Two - 4 hr passes week - MGA Comm -14 to -28, +14 to +28d
4 hrs / day - MGA Comm(2) within ± 14 days
Encounter -
4 hrs / day - MGA Comm within ± 30 days</td></tr>
<tr><td>Navigation</td><td colspan="2">L+1761 d (E-30 d): TCM 10
L+1781 d (E-10 d): TCM 11
L+1789 d (E-2 d): TCM 12</td><td colspan="3">L+1790 d (E-18 h): TCM 13
L+1791 d (E-6 h): TCM 14
L+1821 d (E+30 d): DSM 4 (# 15)</td></tr>
<tr><td rowspan="13">Spacecraft Attitude
(see section 10 for attitude mode definitions)</td><td>Time (days)</td><td>Description</td><td>angz (°)</td><td>angy (°)</td><td>db (°)</td></tr>
<tr><td>L+1691 to 1703</td><td>constant off-sun</td><td>0</td><td>180</td><td>15</td></tr>
<tr><td>L+1703 to 1747</td><td>CIDA cst. off-sun</td><td>-20</td><td>0</td><td>15</td></tr>
<tr><td>L+1747 to 1780</td><td>MGA track Earth</td><td>-</td><td>-</td><td>15</td></tr>
<tr><td>L+1780 to 1789</td><td>HGA track Earth</td><td>-</td><td>-</td><td>15</td></tr>
<tr><td>L+1789 to 1792</td><td>Encounter</td><td>-</td><td>-</td><td>2</td></tr>
<tr><td>L+1792 to 1805</td><td>HGA track Earth</td><td>-</td><td>-</td><td>2</td></tr>
<tr><td>L+1805 to 1811</td><td>HGA track Earth</td><td>-</td><td>-</td><td>15</td></tr>
<tr><td>L+1811 to 1841</td><td>constant off-sun</td><td>0</td><td>0</td><td>15</td></tr>
<tr><td colspan="4">MGA communications: 7° off +z-axis to Earth</td><td>6</td></tr>
<tr><td colspan="4">HGA communications: +z-axis to Earth</td><td>2</td></tr>
<tr><td colspan="4">Encounter mode</td><td>0.3</td></tr>
<tr><td colspan="4">Imaging mode</td><td>0.5</td></tr>
<tr><td>DSN Profile</td><td colspan="2">L+1691 to +1733d: 8 h/w</td><td colspan="3">L+1794 to +1796d: 4 h/d</td></tr>
</table>

All 34-m HEF except selective 70-m from L+1789 to +1804d	L+1733 to +1741d: 2*4 h/w L+1741 to +1747d: 2*8 h/w L+1747 to +1784d: 4 h/d L+1784 to +1789d: 8 h/d L+1789 to +1794d: 24 h/d	L+1796 to +1799d: 24 h/d L+1799 to +1801d: 4 h/d L+1801 to +1804d: 24 h/d L+1804 to +1835d: 4 h/d L+1835 to +1841d: 2*4 h/w

1. DSN Coverage should alternate between Northern Hemisphere and Southern Hemisphere DSN sites.
2. A*B = A number of tracks at B frequency

Table 6.3-2 OPNAV Plan

Time	Frequency	no. of images	bits / pixel	no. of filters	Comments
E -90 to -7 d	2 /wk	1	16	1 (nav)	small yaw turn, mirror, pattern match and window.
E -7 to -2 d	1 per day	same as above			
E -47 to -26 h	1 per hour	same as above			
E -17 to -12h	1 per hour	same as above			

During the Post Encounter subphase, the primary objective is to transmit all of the data stored during the comet encounter. The spacecraft attitude for the first 19 days after encounter is planned to track the Earth with the HGA boresight to reduce spacecraft slewing. It is highly desirable to return this data as quickly as possible to prevent irretrievable loss in the event of a reboot of the spacecraft main computer. In addition, transmission of the data a total of three times is also desired to prevent loss of data due to communications problems. Approximately 55 hours are estimated to be required using HGA and 70-m capability (4000 bps) to return the stored data. With the HGA and 34-m capability (1000 bps), 220 hours are required to return the same data set. Tracking with 70-m stations is requested to support three 55 hour periods with 1 day between each period to allow for spacecraft health and safety verification.

7.0 Earth Return Phase (ER-90 to ER+1 day)

7.1 Overview

This phase of the mission begins 90 days before Earth Return (ER) and ends when the Sample Return Capsule (SRC) is transferred to the ground handling team. Earth approach contains three TCM's and a final divert maneuver, performed after SRC separation, to prevent the spacecraft from following the SRC into the Earth's atmosphere. Prior to separation, the spacecraft will be placed at the separation attitude and the SRC will be spun up using a spin release mechanism. This will provide the spin stabilization that the SRC requires for successful atmospheric entry. Immediately following release, the SRC may be imaged using the imaging camera. Although these images will have minimal OPNAV value, they are considered of high Public Information value. If launch occurs on the first day of the STARDUST launch period, Earth Return will occur on 15 January 2006 09:58:07 ET.

The definition of the Return Phase is established to encompass all activity with direct influence on achieving the goal of landing the SRC at Utah. The first targeting maneuver for the return occurs at 60 days from return. DSN tracking increases in frequency to support the design of this maneuver at 88 days.

The planned landing site is the Utah Test and Training Range (UTTR). The SRC landing at UTTR, in this case - a posigrade entry, occurs at about 3 AM local time. Following touchdown, the SRC will be recovered by helicopter or ground vehicles and will be transported to a staging area at UTTR for the retrieval of the sample canister. The canister will then be transported to the Planetary Materials Curatorial Facility at Johnson Space Center.

The spacecraft approach trajectory for this phase is shown in Figure 7.1-1. Subphases are defined in Table 7.1-1. A trajectory data set containing the following parameters can be found in Appendix 9.5:

Earth-Probe Range	Moon-Probe Range	Sun-Earth-Probe Angle
Sun-Moon-Probe Angle	Sun-Probe-Earth Angle	Sun-Probe-Moon Angle

Table 7.1-1 Earth Return Phase Subphase Definition

Mission Phase	Sub-Phases	Time	Duration
Earth Return		L+2445 - 2536d	91d
(ER-90 to ER+1d)	Approach	L+2521 - 2535d	14d
	TCM 17 (ER-60 d)	L+2475d	-
	TCM 18 (ER-13 d)	L+2522d	-
	TCM 19 (ER-1 d)	L+2534d	-
	SRC release	ER-4h	-
	S/C divert (TCM 20)	ER-3h	-

	SRC Entry / Descent Atmospheric Entry Parachute Descent SRC Recovery S/C Post Divert	 ER+0 - +8m ER+8 - +15m ER+15 - +75m ER-3h - +1d	 ~8 m ~7 m ~60 m ~1 d

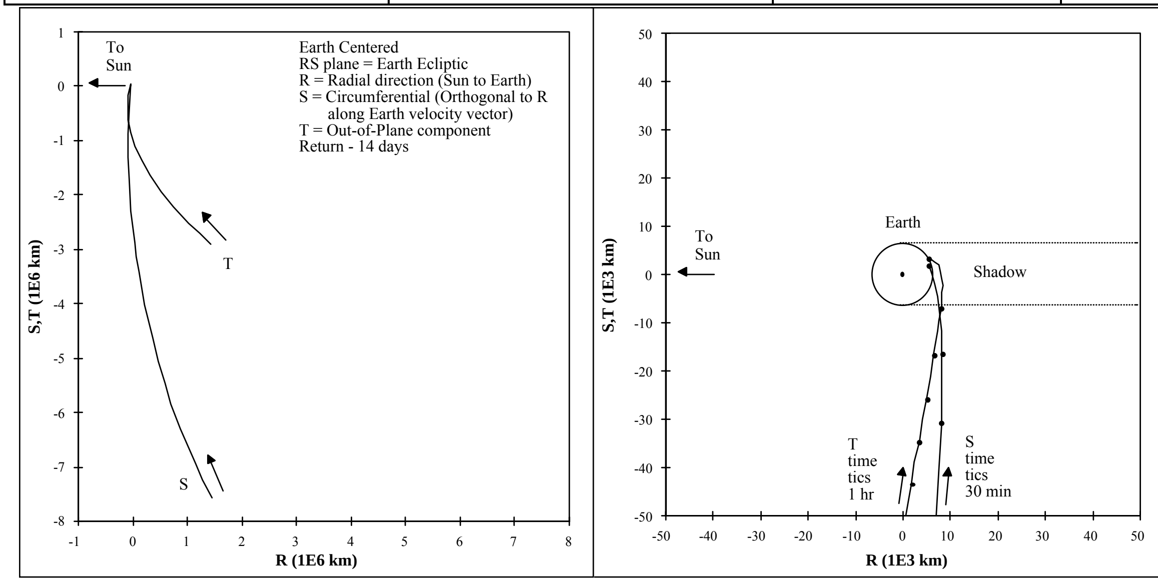


Figure 7.1-1 Earth Return Phase Spacecraft Trajectory

7.2 Earth Return Operations

7.2.1 Approach Subphase

7.2.1.1 Earth Entry Control

The main operational responsibility during this subphase is to attain the critical entry corridor control (±0.08° - entry flight path angle) required for the survival of the SRC and confinement of the landing footprint to the acceptable zone. The entry design parameters and the entry characteristics are summarized in Table 7.2-1. The SRC design assumes a conservative return speed (Vhp) of 6.7 km/s, although the Vhp can vary from 6.4 to 6.6 km/s for the 20 day launch period. The latitude and longitude of the central surface aim point in UTTR is (40.5° N, 113.5° W). The B-plane angle and the entry or landing times presented in Table 7.2-1 are approximate. Refinement to these values will be made in post launch when the details of the atmospheric entry trajectory become available.

Table 7.2-1 SRC Entry Characteristics

Entry Characteristics	Posigrade Entry	Retrograde Entry
Entry Flight Path Angle	-8.2° ± 0.08° (3σ)	-8.2° ± 0.08°
Maximum Angle of Attack	10°	10°
Entry Spin Rate (TBR)	14-16 RPM ± 1 RPM	14-16 RPM ± 1 RPM
B-plane angle (deg)	-41.8	221.8

Inclination (deg)	42.8	137.2
Local Time of Day	3:00 AM	9:00 AM
Local Heading (deg)	105	255

The B-plane aim point upon Earth approach depends on a posigrade or retrograde entry. Figure 7.2-1 describes the differences between these two approaches. A retrograde entry has been established as the baseline, however, a change to the posigrade entry could be made as late as a few months prior to the actual return. The current program baseline is a posigrade entry with a 3 AM landing. A retrograde entry would result in a 9 AM landing.

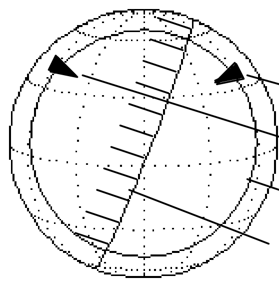


Figure 7.2-1 Approach B-Plane Front View

To attain the required ±0.08° entry flight path angle control, effective orbit determination (OD) and TCM strategies are implemented. The orbit perturbations induced by the uncoupled ACS burns are of significant concern. Results from one phase of study indicate that ±0.06° (3-σ) entry control is attainable. Although the total requirement is 0.08°, 0.02° of error is reserved for other error sources not included in standard navigation analysis (i.e. prior to entry) which is the source of the 0.06° delivery accuracy.

7.2.1.2 Navigation Requirements

The current OD strategy calls for a significant increase in DSN tracking requirements. From the start of the Approach Subphase (ER-14 d), tracking frequency is increased to 16 hours / day. A key element of this tracking requirement is that half of that coverage (8 hours/day) must proceed from the southern hemisphere tracking complex at Canberra, Australia. The remaining half of coverage should be scheduled at tracking stations in the northern hemisphere (Madrid, Spain or Goldstone, California). This tracking split is necessary to establish a North-South orbit determination to bring about accurate OD results. Continued tracking of the deflected spacecraft is planned through at least ER+1 day. Tracking of the spacecraft beyond separation is required to meet the S/C Post-Divert safety requirements.

During the two-week subphase, the Earth-Probe range is small enough (less than 0.05 AU) to allow the spacecraft to be tracked using the LGA and selective off-sun pointing. This permits the spacecraft to satisfy the telecom and power requirements of spacecraft operations.

Two TCM's are planned within this subphase at ER-13 and -1 days. The OD data cut-off for the -1 day maneuver occurs at -2 days.

7.2.1.3 Spacecraft / SRC Separation

This sequence of events begins when the spacecraft reorients in preparation for SRC separation. Separation of the SRC is planned to occur at ER-4 hours. Prior to this time (ER-5h), the spacecraft is slewed to the proper release attitude, SRC is prepared for release and the spin release mechanism is used to spin the SRC up. Immediately following release, the SRC may be imaged using the imaging camera. Detailed plans for taking these images are TBD. However, they are considered of high PIO value.

The final TCM, performed after SRC separation, prior to ER-3 hours, is used to divert the spacecraft to prevent re-entry. DSN tracking of the spacecraft continues during the Post-Recovery subphase to ensure receipt of the SRC separation images as well as for determination that the spacecraft has been diverted into a stable orbit about the sun.

Once released, the SRC is on a ballistic trajectory for direct entry to Earth's atmosphere. The SRC does not carry any type of propulsion or attitude control devices. Proper entry attitude is established by the spacecraft and is maintained by spin stabilization. The SRC is attached to the spacecraft by three spring loaded bolts. Upon separation, these spring loaded bolts will impart a separation ΔV (~0.5 m/s) that must be accounted for in final targeting.

7.2.2 Entry, Descent and Recovery Subphases

Earth Entry (or Earth Return) is defined as the point where the SRC has reached an altitude of 125 km above a 6378 km spherical radius reference. The SRC velocity at this point is expected to not exceed 12.6 km/s. After entry, the SRC will continue to free fall until parachute deployment. With a ballistic coefficient of 54 kg/m^2, the SRC's terminal velocity at drogue chute deployment is expected to be between Mach 1.2 and 1.6. The drogue will provide stability to the SRC as it descends through the transonic and subsonic regimes. A G-switch activated timer with barometric sensor backup will initiate the deployment sequence. At an altitude of approximately 3000 ± 730 meters above sea level, a cutter will release the drogue chute which will extract and deploy the main chute. The elapsed time from entry to parachute deployment is estimated at 8 minutes. The entry profile is depicted in Figure 7.2-2.

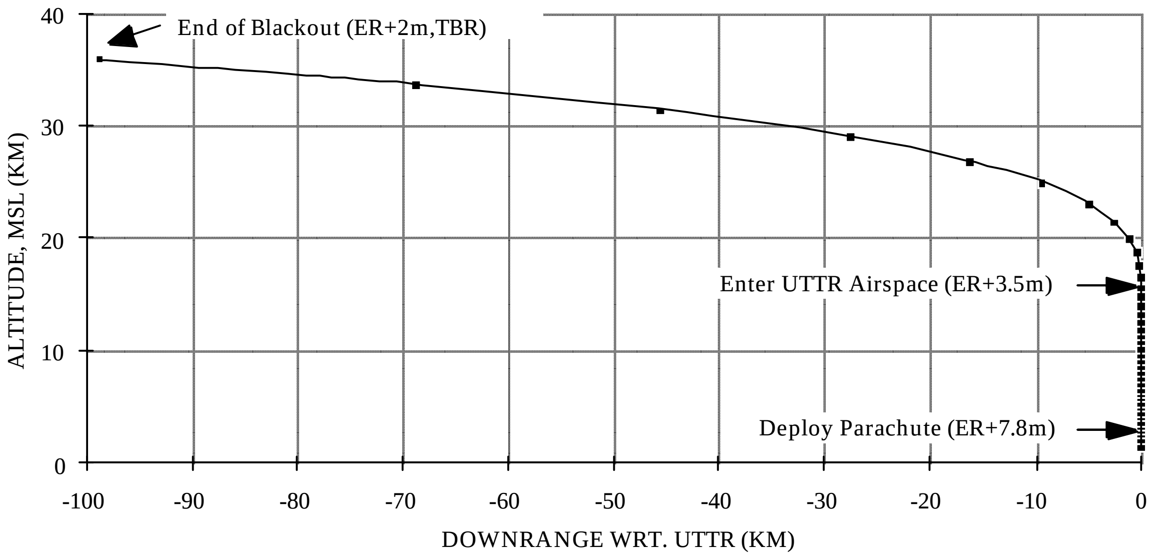


Figure 7.2-2 SRC Entry Profile

Deployment of the parachute is the start of the Descent subphase. A mylar target on the main chute provides a one square meter equivalent radar cross-section for C-band tracking by UTTR radars. The SRC avionics design includes a UHF locator beacon. The beacon is activated upon main parachute deployment. The SRC has sufficient battery capacity to power the beacon for 40 hours. The beacon is used by the ground recovery crews to locate the SRC after touchdown.

At no time during entry and descent will the SRC release its heat shield or backcover. Velocity of the SRC at touchdown is expected to be less than 4.6. Based on historical UTTR wind data, the horizontal velocity should be less than 11 m/s (99% probability).

DSN tracking after the final TCM will be used to update the expected landing footprint. This data will then be faxed to UTTR to aid in recovery operations. Should the actual landing footprint be determined to be in a restricted area (e.g. highly populated), a no-go call would be given and the spacecraft would perform the divert maneuver without having released the SRC.

Taking into account SRC deployment, entry corridor, SRC aerodynamics and atmospheric uncertainties, the landing footprint at UTTR is estimated at 61.2 km long by 22.6 km wide (3-σ). With the currently planned posigrade entry, the flight path of the SRC as it approaches UTTR will be along a heading of 105° from North on a North-West to South-East trajectory. In contrast, should the alternate retrograde entry be selected, the flight path of the SRC will bring it in from North-East to South-West on a heading of 255°.

Figure 7.2-3 depicts the posigrade landing footprint. Local time of the landing for the nominal posigrade entry is approximately 3 A.M., for a retrograde entry, the local time is 9 A.M. Given the small size and mass of the SRC, it is not expected that recovery and transportation of the capsule will require extraordinary handling measures or hardware.

It is important to note that, other than the parachute mortar gas cartridge, the SRC does not contain any explosive ordinance (no pyros, rocket motor, etc).

Once located, the SRC will be transported to a staging area at UTTR for extraction of the sample canister. The sample canister will then be transported to the final destination, the planetary material curatorial facility at JSC.

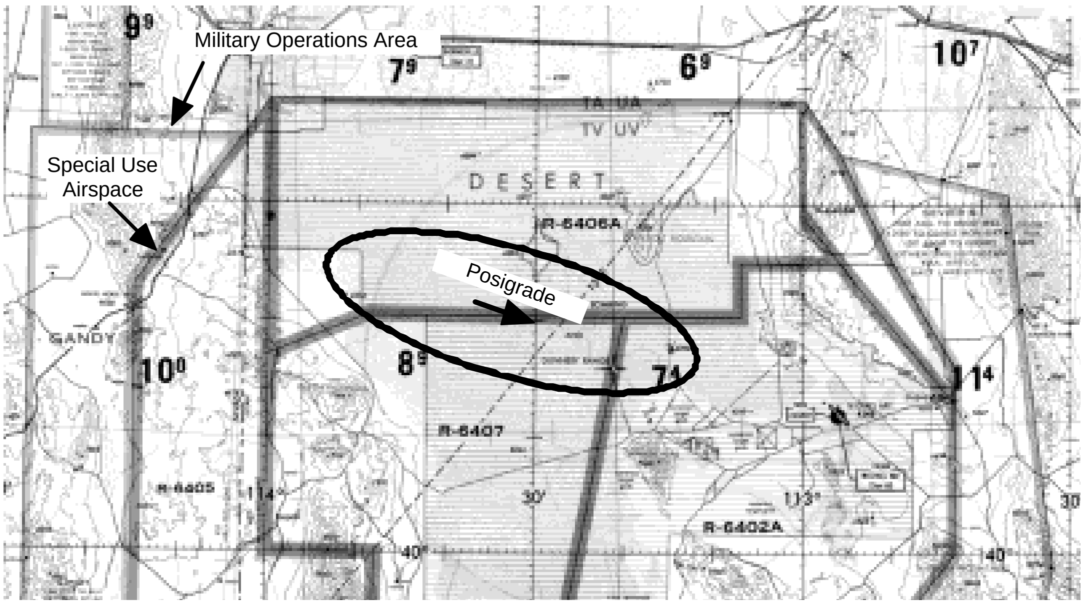


Figure 7.2-3 Posigrade Landing Footprint

7.3 Mission Operations

Mission operations resources for the Earth Return phase are summarized in Table 7.3-1. Key to this phase is the accurate execution of terminal navigation for successful delivery of the SRC to the target interface point. TCMs scheduled at E-13 days and E-1 day, together with extensive DSN tracking are used to achieve this goal.

Table 7.3-1 Earth Return Phase Mission Operations

<table>
<tr><td>Mission Operation</td><td colspan="5">Description</td></tr>
<tr><td>Communications
All MGA, exc.
LGA: > L+2508</td><td colspan="5">Return - 16 hrs /day, within ER-14 days
TCMs - Two - 4 hr passes week, -14 to -28, +14 to +28d
4 hrs / day, within ± 14 days</td></tr>
<tr><td>Navigation</td><td colspan="2">L+2475 (ER-60 d): TCM 17
L+2522 (ER-13 d): TCM 18</td><td colspan="3">L+2533 (ER-1 d): TCM 19
L+2534 (divert): TCM 20</td></tr>
<tr><td rowspan="6">Spacecraft Attitude
(see section 10 for attitude mode definitions)</td><td>Time (days)</td><td>Description</td><td>angz (°)</td><td>angy (°)</td><td>db (°)</td></tr>
<tr><td>L+2445 to 2459</td><td>constant off-sun</td><td>0</td><td>0</td><td>15</td></tr>
<tr><td>L+2459 to 2489</td><td>constant off-sun</td><td>0</td><td>180</td><td>15</td></tr>
<tr><td>L+2489 to 2509</td><td>constant off-sun</td><td>-21</td><td>180</td><td>15</td></tr>
<tr><td>L+2509 to 2533</td><td>constant off-sun</td><td>45</td><td>0</td><td>15</td></tr>
<tr><td>L+2533 to 2535</td><td>constant off-sun</td><td>26</td><td>0</td><td>15</td></tr>
</table>

	L+2535 to 2537	constant off-sun	45	0	15
	MGA communications: 7° off +z-axis to Earth				6
DSN Profile All 34M	L+2445 to +2461 d: 2*4 h/w L+2461 to +2489 d: 4 h/d L+2489 to +2508 d: 2*4 h/w		L+2508 to 2521 d: 2*4 h/w L+2521 to 2536 d: 2*8 h/d		

1. DSN Coverage should alternate between Northern Hemisphere and Southern Hemisphere DSN sites.
2. A*B = A number of tracks at B frequency

8.0 Planetary Protection

The objective of planetary protection is to minimize the uncontrolled exchange of organic or biological material between Earth and solar system bodies on which abiotic chemical evolution could have taken place or life could exist. NASA follows established policy for the protection of planetary environments from contamination by spacecraft, and has obtained international acceptance of this policy through the Committee on Space Research (COSPAR) of the International Council of Scientific Unions. NASA implements this policy by establishing planetary protection requirements for each applicable mission.

For the proposed STARDUST mission of a comet flyby and sample return, the planetary protection restrictions apply to the transport of organic materials from Earth, which could contaminate the comet nucleus in the case of an inadvertent impact. In addition, it addresses the issue of evolved chemical material returned to Earth.

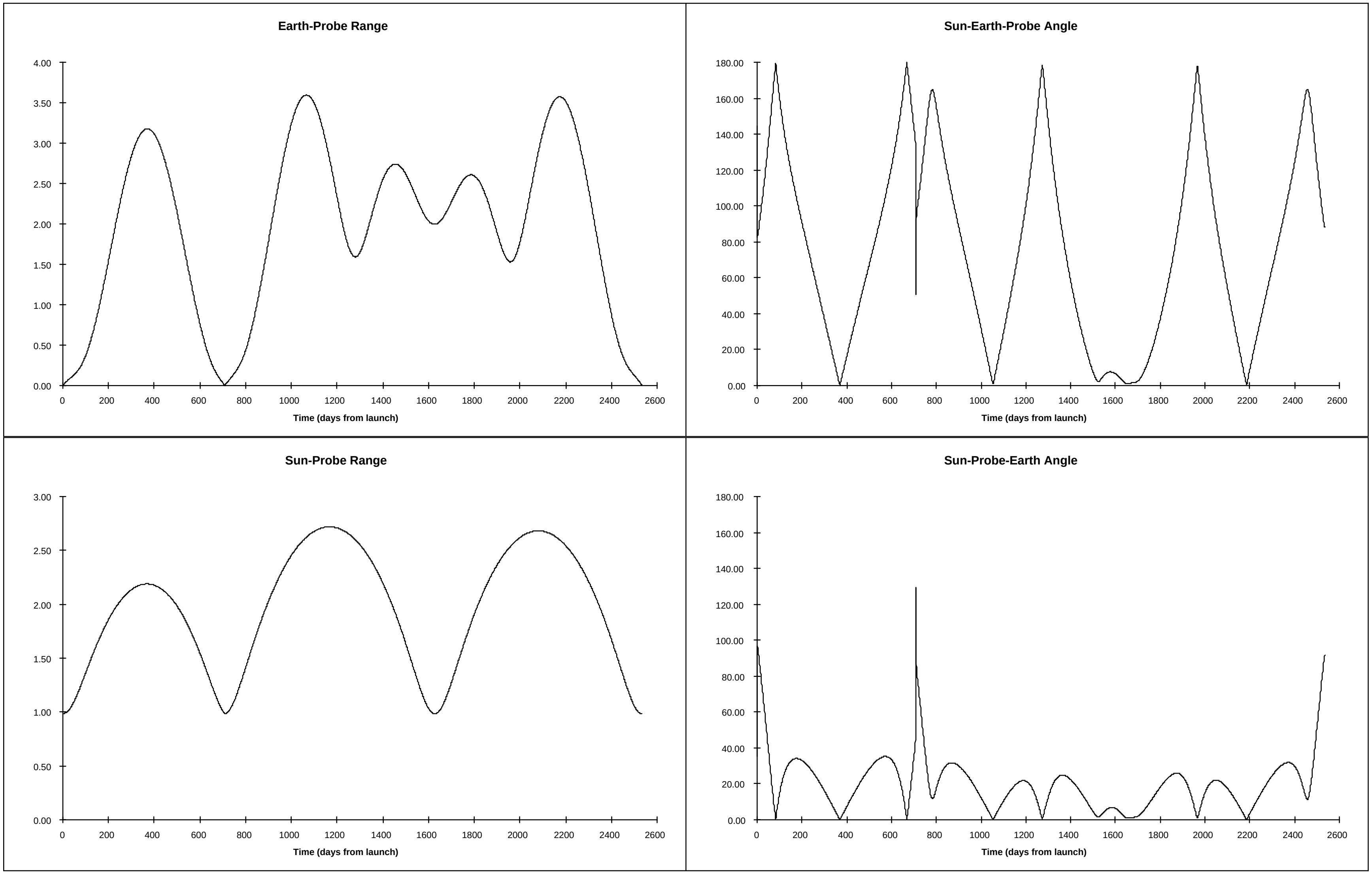
The outbound mission phase covers the mission up to and through the encounter with Wild-2 and flythrough of its coma, during which samples of the ambient dust and molecules will be obtained. For this part of the mission the spacecraft has been classified as a Planetary Protection Category II mission, with a Planet Priority of "B". The object to be protected on the out-bound phase of the mission is the comet Wild-2. A Planet Priority of "B" defines the planetary body as being "of significant interest relative to the process of chemical evolution but only a remote chance that contamination by spacecraft could jeopardize future exploration." There are no specific requirements for clean room assembly for planetary protection. The likelihood of an accidental impact with the comet would result in mission failure and as such would be avoided.

The inbound mission phase covers the mission subsequent to sample acquisition and continues through entry, descent, and landing at Earth. The STARDUST project has requested and received certification as a Planetary Protection Category V mission, "Unrestricted Earth Return," for this mission phase. No further planetary requirements beyond those levied on the outbound phase of the mission would be levied.

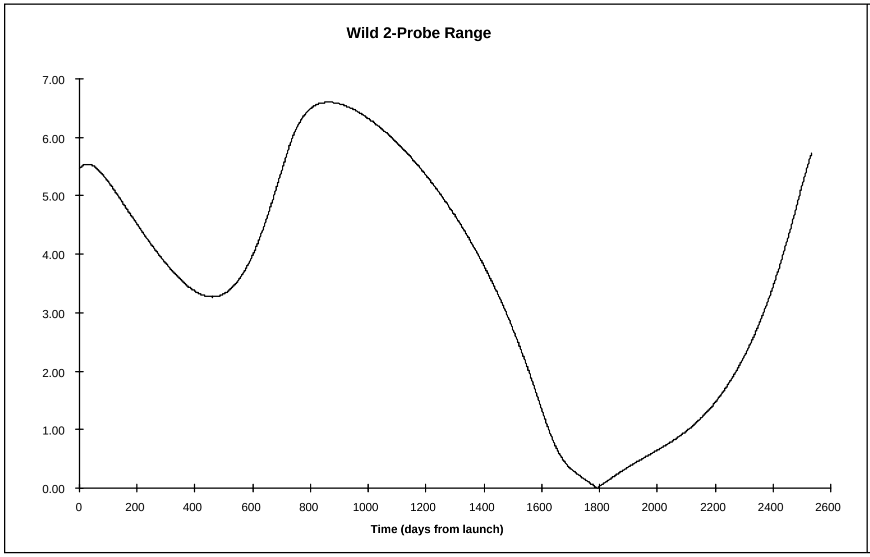
The STARDUST Project will comply with all planetary protection policies and requirements specified by NASA and will document compliance in the STARDUST Planetary Protection Plan.

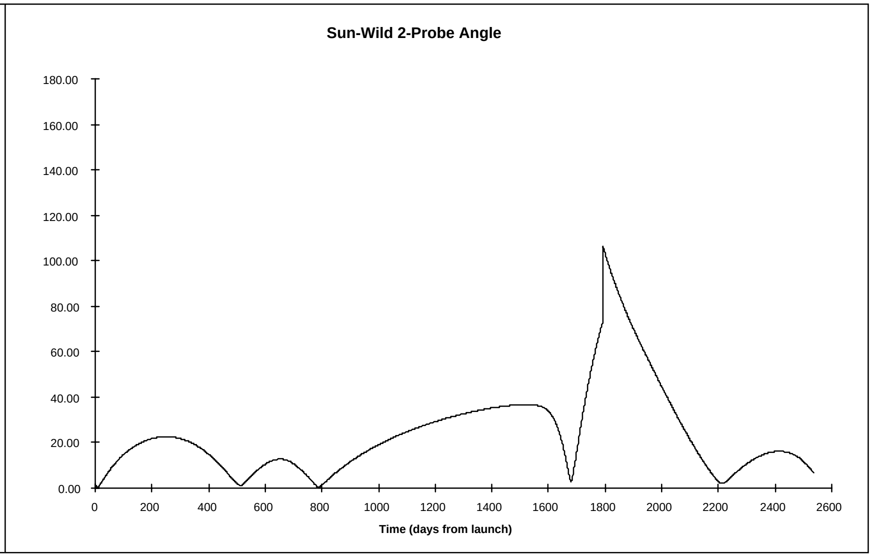
9.0 Appendix A: Geometry Data Sets

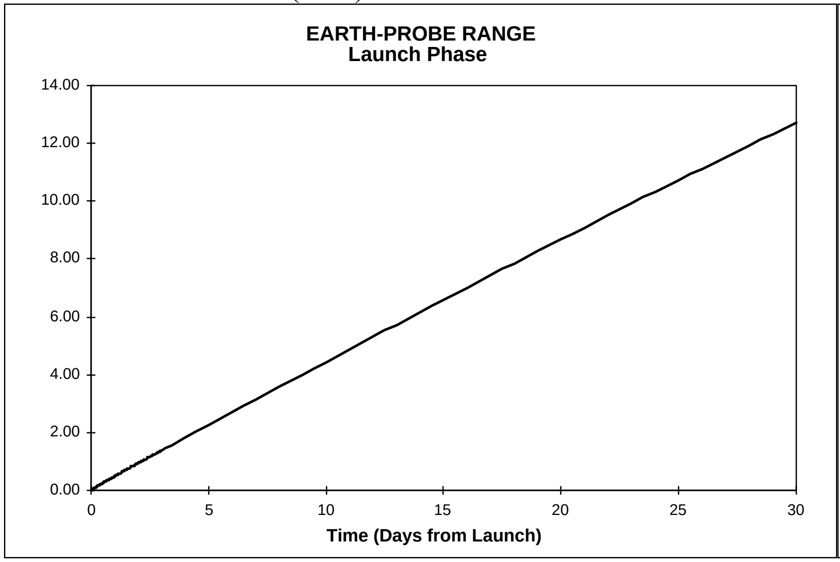
9.1 Mission Data Set
9.2 Launch Data Set
9.3 EGA Data Set
9.4 Wild-2 Encounter Data Set
9.5 Earth Return Data Set
9.6 PRD Traceability Matrix

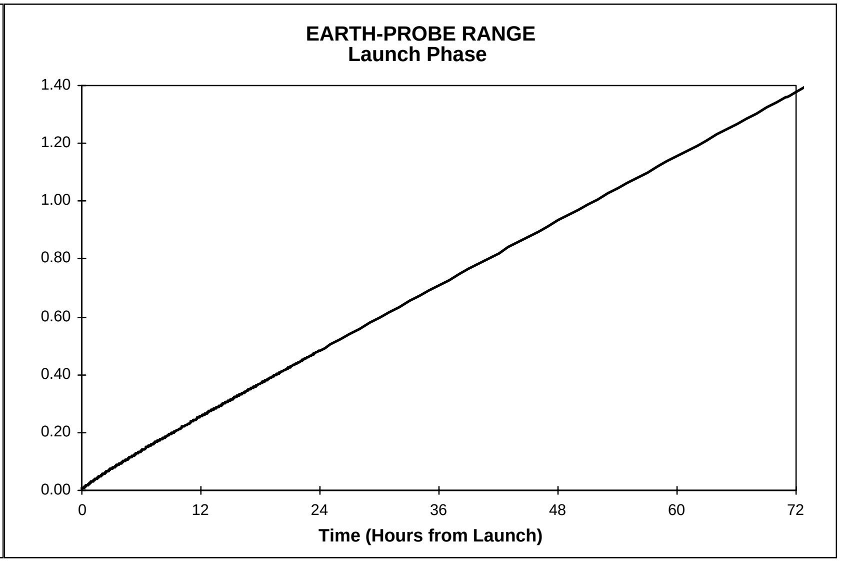


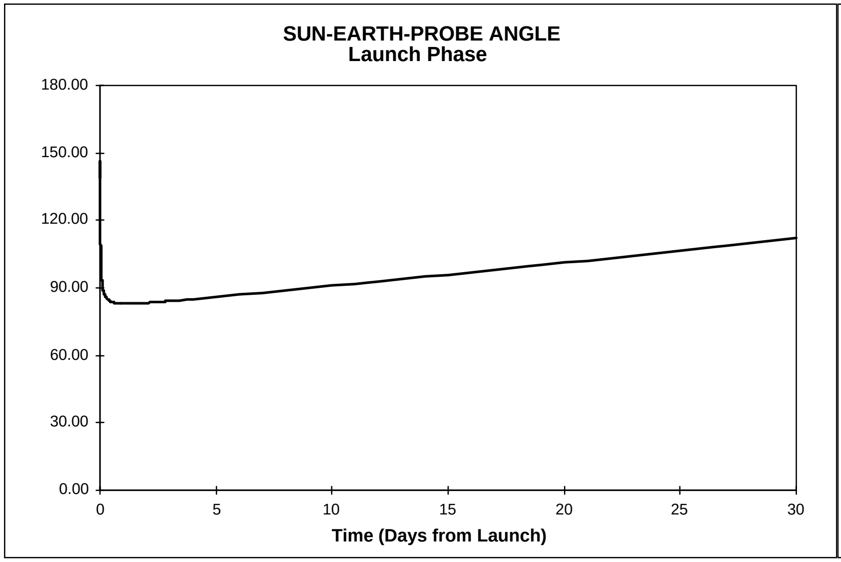
9.1 Mission Data Set

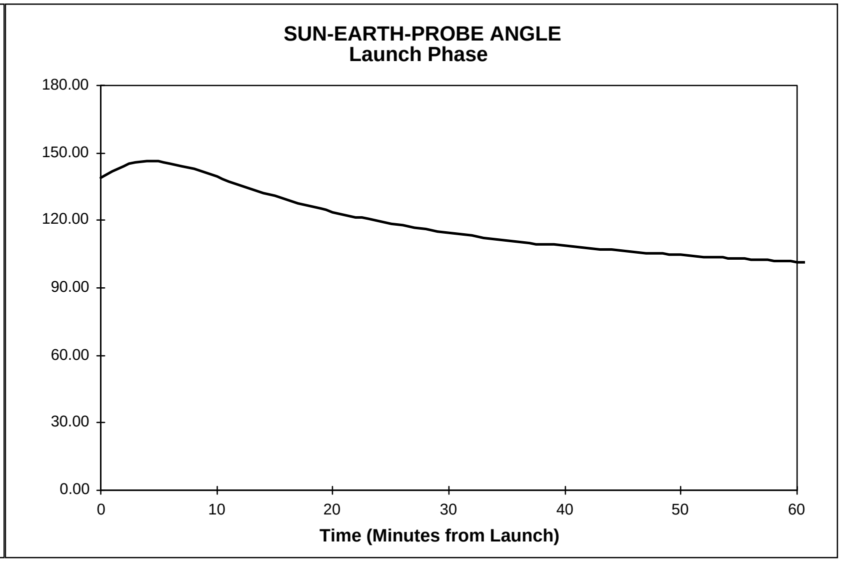

Wild 2-Probe Range
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Time (days from launch)


Sun-Wild 2-Probe Angle
180.00
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Time (days from launch)

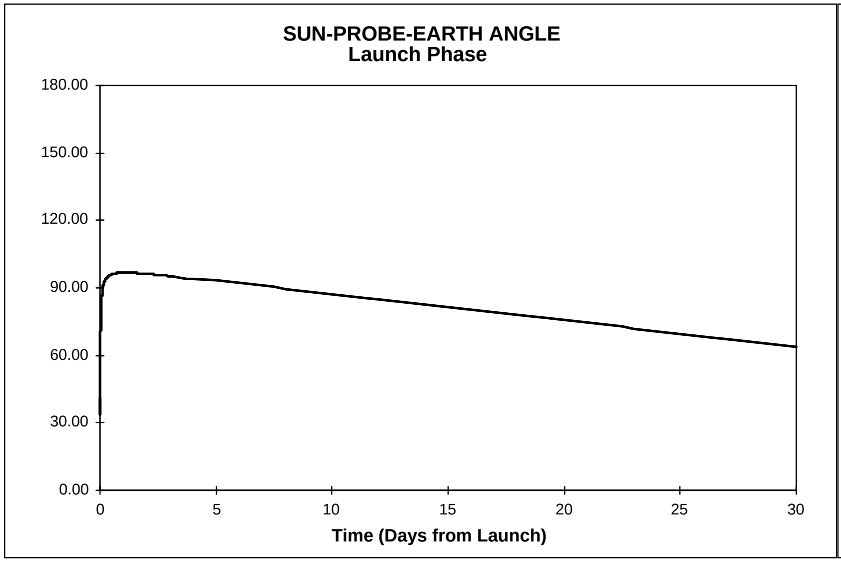

EARTH-PROBE RANGE
Launch Phase
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
0
5
10
15
20
25
30
Time (Days from Launch)

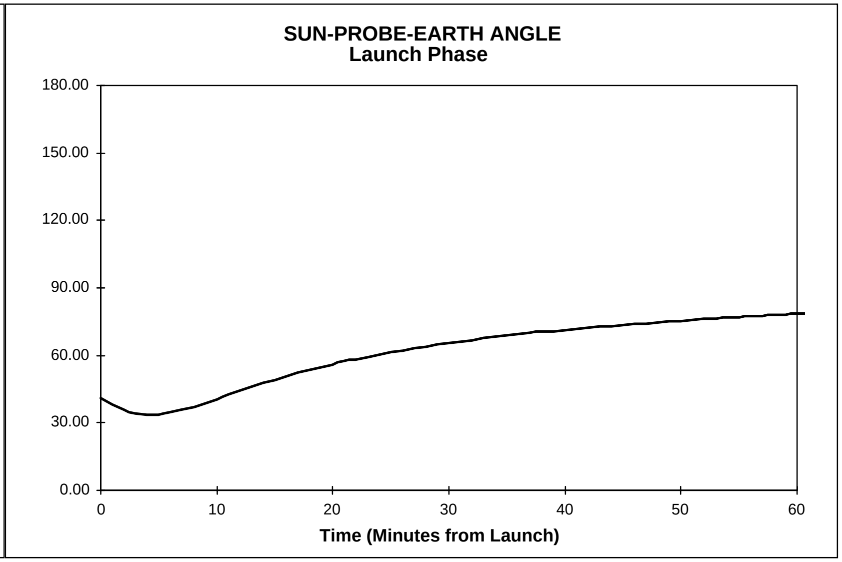

EARTH-PROBE RANGE
Launch Phase
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
12
24
36
48
60
72
Time (Hours from Launch)

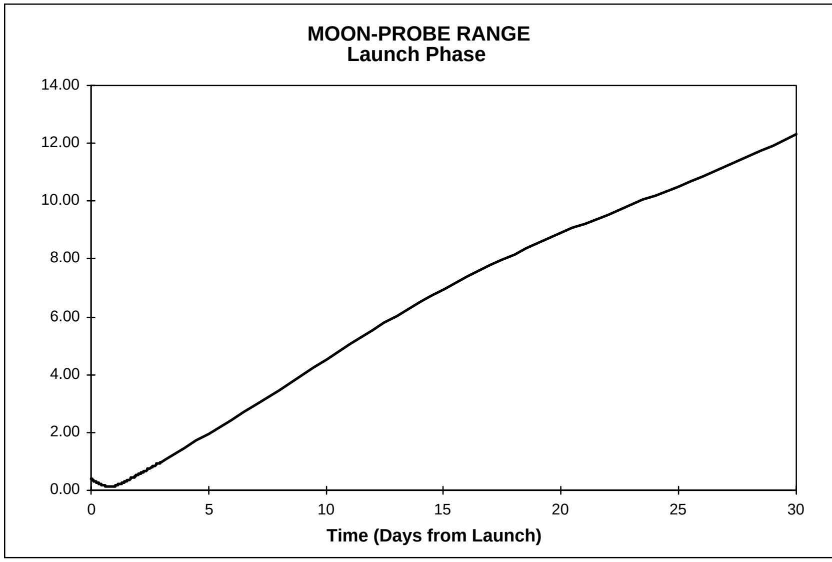


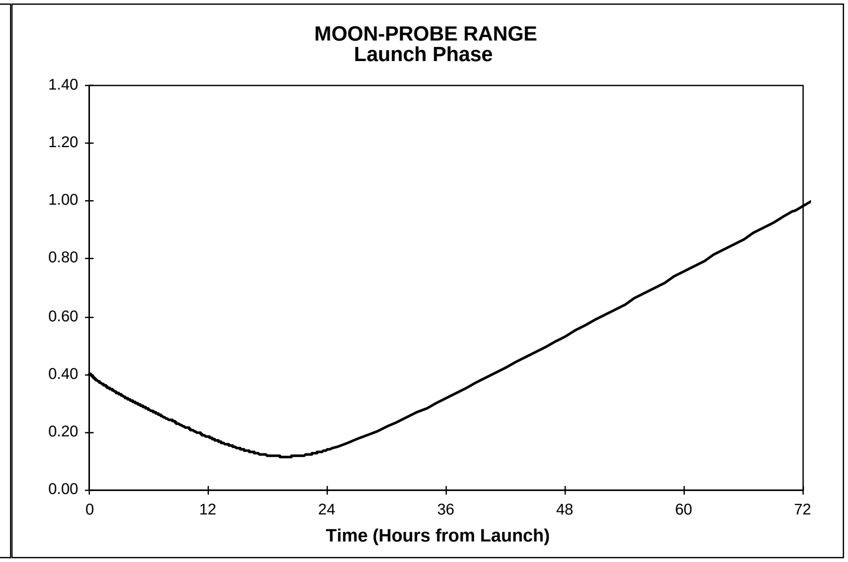


9.2 Launch Data Set









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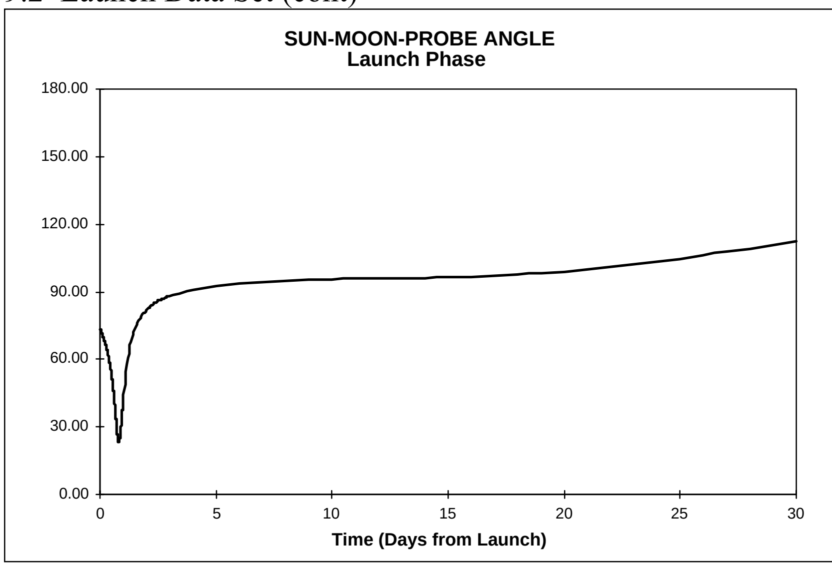

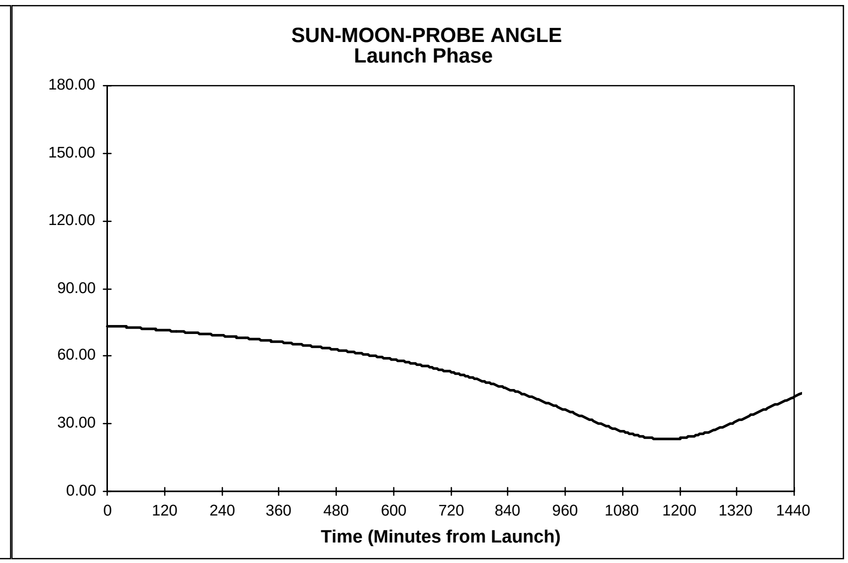

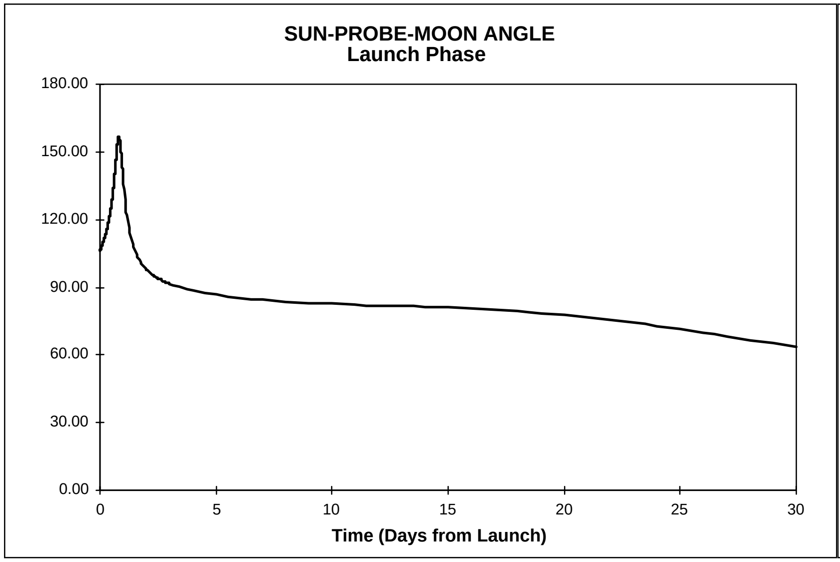

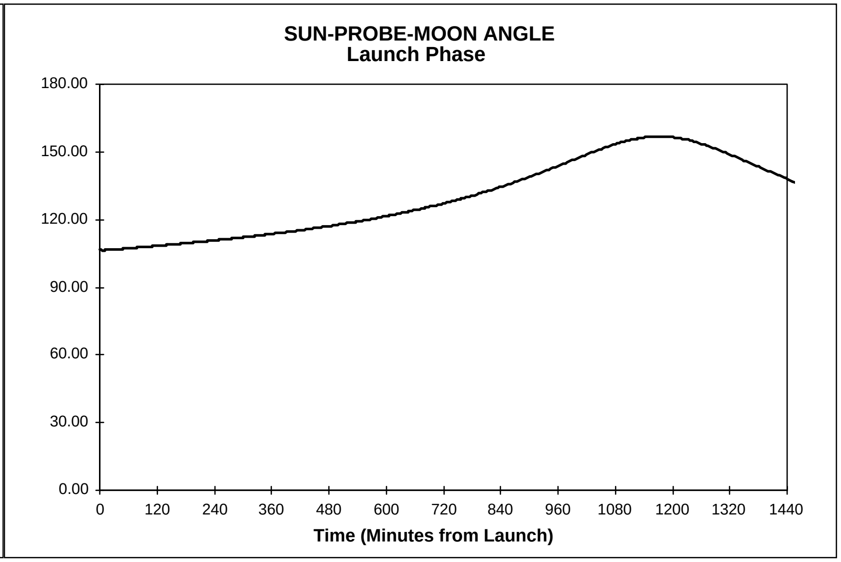

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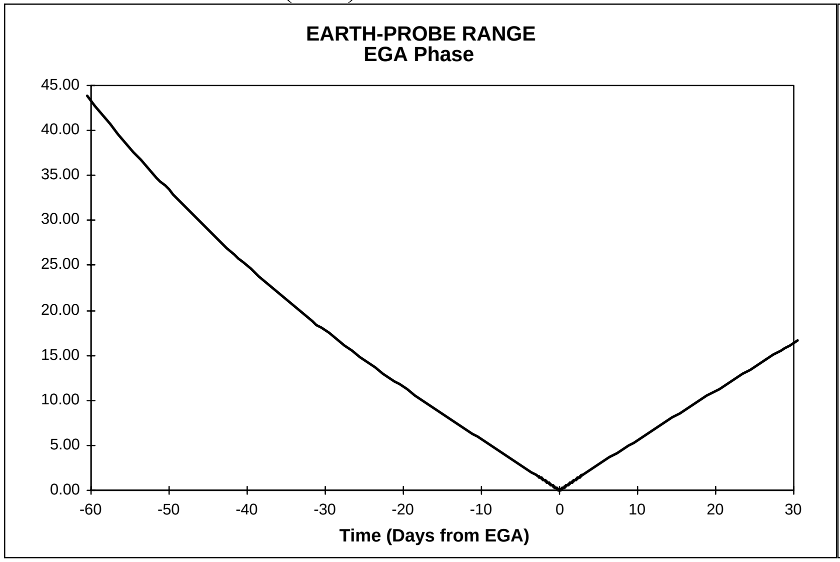
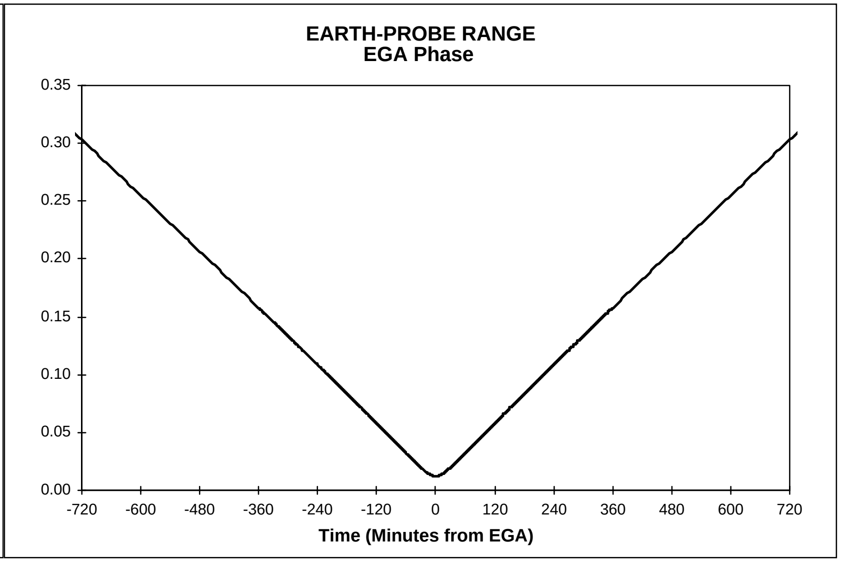
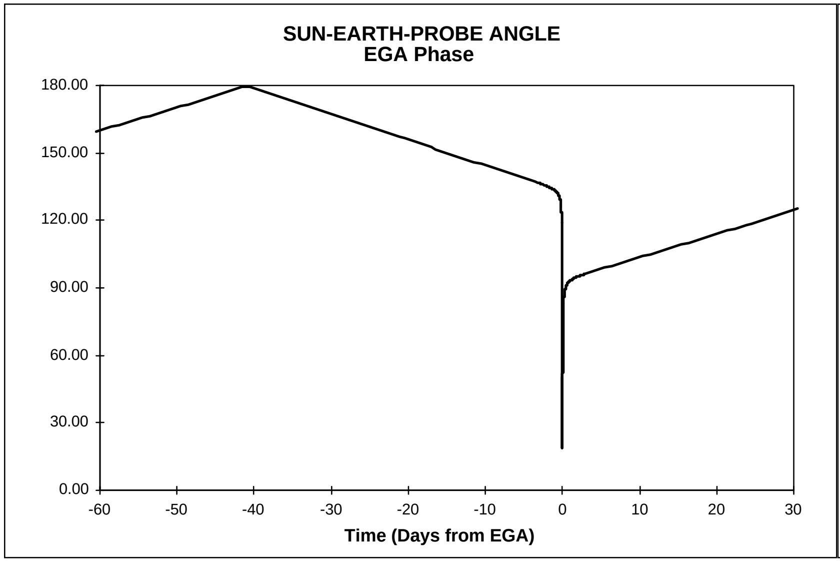
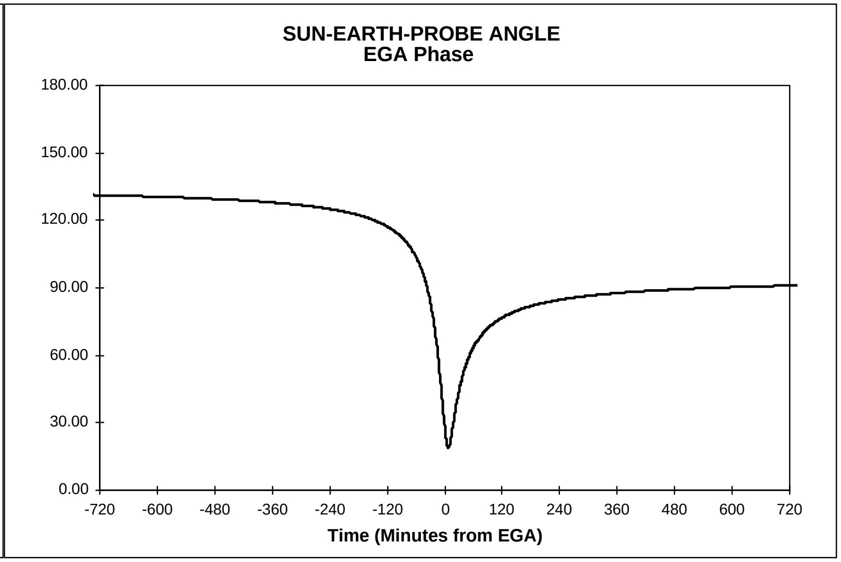
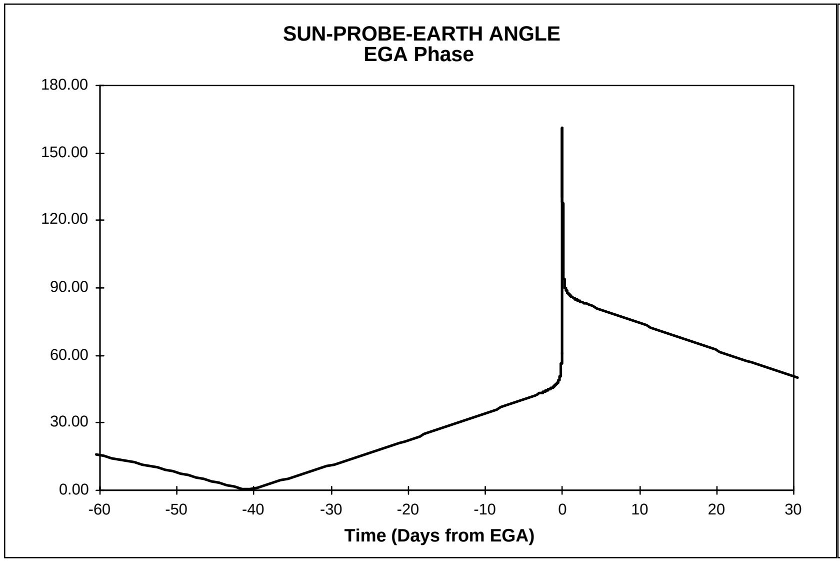


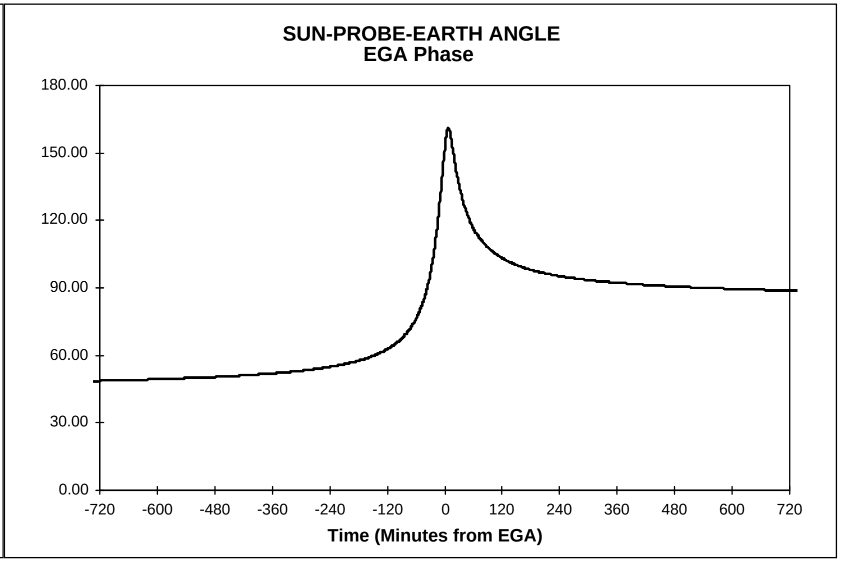


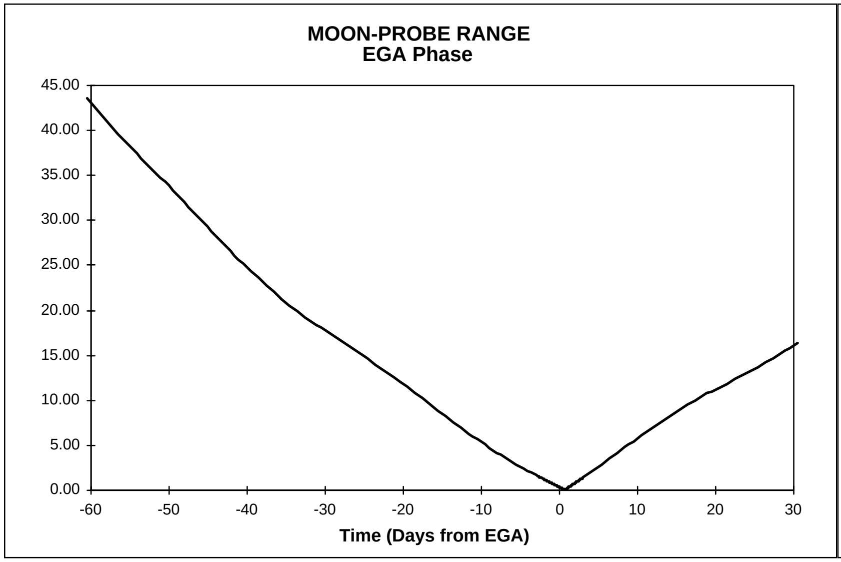


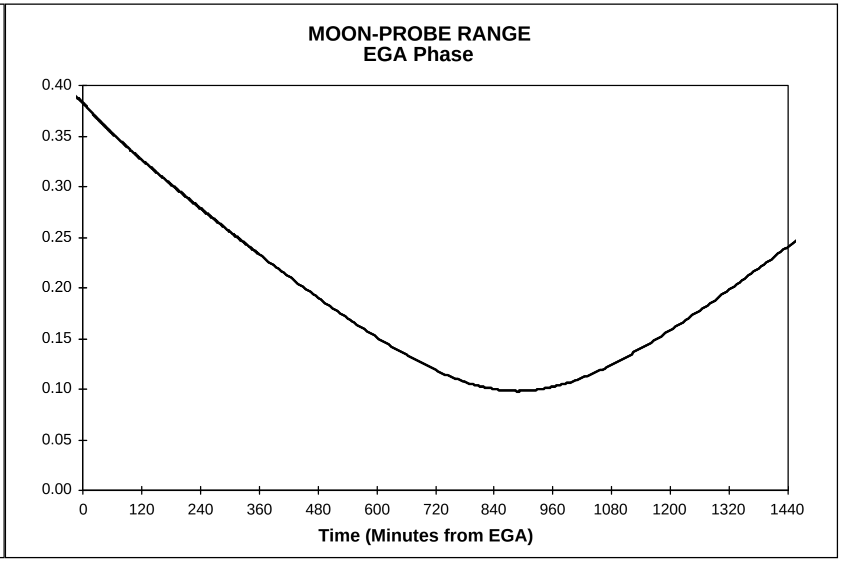


9.3 EGA Data Set









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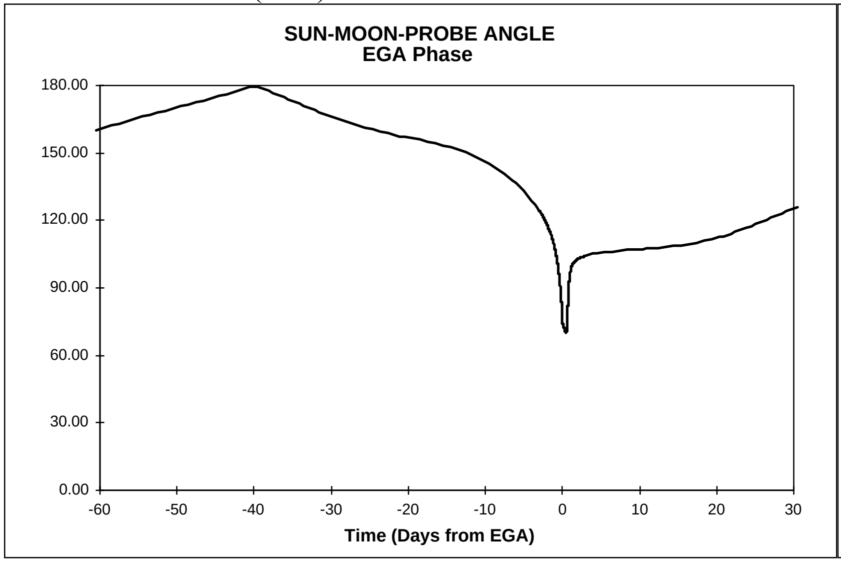

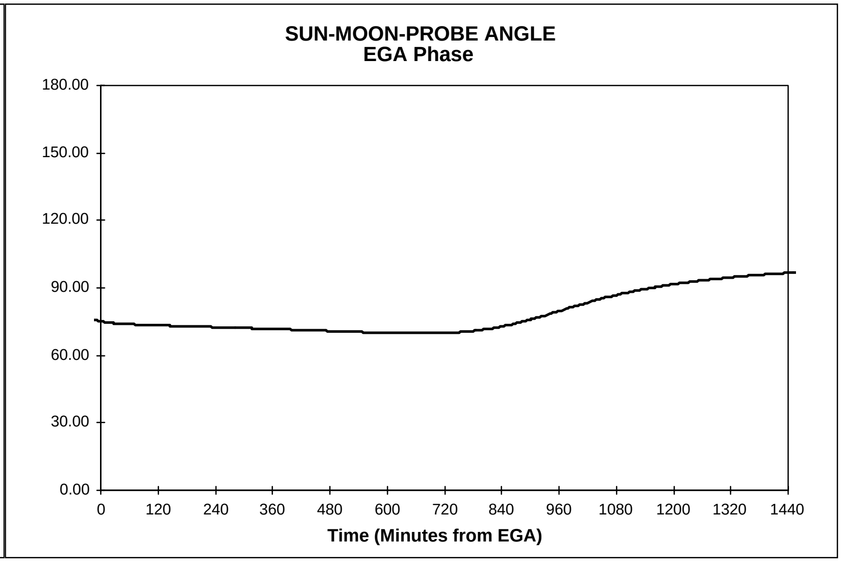

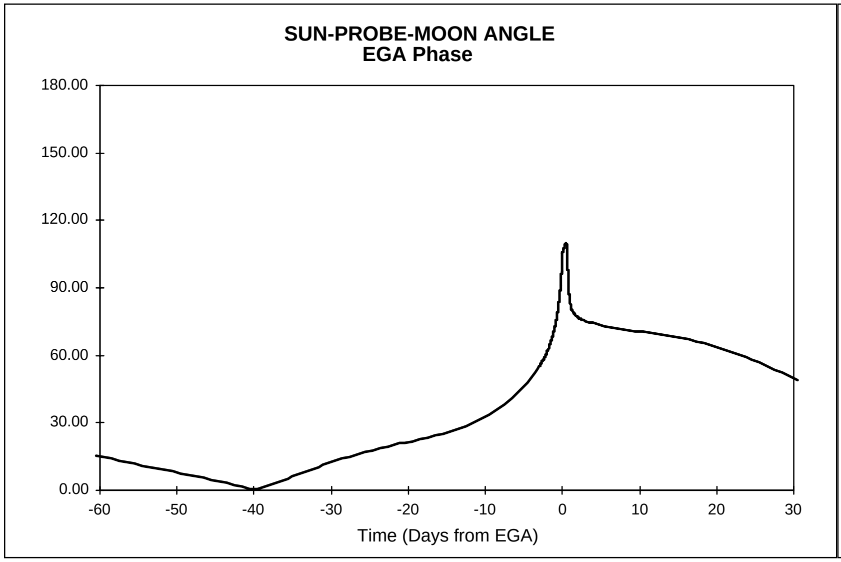

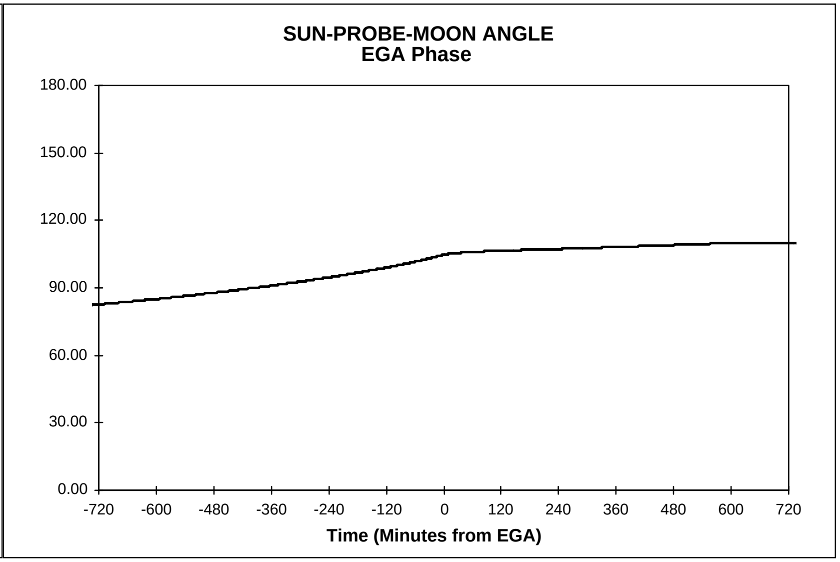

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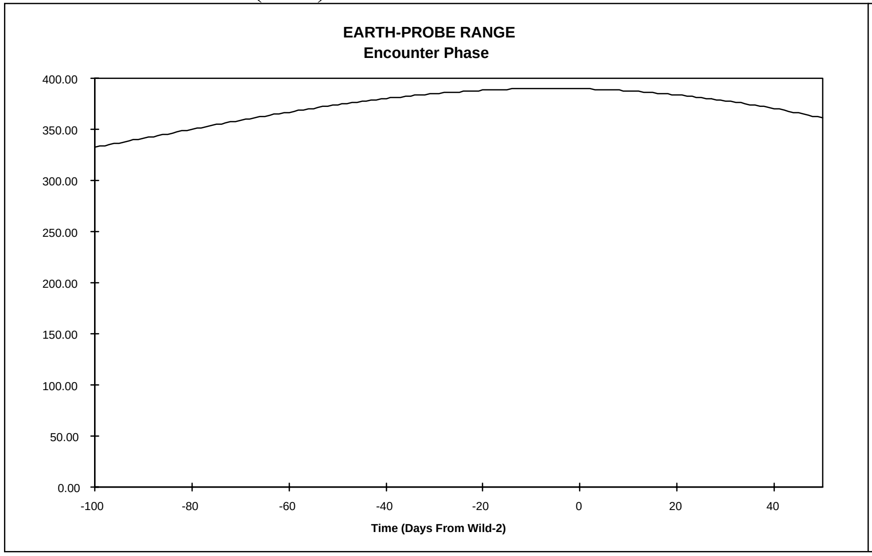

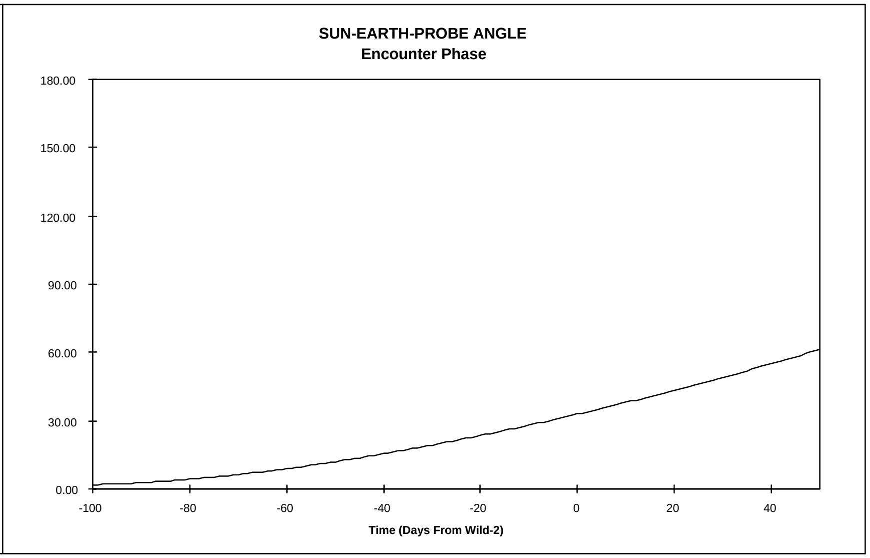

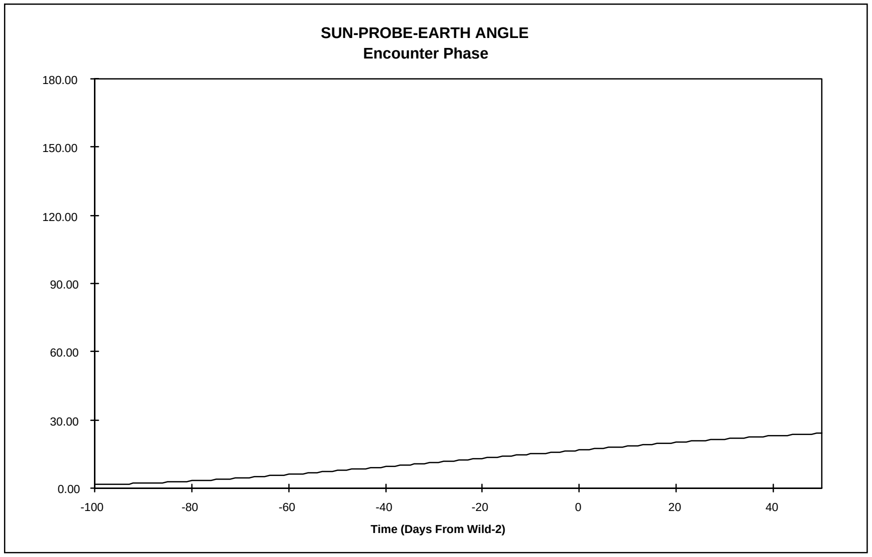

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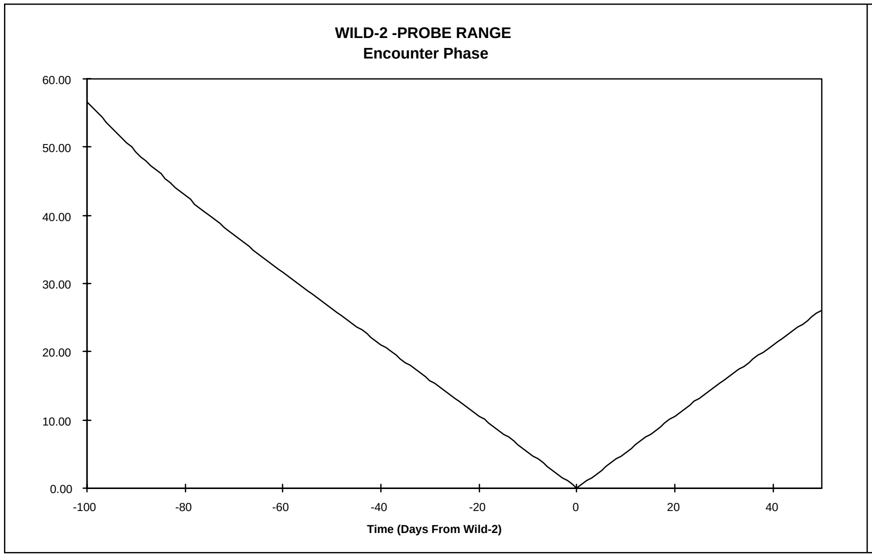

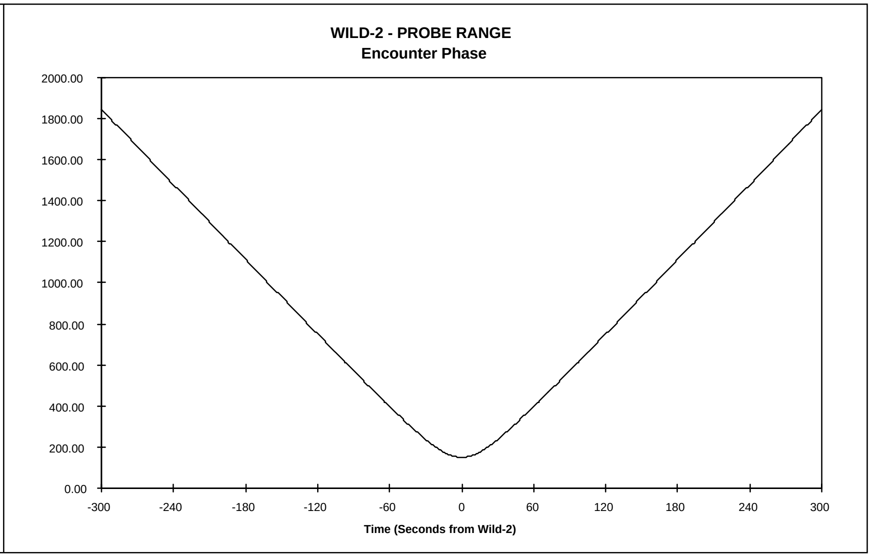

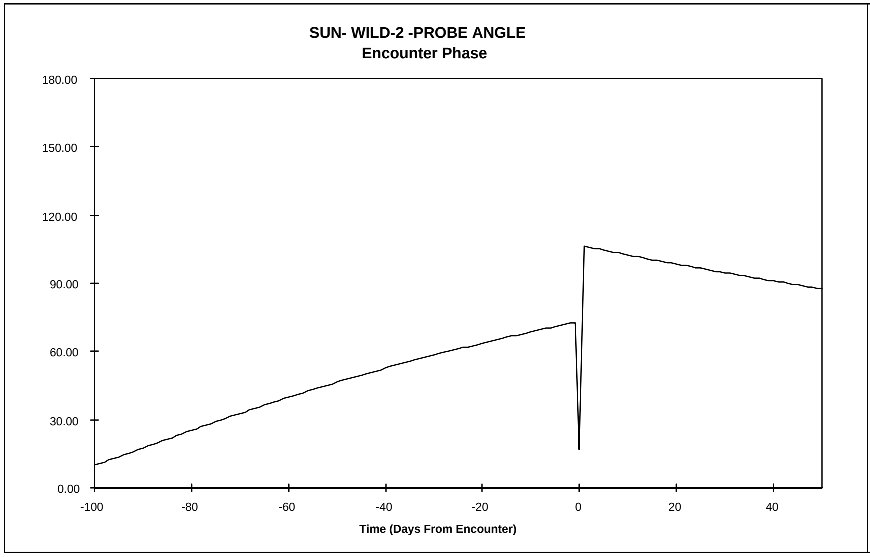

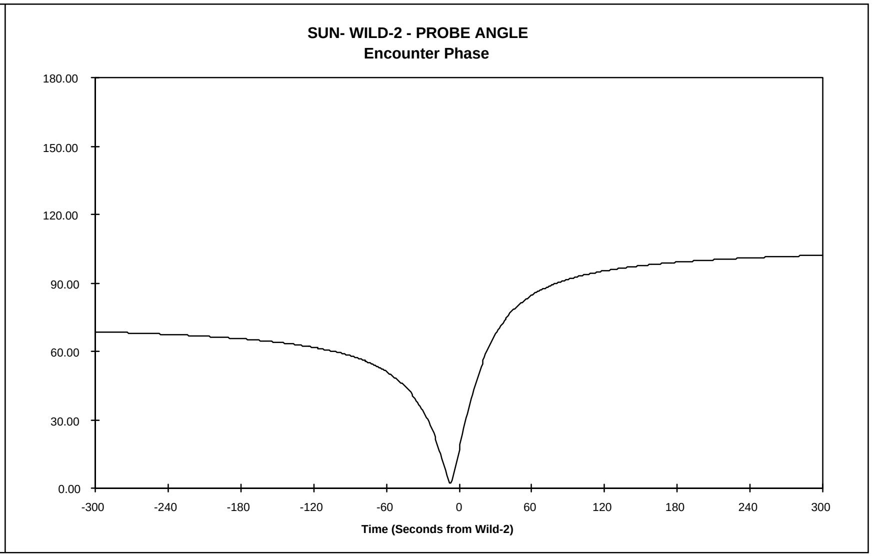

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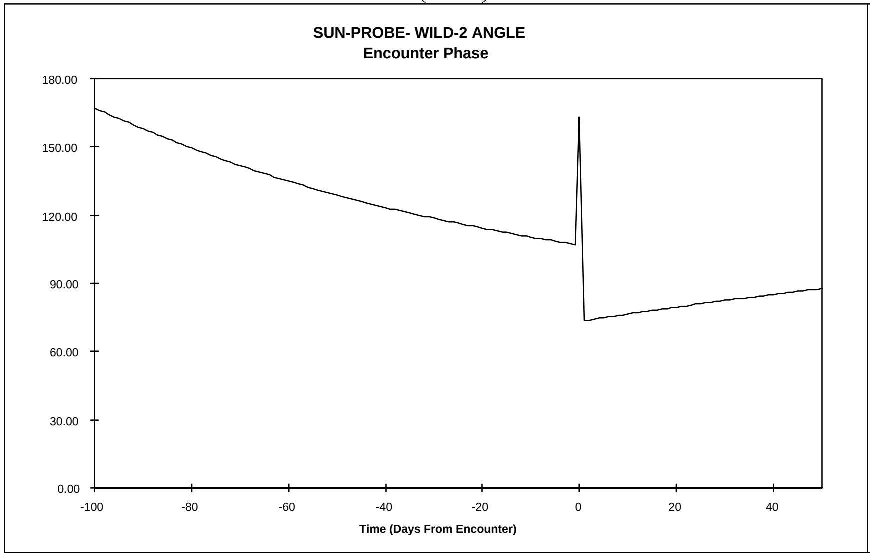

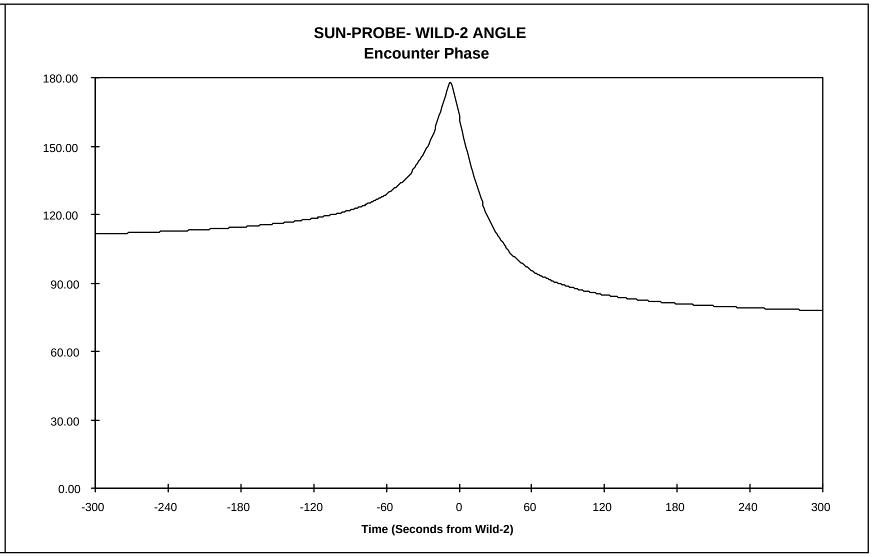

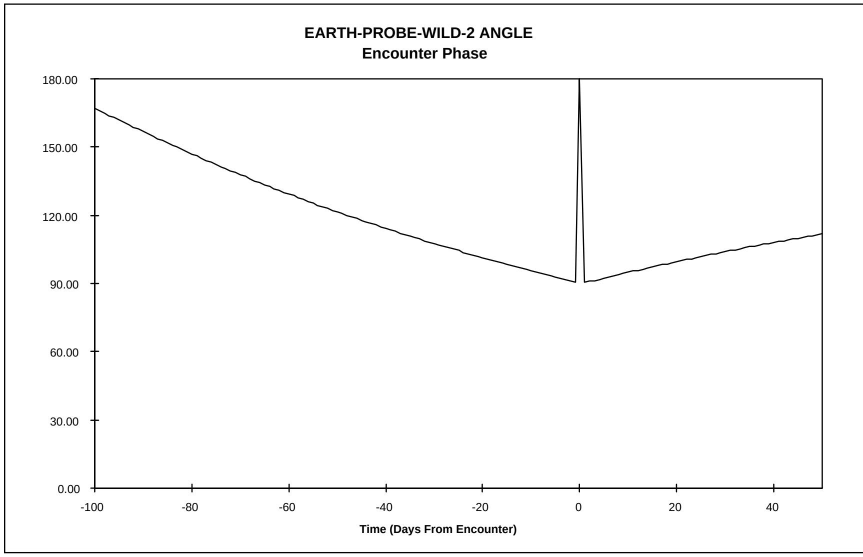

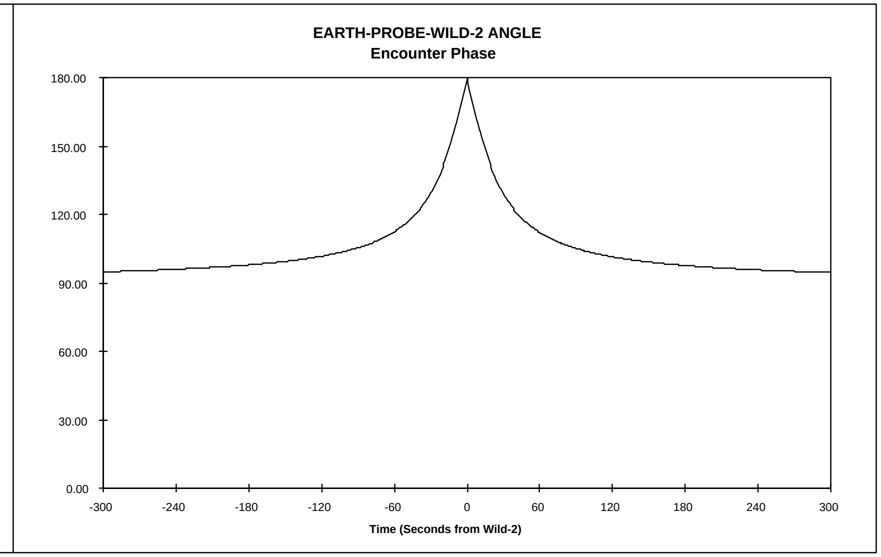

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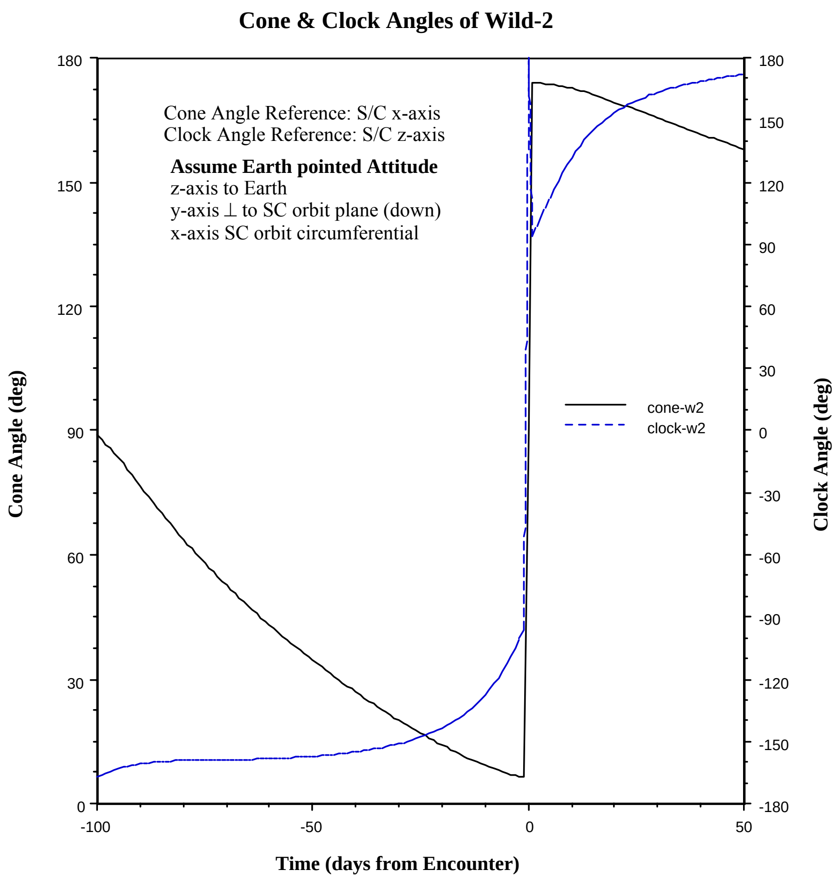

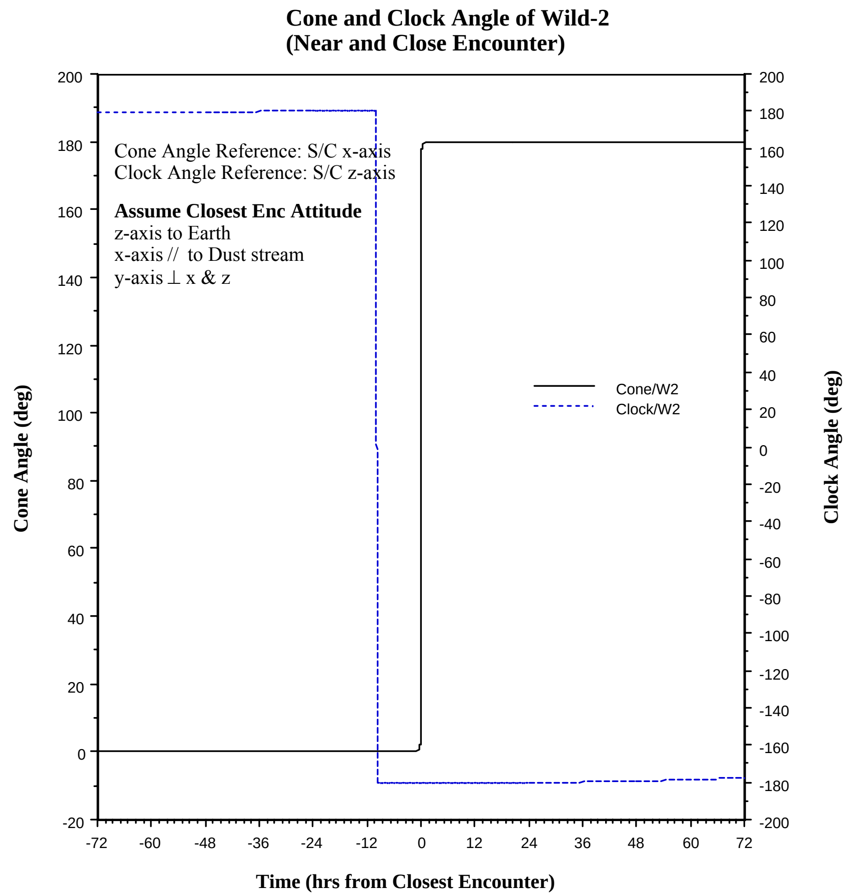

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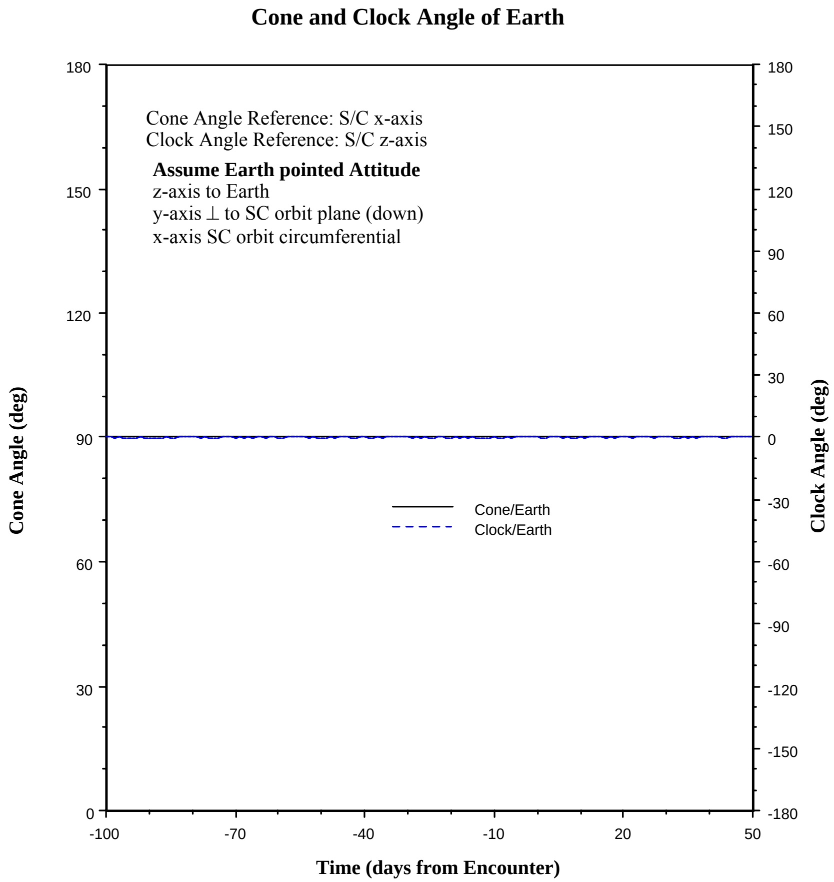

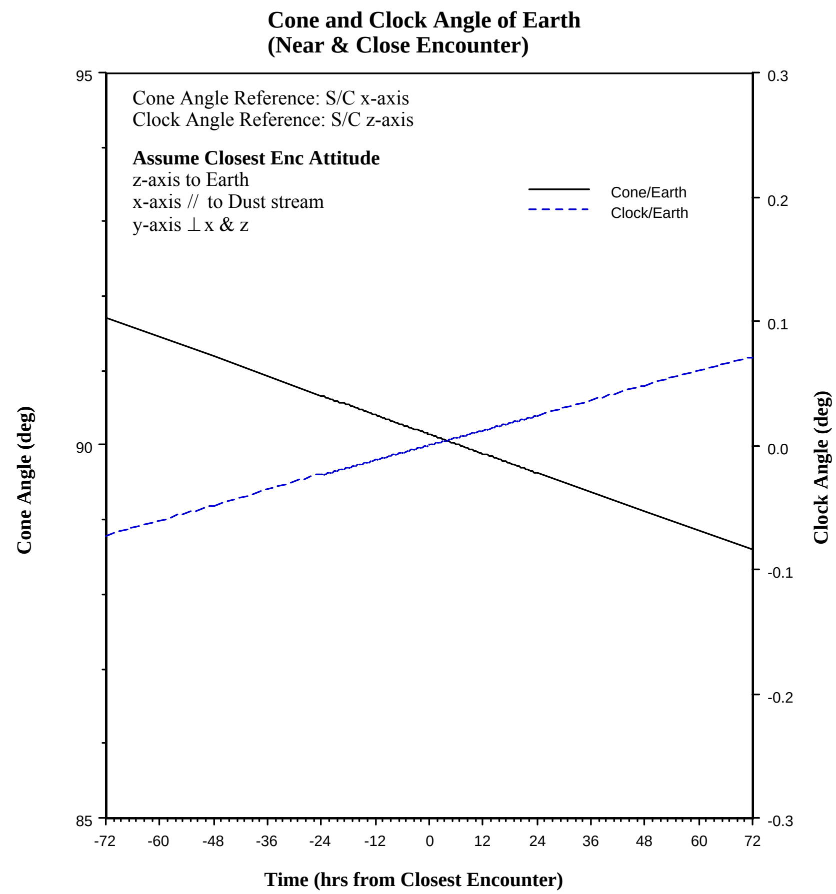

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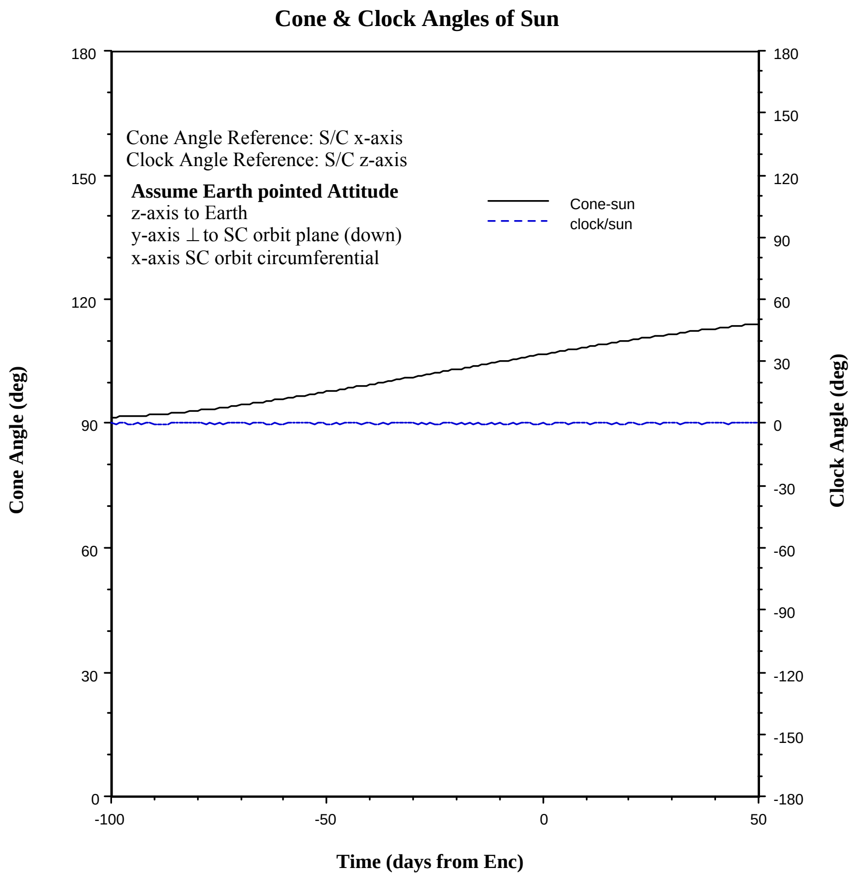
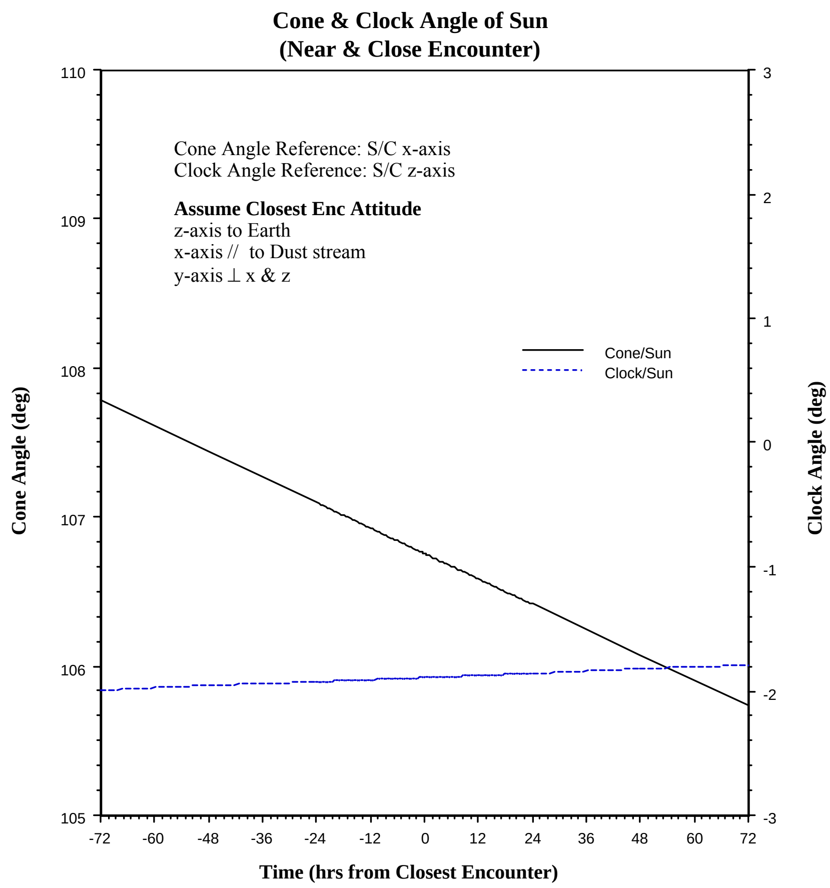
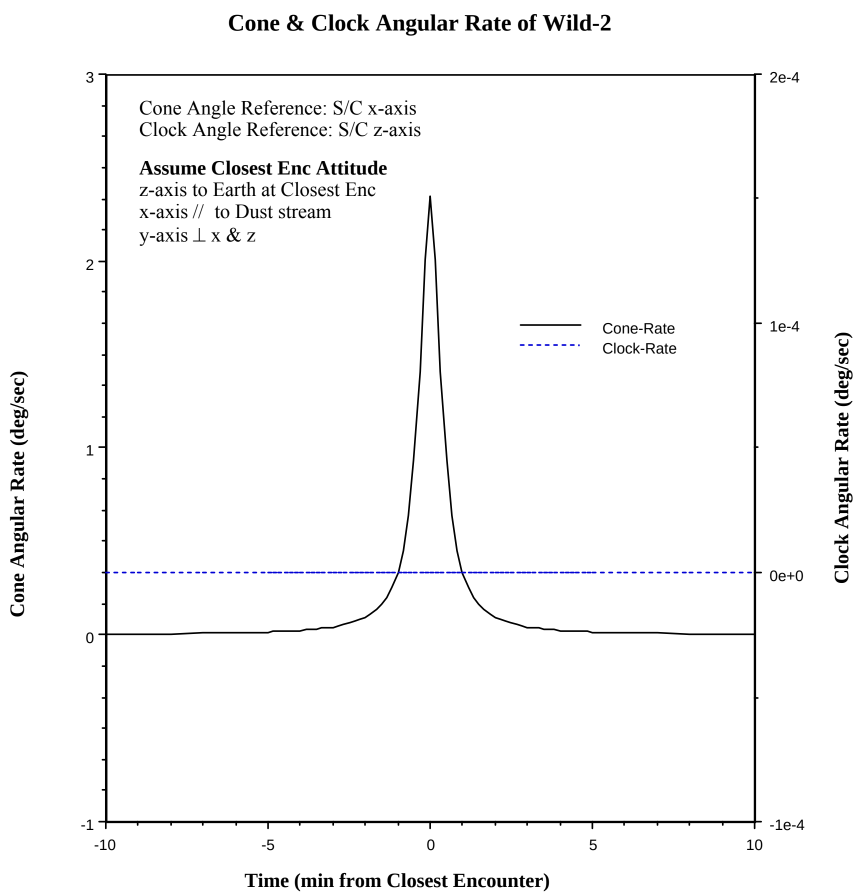

Cone & Clock Angles of Sun
Cone Angle Reference: S/C x-axis
Clock Angle Reference: S/C z-axis
Assume Earth pointed Attitude
z-axis to Earth
y-axis ⊥ to SC orbit plane (down)
x-axis SC orbit circumferential
Cone-sun
clock/sun
Cone Angle (deg)
Clock Angle (deg)
Time (days from Enc)


Cone & Clock Angle of Sun
(Near & Close Encounter)
Cone Angle Reference: S/C x-axis
Clock Angle Reference: S/C z-axis
Assume Closest Enc Attitude
z-axis to Earth
x-axis // to Dust stream
y-axis ⊥ x & z
Cone/Sun
Clock/Sun
Cone Angle (deg)
Clock Angle (deg)
Time (hrs from Closest Encounter)

9.4 Wild-2 Encounter Data Set (cont)



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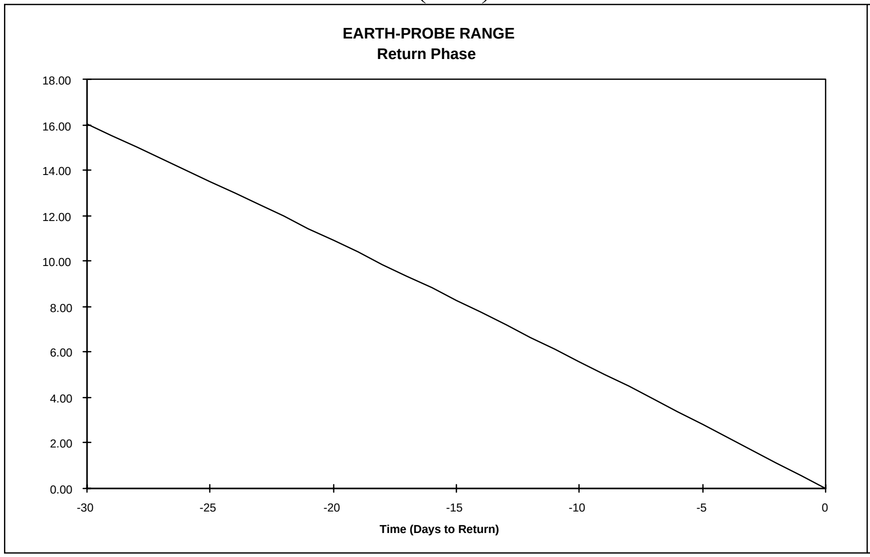
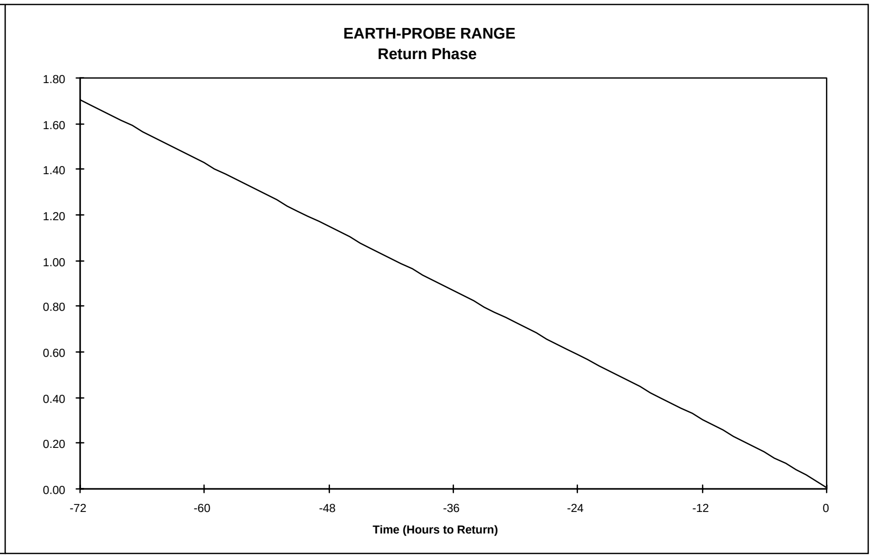
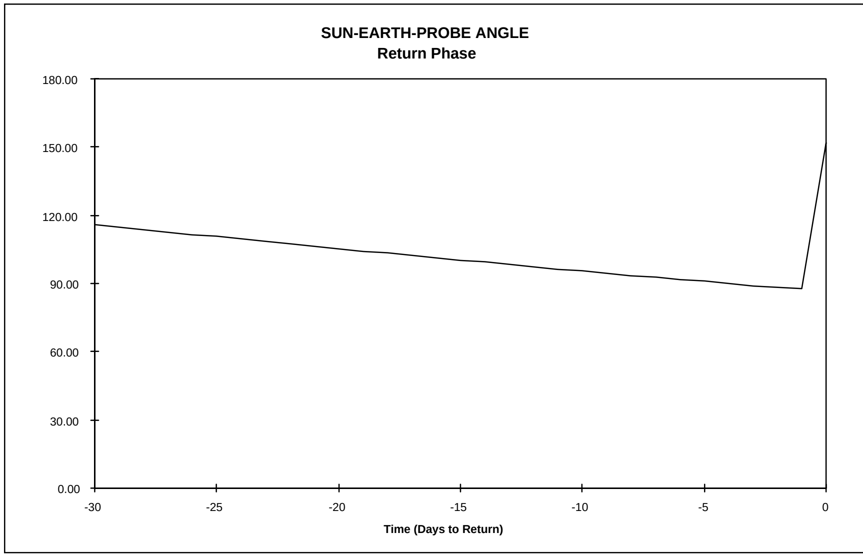
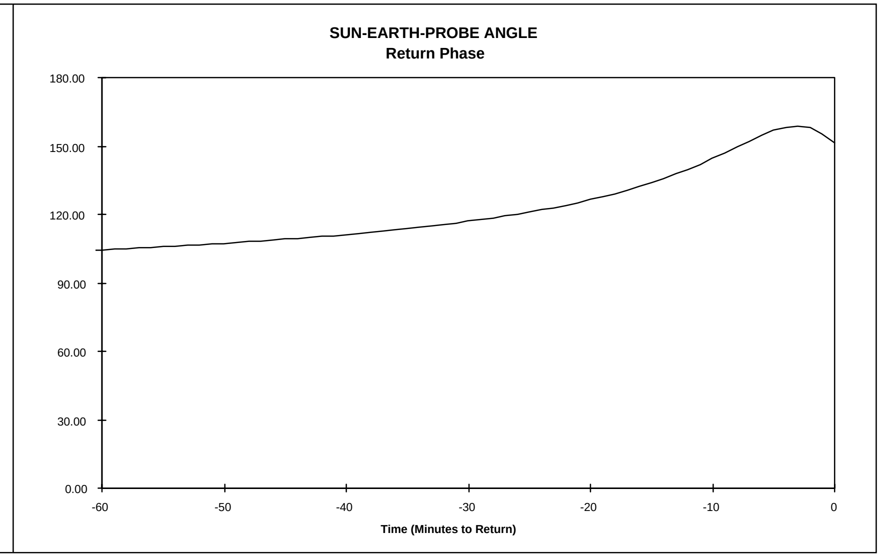
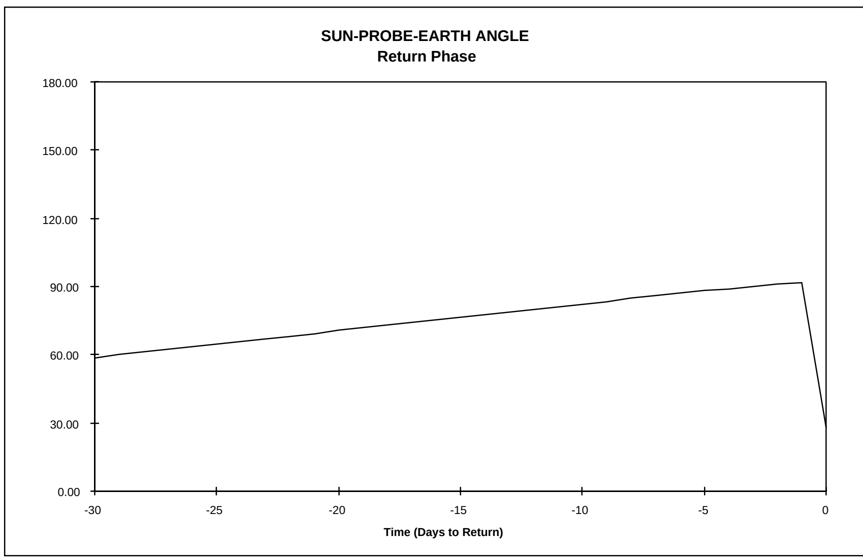


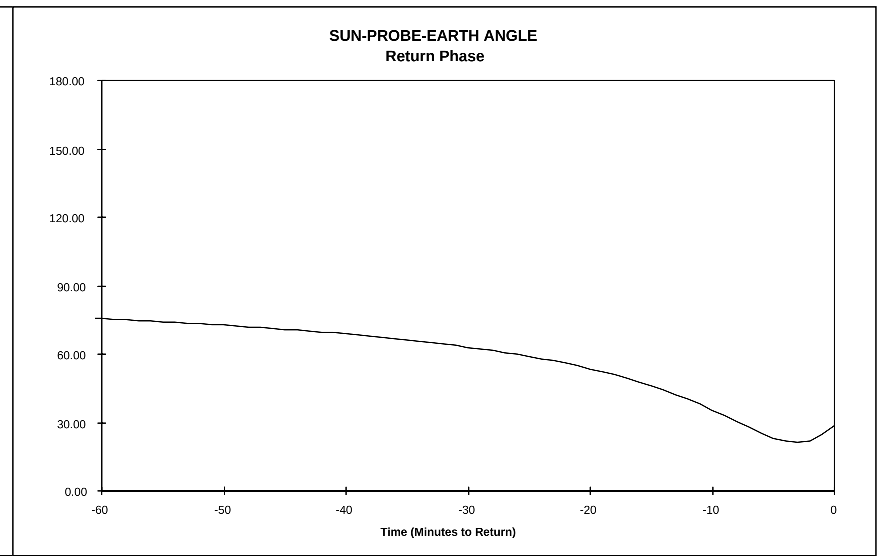


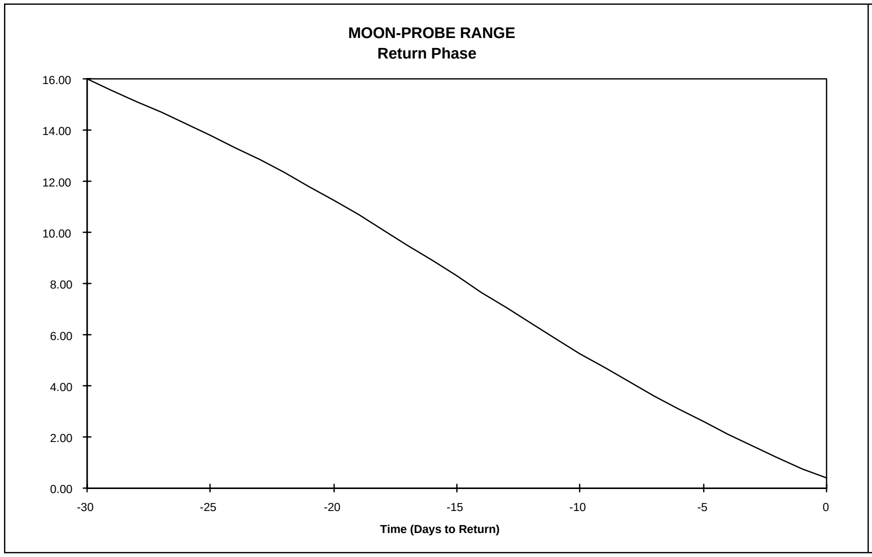


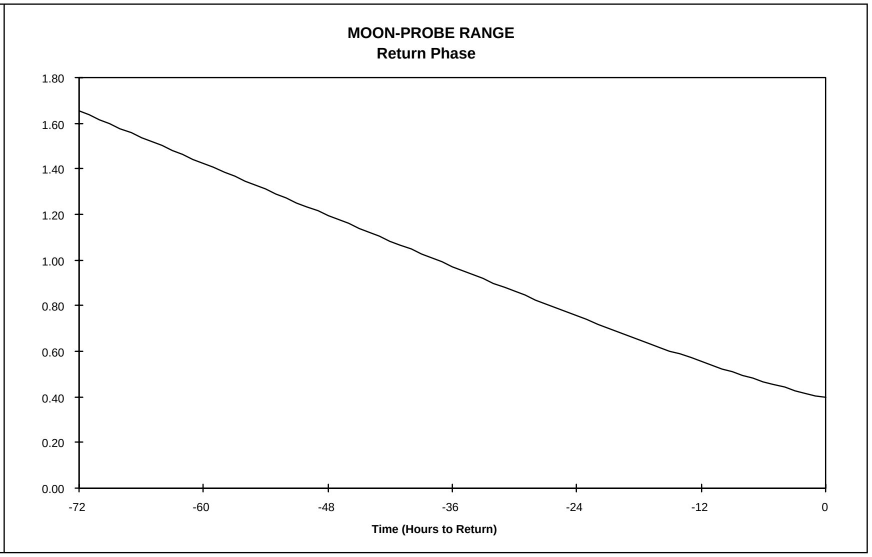


9.5 Earth Return Data Set









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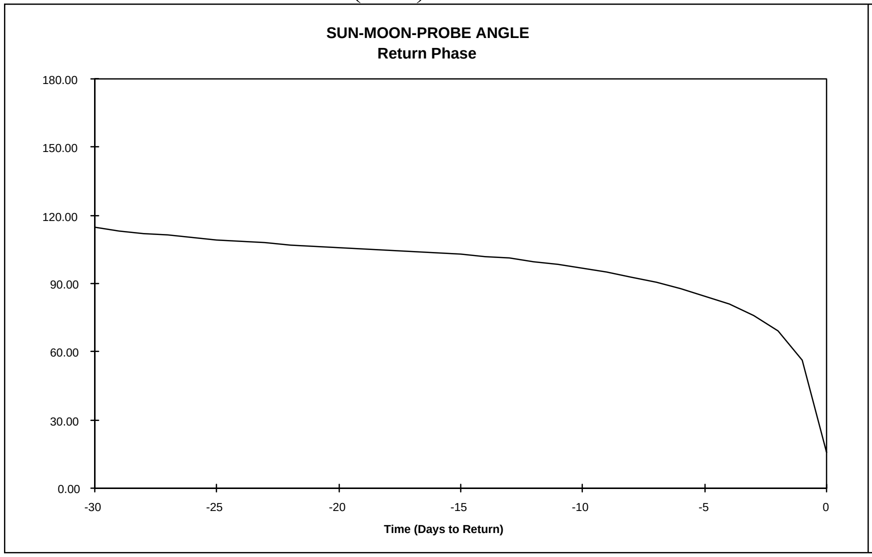

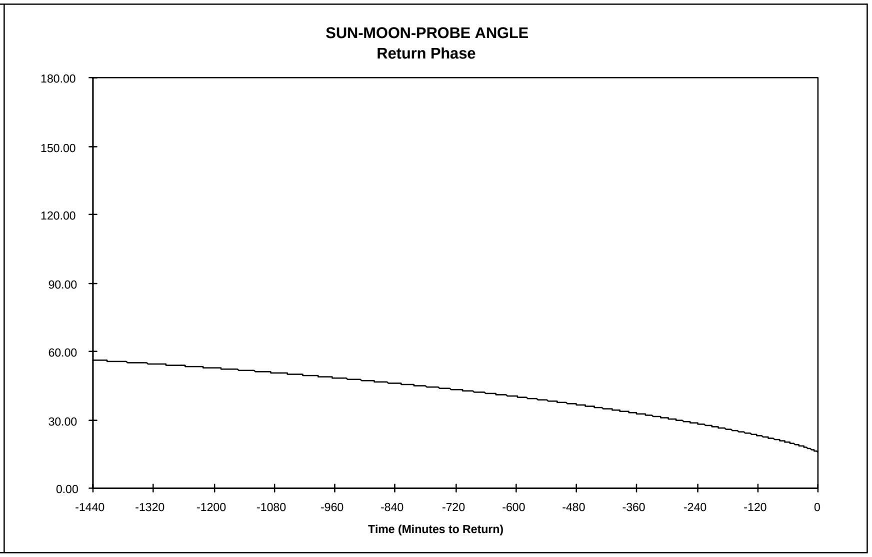

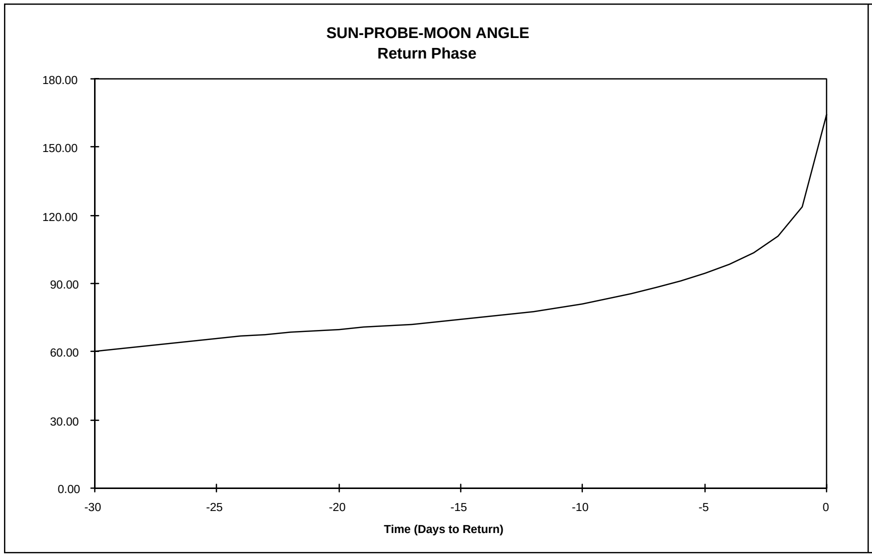

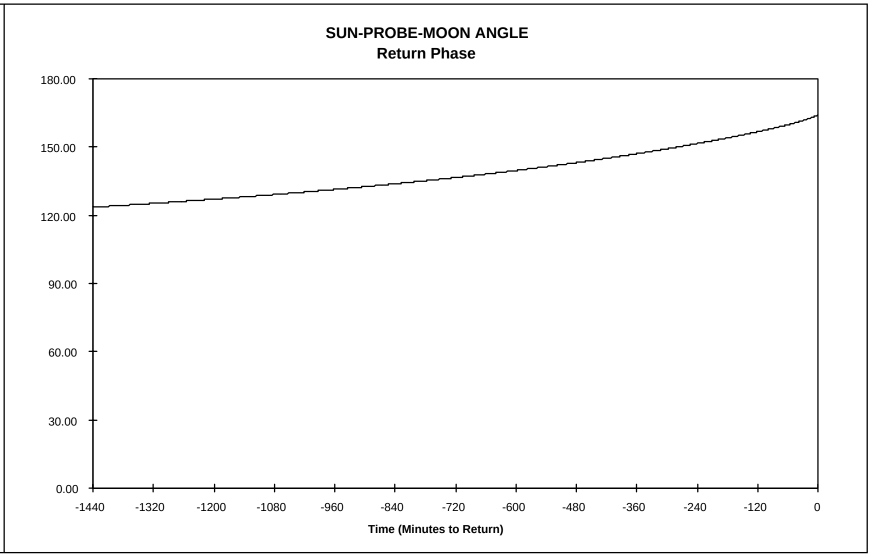

9.5 Earth Return Data Set (cont)

10.0 Appendix B: Unbalanced Attitude Control Force Modeling

The STARDUST spacecraft design imparts an unbalanced force, i.e. translational thrust to the spacecraft, every time attitude control burns are executed. This undesirable condition is dictated by the need to prevent contamination of the sample collector. Over the seven year mission, the cumulative ACS activity is estimated to impart tens of meters per second of ΔV. The sum of trajectory correction maneuvers to compensate for the ACS burns could be intolerably large (~40 m/s) unless the ACS effects are accounted for in advance while designing the nominal trajectories. From the navigator's point of view, the ACS activity is an error source that cannot be ignored in striving to achieve accurate spacecraft delivery at comet and Earth re-entry.

This section describes the methods used to model this perturbation source and its incorporation in the trajectory design and maintenance. The ACS perturbation is divided into two categories: 1) almost continually acting ACS limit cycling and 2) less frequent attitude slewing required for communications, maneuvers and special activities.

The trajectory optimization program can include the first type of perturbations, but discontinuous second types are too cumbersome to deal with. As a result, the decision has been made to include the latter effect in the navigation tools only in the form of a tabular small forces predict file. This will enable accurate predictions, but will be very slightly off-optimal in the ΔV estimates.

10.1 Limit Cycle Model

A mathematical model of the behavior of the attitude control system (ACS) is constructed to compute ACS perturbations to the spacecraft trajectory due to cruise deadbanding or limit cycling.

In this model, ACS thruster pulse frequencies are computed consistent with the planned attitude history. The magnitude of the frequency depends on spacecraft mass distribution, thruster characteristics and configuration, mission geometry, and expected solar torques. These pulse frequencies are not incorporated into the trajectory design as individual pulses, but instead, are converted to average perturbative accelerations.

The performance of the spacecraft's hydrazine-blowdown system is modeled according to the manufacturer's specifications, and the direction of the ACS acceleration is established based on the pre-flight plan for spacecraft attitude.

10.1.1 Spacecraft Attitude History

The spacecraft's trajectory and required cruise attitude history dictates the ACS perturbation due to limit cycling. The main source of attitude offset is the presence of solar torque which depends on the solar range and the spacecraft attitude with respect to the sun. The magnitude of the solar torque and the deadband within which the spacecraft attitude is controlled dictates the frequency at which the ACS thrusters are fired and the corresponding magnitude of the ACS perturbation. The direction of the ACS force, in the case of limit cycling, is parallel to the planned spacecraft +z-axis direction. The forces in the other two axis are assumed to cancel out on average.

For the limit cycle model, the cruise spacecraft attitude is divided into four main modes. Table 10.1-1 summarizes these modes and submodes in terms of spacecraft axis alignment. Spacecraft pointing is controlled to within the accuracy established by planned axis deadbands. Each axis is allowed to deviate from the desired pointing direction by the established angular amount. The axis are kept within the desired region by firing the appropriate thruster pair when one of the deadbands is tripped. Table 10.1-2 summarizes the deadband options available.

Table 10.1-1 Spacecraft Attitude Options - Limit Cycle Model

Option	Sub-option	First Axis	Second Axis
1. Sunpoint	11	+z = -r	+y = -r X v
	12	+z = -r	+y = +r X v
2. Constant off-sun angle	21	same as above *	
	22	same as above *	
	* followed by a single axis rotation about +y axis		
3. Interstellar dust collection	31	+z = -r	+y = -r X ivr
	32*,[1]	+x = ivr	+y = -r X ivr
	33	+x = ivr	+y = -r X ivr
	* followed by a single axis rotation, angcol amount, about +y axis		
4. CIDA experiment	41	+x = -ivr	+y = -r X ivr
	42*	+z = -r	+y = -r X ivr
	* followed by a single axis rotation about +y axis		
where:			
+x, +y, +z	= spacecraft x, y, z axis unit vectors		
r, v	= spacecraft position and velocity		
ivr	= interstellar particle relative velocity vector (visp - v)		
angcol	= maximum aerogel collector deployment angle		
Note 1	= option not used in current model due to off-sun angle constraints		

Table 10.1-2 Spacecraft Deadband Options - Limit Cycle Model

Option	Deadband	Comments
1	x, y, z = 15°	Cruise option 1
2	x, y = 2°, z = 10°	Near encounter
3	x, y, z = 10°	Cruise option 2

It is important to note that the spacecraft attitude for this model is referenced to the orbit plane. During flight, the spacecraft attitude will actually be referenced to the Sun-Earth-Probe plane. This results in slight differences between the modeled and the planned spacecraft attitude when the spacecraft is near Earth. However, this was deemed acceptable in order to reduce the complexity that would have been introduced by adding the Earth ephemeris to the trajectory optimization scheme.

10.1.2 Attitude Control Force Model

The magnitude of the acceleration imparted by the ACS system is determined by calculating the average thruster activity (pulse frequency) as ruled by rigid body dynamics. Pulse frequency is proportional to the number of times the offset exceeds the deadband.

The thrust performance of the blow-down propulsion system is accurately modeled because the performance differs appreciably across the duration of the mission. The equations leading to the ACS force are described below and were documented in a LMA technical memo written by Jason Wynn, TM-053.

The thrust level of the ACS thrusters depends on the feed pressure of the propulsion system which is given by the following equation.

$$p = \frac{p_o u_o}{\left[u_o + \frac{m_o - m}{mp_o (1 - u_o)} \right]}$$

where:

p_o	= initial tank pressure (psi)	u_o	= initial tank ullage (mp_o / m_o)
m_o	= initial total spacecraft mass (kg)	mp_o	= initial propellant mass (kg)
m	= current spacecraft mass (kg)	p	= current tank pressure (psi)

The thruster magnitude per pulse (f_{bit}) is as follows. The factor of 2 indicates that a thruster pair is fired when a deadband limit is tripped.

$$f_{bit} = 2 * (0.0067 + 0.00004984 p)$$

Once the minimum impulse bit has been calculated, rigid body dynamics is invoked to calculate the thruster pulse frequency required to maintain spacecraft motion within the desired attitude deadbands. Based on combination of analysis and motion simulations, conducted at LMA, the following empirical equations are used to represent the thruster firing frequency.

$$n_x = \frac{\tau_{sx} \cos^2 \theta_s (R_{\max} - R) R_{\min}^2}{l_x f_{bit} (R_{\max} - R_{\min}) R^2} + \frac{l_x f_{bit} (R - R_{\min})}{4 db_x I_{xx} (R_{\max} - R_{\min})}$$

$$n_y = \frac{\tau_{sy} \cos^2 \theta_s R_{\min}^2}{l_y f_{bit} R^2} \qquad n_Z = \frac{l_Z f_{bit}}{4 db_Z I_{ZZ}}$$

$$n_T = n_x + n_y + n_Z$$

where:

n_*	= thruster pulse frequency (1/s)	τ_{s*}	= solar torque (x, y axis) (Nm)
θ_s	= z-axis off-sun angle, attitude plan dependent	l_*	= effective thruster moment arms (m), including effect of thruster cant
I_{**}	= mass moments of inertia (kgm^2)	db_*	= deadband limits (radians)
R_{***}	= solar range (AU)		

These equations decouple the motion in each of the spacecraft axis to facilitate the modeling process. Notice that the motion about the y axis of the spacecraft is driven primarily by the influence of the solar torque, while the solar torque components in the spacecraft z-axis is relatively small and ignored. The degree to which motion about the x axis is influenced by solar torque is determined by the solar range history of the mission. Near the sun (R≈Rmin), solar torque is the driving force behind the motion. Far from the sun (R≈Rmax), the influence of solar torque is minimal and represents steady state or pure limit cycling.

The thruster pulse frequencies are then combined with the minimum impulse bit and attitude information to produce an average ACS force and corresponding acceleration. An average mass flow rate is also calculated to keep track of the change in the mass of the spacecraft due to the ACS activity. These values are calculated via the following equations.

$$\vec{f} = f_{bit} n_T \vec{k} \qquad \vec{a} = \vec{f} / m \qquad \dot{m} = \frac{f_{bit} n_T}{Isp_{acs} g}$$

where:

$\vec{f}$	= ACS force vector (m/s)	$\vec{a}$	= ACS acceleration vector (m/s^2)
$\dot{m}$	= mass flow rate (kg/s)	Isp_{acs}	= ACS thruster specific impulse (s)
g	= gravity at Earth's surface (m/s^2)	$\vec{k}$	= unit vector in the direction of +z axis

Deterministic mass decrements due to deterministic maneuvers and ACS burns are also included in the trajectory optimization code.

10.1.3 Model Parameters and Characteristics

The attitude schedule and ACS force model parameters used for the data contained herein are summarized in Tables 10.1-3 and 10.1-4. The resultant total thruster pulse frequency, mass flow rate, acceleration and acceleration direction are illustrated in Figures 10.1-1 thru 10.1-4.

Table 10.1-3 Spacecraft Attitude Profile - Limit Cycle Model

Time From Launch	Attitude Option	Off-sun Angle (deg)	Deadband Option	Time From Launch	Attitude Option	Off-sun Angle (deg)	Deadband Option
0	21	45	1	1385	33	-	1
30	22	22	1	1402	11	-	1
45	41	-	1	1523	12	-	1
54	42	20	1	1658	11	-	1
144	11	-	1	1703	42	20	1
369	12	-	1	1747	22	3	1
403	31	-	1	1760	22	5	1
453	33	-	1	1770	22	7	1
469	12	-	1	1780	22	16	1
668	11	-	1	1790	22	18	2
704	21	17	1	1805	22	20	1
708	22	45	1	1811	12	-	1
709	21	45	1	1965	11	-	1
728	22	20	1	2000	11	-	1
744	12	-	1	2165	11	-	1
769	41	-	1	2185	12	-	1
780	42	20	1	2459	11	-	1
914	11	-	1	2489	21	21	1
1053	12	-	1	2509	22	45	1
1065	12	-	1	2533	22	26	1
1267	31	-	1				

Table 10.1-4 ACS Force Model Parameters

Parameter	Value	Parameter	Value	Parameter	Value
Po	280.56 psi	lx	0.110 m	Rmax	2.72 AU
Uo	0.3148	ly	0.455 m	Rmin	1.00 AU
Mo	390.6 kg	lz	0.125 m	Isp-acs	100 s
Mpo	84.79 kg	Ixx	88 kgm^2	g	9.807 m/s^2
τ-sx	1.7E-7 Nm	Iyy	200 kgm^2	angcol	63°
τ-sy	1.6E-5 Nm	Izz	272 kgm^2		

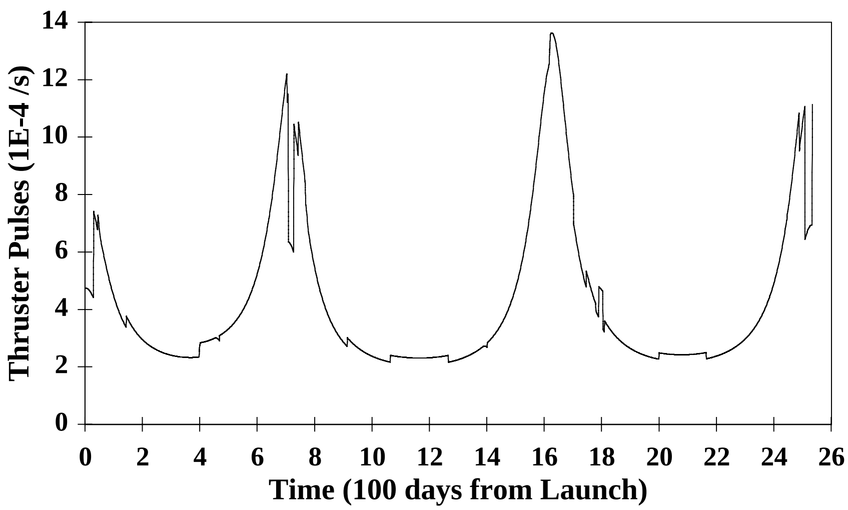

Figure 10.1-1 Total Thruster Pulse History

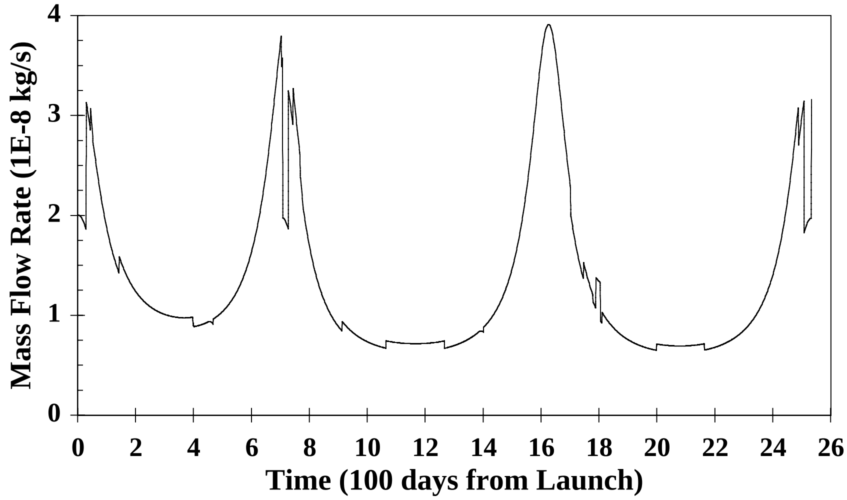

Figure 10.1-2 Mass Flow Rate History

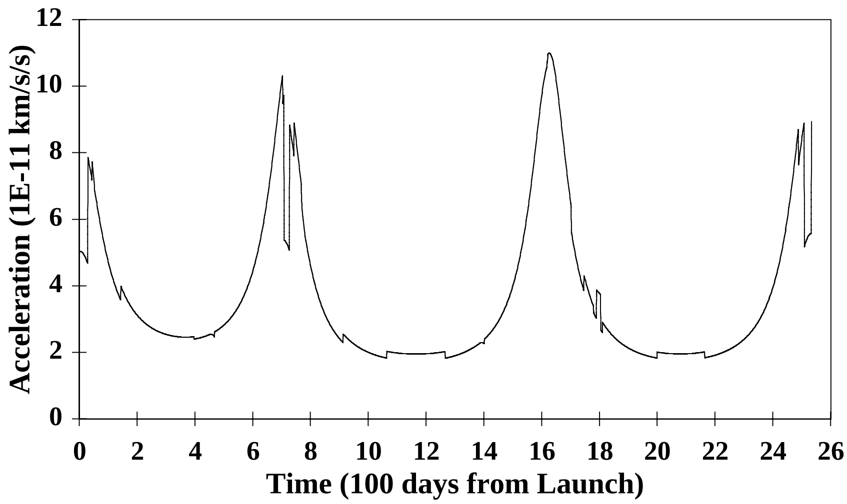

Figure 10.1-3 Acceleration Magnitude History

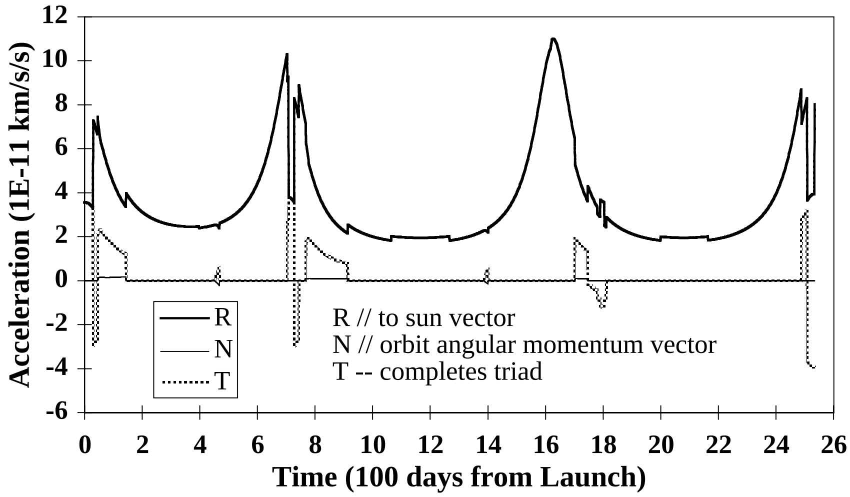

Figure 10.1-4 Acceleration Direction History

10.2 Slew ΔV Model

A mathematical model of the behavior of the attitude control system (ACS) has been constructed to compute translational ΔV imparted to the spacecraft due to slews for communications, OPNAVs and transitions between the background attitude profile. Slews associated with trajectory correction maneuvers (TCMs) are ignored in this modeling. It is assumed that ΔV's associated with turns to and from the burn attitudes will be included in the design of the TCM. As mentioned previously, the purpose of this task was to compose a table or small forces file (time dependent) containing the slew ΔV's for the navigators to attain accurate orbit prediction capability.

The modeling is based on simulation-derived equations documented in a LMA technical memo written by Jason Wynn, TM-206. The equations provide mean ΔV magnitudes as a function of spacecraft mass and initial and final attitudes of the spacecraft slew. Mass expenditure for each slew is also listed in the memo.
It should be noted, finally, that the modeling here addresses only the deterministic (known) effects and makes no attempt to account for uncertainties and their implications. Equations for 1-sigma errors are provided in TM-206 and should be considered by the navigation team.

10.2.1 Slew Types and ΔV Equations

The ACS slews have been organized into eight different slew types. The equations for ΔV components and a mass decrement are shown in Table 10.2-1 for each slew type.
The ΔV (x,y,z) reference is a coordinate frame that is fixed in inertial space and coincides with the commanded spacecraft body frame at the initiation of the slew. Notice that most

of the ΔV is applied in the +z-axis direction which is consistent with the thrusters being pointed toward the -z-axis of the spacecraft.

Table 10.2-1 Slew Types and ΔV Equations

Type	Description	Turn angle (deg)	dVx, dVy, dVz (m/s)	dM (gms)
1	To attitude pitch, includes deadband clamp, 20 min	0-15	dVx = (1.4217/mass)(sin(pitch)) dVy = 0 dVz = (1.4217/mass)(1+cos(pitch))	3.0
2	To attitude pitch, includes deadband clamp, 20 min	15-45	dVx = (1.7060/mass)(sin(pitch)) dVy = 0 dVz = (1.7060/mass)(1+cos(pitch))	3.6
3	To attitude pitch/yaw combined, includes deadband clamp, 20 min	0-30	dVx = (2.6540/mass)(sin(pitch)) dVy =0 dVz = (2.6540/mass)(1+cos(pitch))	5.6
4	deadband clamp only, 20 min	-	dVx = 0, dVy = 0 dVz = (2.4629/mass)	2.6
5	From attitude pitch, no deadband clamp, 40 min	0-15	dVx = (0.1422/mass)(sin(pitch)) dVy = 0 dVz = (0.1422/mass)(1+cos(pitch))	0.3
6	From attitude pitch, no deadband clamp, 40 min	15-45	dVx = (0.4264/mass)(sin(pitch)) dVy = 0 dVz = (0.4264/mass)(1+cos(pitch))	0.9
7	From attitude pitch/yaw combined, no deadband clamp, 40 min	0-30	dVx = (0.8052/mass)(sin(pitch)) dVy = 0 dVz = (0.8052/mass)(1+cos(pitch))	1.7
8	yaw only, no deadband clamp, 4 hr max	30-180	dVx = 0, dVy = 0 dVz = (2.085/mass)	2.2

Two turns are involved in this modeling scheme: a pitch turn and a yaw turn. Pitch is a rotation about the spacecraft +y-axis and yaw is a rotation about the spacecraft +z-axis. Roll, a rotation about the spacecraft +x-axis, completes the rotation triad, but is not anticipated very frequently during the mission and as such is not a key component of the slew ΔV modeling. See Figure 10.2-1 for an illustration of these rotation angles.

To ease the use of the output of this model, one ΔV vector is produced for each slew event (communications, OPNAVs and background attitude change). Slew events are collapsed to a single event time and contain ΔV's accumulated during the turn to the event attitude, the

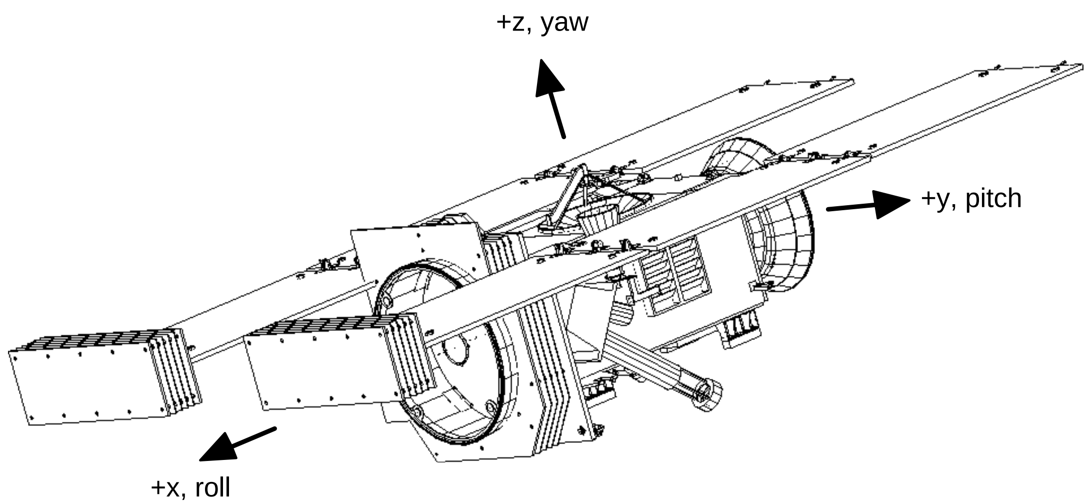

Figure 10.2-1 Spacecraft Rotation Angles

turn from the event attitude and the time spent limit cycling at the event attitude. The last of these is included to counteract and replace ACS accelerations computed at the background attitude as part of the background limit cycle modeling being performed in parallel. Even in the case of a single attitude change (background attitude change), the final ΔV vector can be comprised of a few different ΔV vectors from different slew types. To ease the analysis, the slew types described in Table 10.2-1 are further combined into slew groups, summarized in Table 10.2-2. These slew groups provide the analyst with easier control over the slew sequence and easier scheduling of slew activity.

Table 10.2-2 Slew Groups

Opt	Description (usage)	Slew Type/Sequence (to/from event attitude)	
1	deadband clamp only (comm)	To: 4	From: -
2	pitch only (mode change, comm)	To: 1 or 2	From: 5 or 6
3	pitch, yaw, pitch (mode change, comm)	To: 5 or 6, 8, 1 or 2	From: 5 or 6, 8, 5 or 6
4	pitch, yaw combined (mode, OPNAV, comm)	To: 3	From: 7
5	yaw only (mode change)	To: 8, 4	From: 8
6	pitch, yaw (mode change)	To: 5 or 6, 8, 4	From: 5 or 6, 8
7	yaw, pitch (mode change, comm)	To: 8, 1 or 2	From: 8, 5 or 6

1. Mode change uses 'from' sequence only
2. Option index is switched from 6 to 7, or 7 to 6, after 'to' slew, for round trip slews.

10.2.2 Spacecraft Slew History

In constructing the model for slew ΔV's, the attitude portion of the limit cycling model has been replaced by a more recent formulation. The new attitude modes are referenced to the Sun-Earth-Probe plane and not the orbit plane. The same limit cycle force modeling equations and parameters, as described in Section 10.1.2, apply to small force file generation, and are used in parallel with slew ΔV modeling to ensure accurate results.

The ACS limit cycle modeling for trajectory design using CATO remains referenced to the orbit plane in order to not introduce the Earth ephemeris into the optimization problem. The small differences in acceleration direction caused by this split approach are deemed acceptable. Table 10.2-3 summarizes the attitude options available in this modified attitude formulation.

Table 10.2-3 Spacecraft Attitude Options - Slew ΔV Model

Option	Description	Construction (only two axis defined, triad is orthogonal)
1	Constant off-sun	kk = single axis rotation of rr about nn, angle given by angz jj = kk X tt, if angy = 0, or - kk X tt, if angy = 180
2	CIDA tracking	ii = ivr jj = rr X ivr
3	CIDA constant off-sun	kk = single axis rotation of rr about n-isp, angle given by angz jj = kk X ivr
4	Earth tracking (+z-axis)	kk = re jj = rr X kk
5	ISP collector steering	kk = rr jj = ivr X kk
6	ISP tracking	ii = -ivr jj = rr X ii
7	DSMs	kk = ΔV jj = rr X kk
8	OPNAV during option 3	kk = single axis rotation of rr about n-isp, angle by angoff jj = xim X kk
9	OPNAV during option 12	kk = from 12 jj = kk X xim
10	Encounter attitude	ii = uws jj = re X ii **
11	MGA comm Earth tracking	kk = single axis rotation of rr about nn, angle by ang1 jj = rr X kk, if ang1 ≥ 0, or kk X rs, if ang1 < 0
12	HGA comm Earth tracking	kk = re jj = rr X kk, if opt=0, or kk X rs, if opt=1
13	OPNAV during option 11	kk = from 11 jj = kk X xim
14	OPNAV during option 10	kk = from 10 jj = kk X xim

where:

ii, jj, kk	= spacecraft x, y, z axis unit vectors
rr, nn, tt	= reference SPE plane attitude, rr = to sun vector, nn = ±re X rr [nn(3)>0], tt = nn X rr
re	= to earth vector
n-isp	= isp plane normal, n-isp = ivr X rr
xim	= to image vector
uws	= unit vector of comet velocity with respect to spacecraft
ivr	= interstellar particle relative velocity vector (visp - v)
angz	= angle between kk and rr, positive right hand rule about nn
angy	= angle between jj and nn, positive right hand rule about rr
angoff	= off-sun angle for CIDA3, input as part of OPNAV input file
ΔV	= direction of delta-V vector
ang1	= angle between rr and re minus mgaoff
mgaoff	= mga off +z boresight angle, input as part of comm input file
opt	= input flag that allows the +y axis to be flipped during HGA comm

** vectors evaluated at the time of closest approach

This attitude description is also used in the formulation of a predict attitude C-kernel file. The DSM attitude option is used primarily for this purpose. It is not used during small forces calculations as turns related to DSMs are assumed to be part of the DSM design.

The inclusion of slew events in the modeling also expands the number of deadband options available to the analyst. In addition to those listed in Table 10.1-2, deadband options are made available for OPNAVs and MGA communications. The near encounter option in Table 10.1-2 is the same as is used for HGA communications. Table 10.2-4 lists the complete set of deadband options available in the slew ΔV model.

Table 10.2-4 Spacecraft Deadband Options - Slew ΔV Model

Option	Deadband	Comments
1	x, y, z = 15°	Cruise option 1
2	x, y, z = 10°	Cruise option 2
3	x, y = 2°, z = 10°	HGA comm / Near encounter
4	x, y, z = 6°	MGA comm
5	x, y, z = 0.25°	Image

The spacecraft's attitude and slew history contribute to the calculation of the slew ΔV's by providing the initial and final attitudes that allow computations of turn angles. In a semi-iterative process, the turn angles are used by the analyst to schedule the appropriate slew group for each slew event. This process places the burden of selecting the appropriate slew group on the analyst, but this approach is selected in favor of the extensive coding that would be required to make the slew group selection completely autonomous.

Three events are considered in the construction of the slew history: communications, OPNAVs and background attitude mode transitions. Slews for communications comprise the bulk of slewing activity on STARDUST with 630 events. Current plans call for 44 OPNAV events and 30 background attitude mode transitions. There are 40 different attitude modes, but 9 transitions occur naturally and do not require a slew.

Construction of the communications schedule is strongly guided by the desired to maintain the +x-axis of the spacecraft pointing away from the sun to eliminate shadowing across the solar panels from the whipple shields. This results in the pitch-yaw-pitch slew sequence described in the slew group options (Table 10.2-2). Some mitigation to using this sequence is possible at low Sun-Probe-Earth angles, where the off-sun angles required for communications and corresponding array shadowing is minimal. Selection of this strategy typically involves scheduling of the HGA instead of the MGA to eliminate the 7 deg off-z-axis boresight angle of the MGA and invoking a 'spacecraft flip' input flag that overrides the typical HGA attitude and the +x-axis to be pointed toward the sun.

The communications schedule only includes those communications events that require a slew. This results in no slews for some portions of launch (LGA comm: L+0-30 days), EGA (LGA comm: L+708-727 days), encounter (L+1789-1804 days), and return (LGA comm: L+2509-2535 days).

10.2.3 Model Parameters and Characteristics

The background attitude schedule, communications and OPNAV schedules used in the current modeling runs are summarized in Tables 10.2-5 through 10.2-7. The resultant ΔV magnitudes and directions are illustrated in Figures 10.2-2 through 10.2-4.

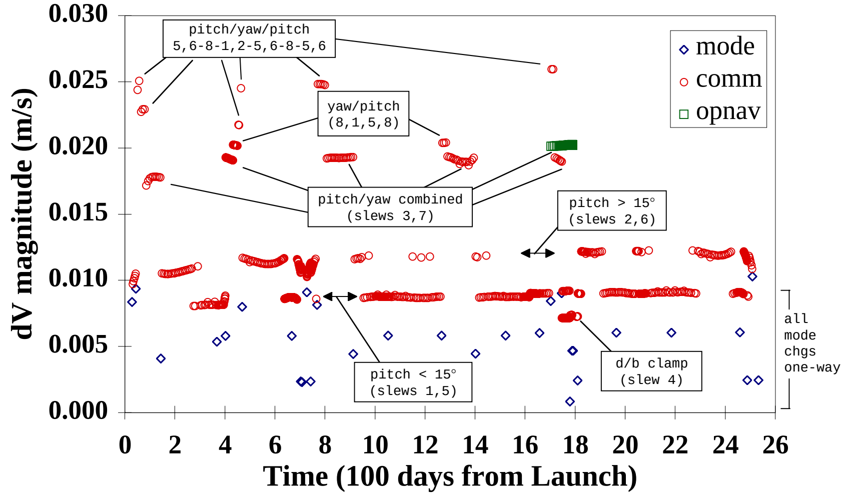

Figure 10.2-2 Slew ΔV Magnitude Profile

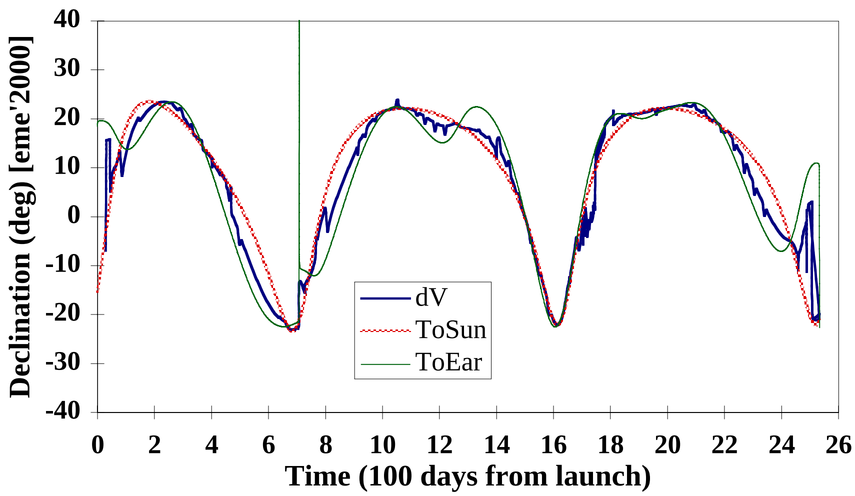

Figure 10.2-3 Slew ΔV Direction Comparison - Declination

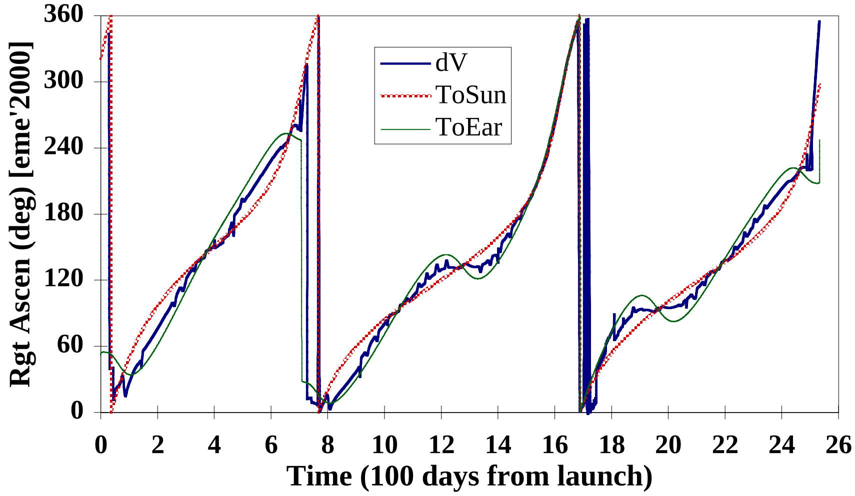

Figure 10.2-4 Slew ΔV Direction Comparison - Right Ascension

Table 10.2-5 Spacecraft Attitude Profile - Slew ΔV Model

Start Time (dFL)	End Time (dFL)	Attitude index	Angz (deg)	Angy[1] (deg)	Flip-y? (opt)	Deadband	Slew Group
0	30	1	-45	180	(0)	1	0
30	45	1	22	0	(0)	1	3
45	54	2	(0)	(180)	(0)	1	3
54	144	3	-20	(180)	(0)	1	0
144	369	1	0	180	(0)	1	4
369	403	1	0	0	(0)	1	5
403	453	5	(0)	(180)	(0)	1	5
453	469	6	(0)	(180)	(0)	1	0
469	668	1	0	0	(0)	1	6
668	704	1	0	180	(0)	1	5
704	708	1	-17	180	(0)	1	2
708	709	1	-45	0	(0)	1	3
709	728	1	-45	180	(0)	1	3
728	744	1	20	0	(0)	1	3
744	769	1	0	0	(0)	1	2
769	780	2	(0)	(180)	(0)	1	7
780	914	3	-20	(180)	(0)	1	0
914	1053	1	0	180	(0)	1	4
1053	1065	1	0	0	(0)	1	5
1065	1267	1	0	0	(0)	1	0
1267	1385	5	(0)	(180)	(0)	1	5
1385	1402	6	(0)	(180)	(0)	1	0
1402	1523	1	0	180	(0)	1	4
1523	1658	1	0	0	(0)	1	5
1658	1703	1	0	180	(0)	1	5
1703	1747	3	-20	(180)	(0)	1	7
1747	1780	11	(0)	(0)	(0)	1	3
1780	1789	12	(0)	(0)	0	1	2
1789	1792	10	(0)	(0)	(0)	3	4
1792	1805	12	(0)	(0)	0	3	4
1805	1811	12	(0)	(0)	0	1	0

1811	1965	1	0	0	(0)	1	2
1965	2000	1	0	180	(0)	1	5
2000	2165	1	0	180	(0)	1	0
2165	2185	1	0	180	(0)	1	0
2185	2459	1	0	0	(0)	1	5
2459	2489	1	0	180	(0)	1	5
2489	2509	1	-21	180	(0)	1	2
2509	2533	1	45	0	(0)	1	3
2533	2535	1	26	0	(0)	1	2
2535	2537	1	45	0	(0)	1	2

1. Values in parentheses do not influence actual attitude

Table 10.2-6 Communications Schedule

Time (dFL)	Dur (hrs)	Antenna	Flip-y? (opt)	Slew option
32,35,38,41,44	4	MGA	0	2
51,58,65,72,79	4	MGA	0	3
86,93,100,107,114,121,128,135,142	4	MGA	0	4
149,156,163,170,174,184,191,198,205,212,219, 226,233,240,247,254	4	MGA	0	2
261	4	HGA	0	2
268,275,282	4	MGA	0	2
292	4	HGA	0	2
303,309,319,324	4	MGA	0	2
331	4	HGA	0	2
338, 345	4	MGA	0	2
352	4	HGA	0	2
362, 364, 366, 371, 374, 376, 380, 384-401	4	MGA	0	2
402	4	HGA	0	2
403-409, 412, 415, 417, 419, 422, 425-432	4	HGA	1	4
433-439, 442, 445, 448, 451	4	MGA	0	7
454,457	4	MGA	0	3
464	4	HGA	0	3
471,478,485,492	4	MGA	0	2
499	4	HGA	0	2
506,513,520,527,534,541,548,555,562,569,576, 583,590,597,604,611,618,623,626,629,632,635-663,666,669,672,674,676,679,682,685-694	4	MGA	0	2
695-707	8	MGA	0	2
728-753,756,759,762,765	4	MGA	0	2
772,779,786,793,800	4	MGA	0	3
807,814,821,828,835,842,849,856,863,870,877, 884,891,898,905,912	4	MGA	0	4
919,926,933	4	MGA	0	2
940	4	HGA	0	2
947,954,961,968	4	MGA	0	2
975	4	HGA	0	2
982, 989, 996, 1003	4	MGA	0	2
1010	4	HGA	0	2
1017, 1024, 1031	3	MGA	0	2
1038	3	HGA	0	2
1046, 1048, 1057, 1066, 1073	3	MGA	0	2
1080	3	HGA	0	2
1087, 1094, 1101, 1104, 1107, 1110, 1113, 1116, 1118, 1120	3	MGA	0	2
1122	3	HGA	0	2
1124, 1126, 1128, 1130, 1132, 1134, 1136, 1138, 1140, 1142, 1144, 1147	3	MGA	0	2
1150	3	HGA	0	2
1153, 1157, 1164, 1171, 1178	3	MGA	0	2
1185	3	HGA	0	2
1192,1199,1206,1213	3	MGA	0	2
1220	3	HGA	0	2
1227,1234,1241,1248,1255,1262	3	MGA	0	2

Table 10.2-6 Communications Schedule (cont)

Time (dFL)	Dur (hrs)	Antenna	Flip-y? (opt)	Slew option
1269,1276,1283	3	MGA	0	7
1290,1297,1304,1311,1318	3	MGA	0	4
1325,1332	4	MGA	0	4
1339	4	HGA	0	4
1346,1353,1360,1367	4	MGA	0	4
1374	4	HGA	0	4
1381,1388,1395	4	MGA	0	4
1402	4	MGA	0	2
1409	4	HGA	0	2
1416,1423,1430,1437	4	MGA	0	2
1444	4	HGA	0	2
1451,1458,1465,1472	4	MGA	0	2
1479	4	HGA	0	2
1486,1493,1500,1507	4	MGA	0	2
1514	4	HGA	0	2
1521,1528,1535,1542	4	MGA	0	2
1549	4	HGA	0	2
1556,1563,1570,1577, 1579, 1582	4	MGA	0	2
1585	4	HGA	0	2
1588, 1591, 1594-1615	4	MGA	0	2
1616	4	HGA	0	2
1617-1630, 1633, 1636, 1639, 1642, 1645, 1647 1654, 1661	4	MGA	0	2
1668	4	HGA	0	2
1675, 1682	4	MGA	0	2
1691	6	HGA	0	2
1698	8	HGA	0	2
1705, 1712	8	HGA	1	3
1719, 1726, 1733, 1739, 1742, 1746	8	HGA	1	4
1747,1748	4	MGA	0	1
1749	8	HGA	0	2
1750-1752	4	MGA	0	1
1753	8	HGA	0	2
1754,1755	4	MGA	0	1
1756	8	HGA	0	2
1757-1759	4	MGA	0	1
1760	8	HGA	0	2
1761,1762	4	MGA	0	1
1763	8	HGA	0	2
1764-1766	4	MGA	0	1
1767	8	HGA	0	2
1768,1769	4	MGA	0	1
1770	8	HGA	0	2
1771-1773	4	MGA	0	1
1774	8	HGA	0	2
1775,1776	4	MGA	0	1
1777	8	HGA	0	2
1778,1779	4	MGA	0	1
1780	8	HGA	0	1

Table 10.2-6 Communications Schedule (cont)

Time (dFL)	Dur (hrs)	Antenna	Flip-y? (opt)	Slew option
1781	4	HGA	0	1
1782	8	HGA	0	1
1783	4	HGA	0	1
1784-1788	8	HGA	0	1
1805-1810	4	HGA	0	1
1811-1834,1837,1840	4	MGA	0	2
1843	4	HGA	0	2
1846,1850,1857,1864,1871	4	MGA	0	2
1878	4	HGA	0	2
1885,1892,1899,1906,1913,1920,1927,1934,1941	4	MGA	0	2
1948,1955,1962,1969,1976,1983,1990,1997, 2004,2011,2018,2025,2032,2037,2040,2043, 2046,2049,2051,2053,2055,2057,2059,2061,2063	3	MGA	0	2
2065	3	HGA	0	2
2067,2069,2071,2073,2075,2077,2080,2083	3	MGA	0	2
2095	3	HGA	0	2
2102,2109,2116,2123	3	MGA	0	2
2130	3	HGA	0	2
2137,2144,2151,2158	3	MGA	0	2
2165	3	HGA	0	2
2172,2179,2190,2193	3	MGA	0	2
2200	3	HGA	0	2
2207,2214	3	MGA	0	2
2221,2228	4	MGA	0	2
2235	4	HGA	0	2
2242,2249,2256,2263	4	MGA	0	2
2270	4	HGA	0	2
2277,2284,2291,2298	4	MGA	0	2
2305	4	HGA	0	2
2312,2319,2326,2333	4	MGA	0	2
2340	4	HGA	0	2
2347,2354,2361,2368,2375,2382,2389,2396, 2403,2410,2417,2424,2431,2438,2445,2449, 2452,2455,2458,2461-2489,2492,2495,2497, 2500,2502,2505,2508	4	MGA	0	2

1. The communications schedule only shows those communication events that require a spacecraft turn to get to the communications attitude. This results in no slews scheduled just after launch (LGA comm: L+0-30 days), at and just after EGA (LGA comm: L+708-727 days) , at and just after encounter (encounter attitude is HGA to Earth: L+1789-1804 days), and just prior to Return (LGA comm: L+2509-2535 days).

Table 10.2-7 OPNAV Schedule

1	2	3	4	5	6	7	1	2	3	4	5	6	7
031007	071800	3.890	165.816	0.5	3	5	031231	221800	5.676	159.258	0.5	4	5
031010	191800	4.035	165.218	0.5	4	5	031231	231800	5.676	159.258	0.5	4	5
031014	071800	4.180	164.640	0.5	4	5	040101	001800	5.676	159.258	0.5	4	5
031017	191800	4.322	164.086	0.5	4	5	040101	011800	5.676	159.258	0.5	4	5
031021	071800	4.460	163.560	0.5	4	5	040101	021800	5.676	159.259	0.5	4	5
031024	191800	4.591	163.064	0.5	4	5	040101	031800	5.676	159.259	0.5	4	5
031028	071800	4.716	162.601	0.5	4	5	040101	041800	5.676	159.259	0.5	4	5
031031	191800	4.833	162.172	0.5	4	5	040101	051800	5.676	159.259	0.5	4	5
031104	071800	4.943	161.777	0.5	4	5	040101	061800	5.676	159.259	0.5	4	5
031107	191800	5.044	161.416	0.5	4	5	040101	071800	5.675	159.260	0.5	4	5
031111	071800	5.136	161.089	0.5	4	5	040101	081800	5.675	159.260	0.5	4	5
031114	191800	5.220	160.795	0.5	4	5	040101	091800	5.675	159.260	0.5	4	5
031118	071800	5.296	160.533	0.5	4	5	040101	101800	5.675	159.260	0.5	4	5
031121	191800	5.363	160.302	0.5	4	5	040101	111800	5.675	159.261	0.5	4	5
031125	071800	5.423	160.099	0.5	4	5	040101	121800	5.675	159.261	0.5	4	5
031128	191800	5.475	159.923	0.5	4	5	040101	131800	5.675	159.261	0.5	4	5
031202	071800	5.520	159.772	0.5	4	5	040101	141800	5.675	159.262	0.5	4	5
031205	191800	5.558	159.645	0.5	4	5	040101	151800	5.675	159.262	0.5	4	5
031209	071800	5.590	159.539	0.5	4	5	040101	161800	5.674	159.263	0.5	4	5
031212	191800	5.616	159.453	0.5	4	5	040101	171800	5.674	159.263	0.5	4	5
031216	071800	5.637	159.384	0.5	4	5	040102	021800	5.672	159.270	0.5	4	5
031219	191800	5.653	159.332	0.5	4	5	040102	031800	5.671	159.272	0.5	4	5
031223	071800	5.665	159.294	0.5	4	5	040102	041800	5.671	159.273	0.5	4	5
031226	191800	5.673	159.269	0.5	4	5	040102	051800	5.670	159.275	0.5	4	5
031227	191800	5.674	159.265	0.5	4	5	040102	061800	5.669	159.277	0.5	4	5

031228	191800	5.675	159.261	0.5	4	5	040102	071800	5.668	159.279	0.5	4	5
031229	191800	5.676	159.258	0.5	4	5	040102	081800	5.667	159.282	0.5	4	5
031230	191800	5.676	159.257	0.5	4	5	040102	091800	5.666	159.286	0.5	4	5
031231	191800	5.676	159.258	0.5	4	5	040102	101800	5.665	159.290	0.5	4	5
031231	201800	5.676	159.258	0.5	4	5	040102	111800	5.663	159.295	0.5	4	5
031231	211800	5.676	159.258	0.5	4	5	040102	121800	5.661	159.301	0.5	4	5

Columns:
1 = Date (yymmdd)
2 = Hour (hhmmss)
3 = Image Dec* (deg)
4 = Image RA* (deg)
5 = Duration (hours)
6 = Slew Option
7 = Deadband Option

* = Earth Mean Equator and Equinox of J2000.

11.0 Appendix C: Event Listing

The event listing is provides a very high-level timeline of key events in the STARDUST mission. It is designed to accompany the Mission Overview and list geometric events as well as mission events. The event listing output is provided in Tables 11-1 and 11-2.

Table 11-1 Event Listing

```
STARDUST EVENT LISTING OUTPUT
 Generated on = 981021.  144133.

 SCID =   -656
 SPK FILE = /usr/people/eah/neweph/ann06.bsp
 LAU DATE = 2451216.39904440  990206.  213437.
 RET DATE = 2453750.91536000   60115.   95807.

 Planetary ephemeris = /usr/yyy/masl/ephem/de405s.bsp
 Comet ephemeris     = /usr/yyy/masl/ephem/wild2v4.bsp

 FILE NOTES:
 1.  Trajectory events established from CATO summary.
 2.  Mission phases and TCMs established from pre-set schedule.
 3.  Geometry events identified from values calculated every   1.0
     hours.
 4.  ISP and CIDA events determined by geometric constraints only.
     Conflicts with mission events are NOT reflected in listings.
     Geometric constraints examined in terms of I-ANG and BETA angles.
     I-ANG is the angle between the To Sun vector and the To ISP vector.
     BETA is the angle between the To ISP vector and the To BETA vector.

 TRAJECTORY EVENTS
 EVENT, JD, CALDATE(yymmdd hhmmss), TFL(day)
  LAUNCH      2451216.39904440  990206.  213437.     0.00
  DSM 1-1     2451613.50000000     310.       0.   397.10
  DSM 1-2     2451615.50000000     312.       0.   399.10
  DSM 1-3     2451617.50000000     314.       0.   401.10
  EGA         2451924.95930640   10115.  110124.   708.56
  DSM 2       2452346.81350700   20313.   73127.  1130.41
  DSM 3-1     2452824.50000000   30704.       0.  1608.10
  DSM 3-2     2452826.50000000   30706.       0.  1610.10
  WILD-2      2453007.30555560   40102.  192000.  1790.91
  DSM 4       2453037.30555560   40201.  192000.  1820.91
  RETURN      2453750.91536000   60115.   95807.  2534.52

 MISSION PHASES
 EVENT, JD, CALDATE(yymmdd hhmmss), TFL(days)
  START LAUNCH  2451216.39904440  990206.  213437.     0.00
  END LAUNCH    2451246.39904440  990308.  213437.    30.00
  START EGA     2451864.95930640    1116.  110124.   648.56
  END EGA       2451954.95930640   10214.  110124.   738.56
  START ENCOUN  2452907.30555560   30924.  192000.  1690.91
```

Table 11-1 Event Listing (cont)

```
 MISSION PHASES (cont)
 EVENT, JD, CALDATE(yymmdd hhmmss), TFL(days)
  END ENCOUN    2453057.30555560   40221.  192000.  1840.91
  START RETURN  2453660.91536000   51017.   95807.  2444.52
  END RETURN    2453751.91536000   60116.   95807.  2535.52
```

TRAJECTORY CORRECTION MANEUVERS

EVENT, JD, CALDATE(yymmdd hhmmss), TFL(days)

EVENT	JD	CALDATE		TFL
TCM 1	2451231.39904440	990221.	213437.	15.00
TCM 2a	2451613.50000000	310.	0.	397.10
TCM 2b	2451615.50000000	312.	0.	399.10
TCM 2c	2451617.50000000	314.	0.	401.10
TCM 3	2451647.50000000	413.	0.	431.10
TCM 4	2451864.95930640	1116.	110124.	648.56
TCM 5	2451914.95930640	10105.	110124.	698.56
TCM 6	2451954.95930640	10214.	110124.	738.56
TCM 7	2452346.81350700	20313.	73127.	1130.41
TCM 8a	2452824.50000000	30704.	0.	1608.10
TCM 8b	2452826.50000000	30706.	0.	1610.10
TCM 9	2452833.50000000	30713.	0.	1617.10
TCM 10	2452977.30555560	31203.	192000.	1760.91
TCM 11	2452997.30555560	31223.	192000.	1780.91
TCM 12	2453005.30555560	31231.	192000.	1788.91
TCM 13	2453006.55555560	40102.	12000.	1790.16
TCM 14	2453007.05555560	40102.	132000.	1790.66
TCM 15	2453037.30555560	40201.	192000.	1820.91
TCM 16	2453279.50000004	41001.	0.	2063.10
TCM 17	2453690.91536000	51116.	95807.	2474.52
TCM 18	2453737.91536000	60102.	95807.	2521.52
TCM 19	2453749.91536000	60114.	95807.	2533.52
TCM 20	2453750.74869333	60115.	55807.	2534.35

SOLAR RANGE

JD, CALDATE, TFL, RANGE (AU), MIN/MAX

JD	CALDATE		TFL	RANGE (AU)	MIN/MAX
2451219.02404440	990209.	123437.	2.62	0.99	MIN
2451584.44071107	209.	223437.	368.04	2.19	MAX
2451924.98237773	10115.	113437.	708.58	0.98	MIN
2452382.73237773	20418.	53437.	1166.33	2.72	MAX
2452843.02404440	30722.	123437.	1626.62	0.98	MIN
2453295.98237773	41017.	113437.	2079.58	2.68	MAX
2453748.98237773	60113.	113437.	2532.58	0.98	MIN
2453750.89904440	60115.	93437.	2534.50	0.98	MAX

EARTH RANGE

JD, CALDATE, TFL, RANGE (AU), MIN/MAX

JD	CALDATE		TFL	RANGE (AU)	MIN/MAX
2451585.85737773	211.	83437.	369.46	3.18	MAX
2451924.94071107	10115.	103437.	708.54	0.00	MIN
2452281.48237773	20106.	233437.	1065.08	3.59	MAX
2452495.31571107	20808.	193437.	1278.92	1.59	MIN
2452669.85737773	30130.	83437.	1453.46	2.74	MAX
2452841.48237773	30720.	233437.	1625.08	2.00	MIN
2453001.06571107	31227.	133437.	1784.67	2.61	MAX

Table 11-1 Event Listing (cont)

EARTH RANGE (cont)

JD, CALDATE, TFL, RANGE (AU), MIN/MAX

JD	CALDATE		TFL	RANGE (AU)	MIN/MAX
2453173.52404440	40617.	3437.	1957.12	1.53	MIN
2453389.48237773	50118.	233437.	2173.08	3.57	MAX
2453750.89904440	60115.	93437.	2534.50	0.00	MIN

SEP ANGLE

JD, CALDATE, TFL, SEP (deg), MIN/MAX

JD	CALDATE		TFL	SEP (deg)	MIN/MAX
2451217.52404440	990208.	3437.	1.12	83.03	MIN
2451298.69071107	990430.	43437.	82.29	179.95	MAX
2451584.73237773	210.	53437.	368.33	0.00	MIN
2451883.98237773	1205.	113437.	667.58	179.98	MAX
2451924.98237773	10115.	113437.	708.58	47.10	MIN
2451997.52404440	10329.	3437.	781.12	164.97	MAX
2452269.02404440	11225.	123437.	1052.62	0.96	MIN

2452488.94071107	20802.	103437.	1272.54	178.51	MAX
2452739.10737773	30409.	143437.	1522.71	2.13	MIN
2452793.35737773	30602.	203437.	1576.96	7.63	MAX
2452868.77404440	30817.	63437.	1652.38	0.93	MIN
2453180.98237773	40624.	113437.	1964.58	177.76	MAX
2453400.69071107	50130.	43437.	2184.29	0.69	MIN
2453672.69071107	51029.	43437.	2456.29	164.95	MAX
2453749.81571107	60114.	73437.	2533.42	88.76	MIN
2453750.89904440	60115.	93437.	2534.50	123.52	MAX

SPE ANGLE

JD, CALDATE, TFL, SPE (deg), MIN/MAX

2451217.44071107	990207.	223437.	1.04	96.77	MAX
2451298.69071107	990430.	43437.	82.29	0.04	MIN
2451390.89904440	990731.	93437.	174.50	34.09	MAX
2451584.73237773	210.	53437.	368.33	0.00	MIN
2451788.19071107	831.	163437.	571.79	35.22	MAX
2451883.98237773	1205.	113437.	667.58	0.01	MIN
2451924.98237773	10115.	113437.	708.58	132.89	MAX
2451998.35737773	10329.	203437.	781.96	11.54	MIN
2452083.98237773	10623.	113437.	867.58	31.74	MAX
2452269.02404440	11225.	123437.	1052.62	0.36	MIN
2452404.77404440	20510.	63437.	1188.38	21.83	MAX
2452488.94071107	20802.	103437.	1272.54	0.58	MIN
2452579.06571107	21031.	133437.	1362.67	24.84	MAX
2452738.77404440	30409.	63437.	1522.38	1.44	MIN
2452800.94071107	30610.	103437.	1584.54	6.93	MAX
2452869.14904440	30817.	153437.	1652.75	0.91	MIN
2453088.85737773	40324.	83437.	1872.46	25.94	MAX
2453180.98237773	40624.	113437.	1964.58	0.89	MIN
2453264.52404440	40916.	3437.	2048.12	22.08	MAX
2453400.69071107	50130.	43437.	2184.29	0.26	MIN
2453587.06571107	50804.	133437.	2370.67	31.91	MAX
2453671.94071107	51028.	103437.	2455.54	11.45	MIN
2453749.94071107	60114.	103437.	2533.54	91.00	MAX
2453750.89904440	60115.	93437.	2534.50	56.47	MIN

Table 11-1 Event Listing (cont)

SEP ANGLE = 3

JD, CALDATE, TFL, SEP (deg), INB/OUTB

2451579.10737773	204.	143437.	362.71	3.00	INB
2451590.35737773	215.	203437.	373.96	3.00	OUTB
2452264.35737773	11220.	203437.	1047.96	3.01	INB
2452273.69071107	11230.	43437.	1057.29	3.01	OUTB
2452731.56571107	30402.	13437.	1515.17	3.00	INB
2452747.73237773	30418.	53437.	1531.33	3.00	OUTB
2452844.77404440	30724.	63437.	1628.38	3.00	INB
2452919.31571107	31006.	193437.	1702.92	3.00	OUTB
2453395.89904440	50125.	93437.	2179.50	3.00	INB
2453405.52404440	50204.	3437.	2189.12	2.99	OUTB

ISP COLLECTION

JD, CALDATE, TFL, I-ANG/BETA (deg), COMMENT

2451571.98237773	128.	113437.	355.58	152.99	START shadowed
2451598.94071107	224.	103437.	382.54	140.98	CONT end shadow
2451668.52404440	504.	3437.	452.12	89.96	CONT end steer
2451686.02404440	521.	123437.	469.62	89.98	END beta meteor
2452482.98237773	20727.	113437.	1266.58	152.99	START shadowed
2452518.27404440	20831.	183437.	1301.88	140.99	CONT end shadow
2452601.10737773	21122.	143437.	1384.71	89.98	CONT end steer
2452618.89904440	21210.	93437.	1402.50	89.97	END beta meteor
2453394.52404440	50124.	3437.	2178.12	152.99	START shadowed
2453428.73237773	50227.	53437.	2212.33	141.00	CONT end shadow

2453509.10737773	50518.	143437.	2292.71	89.98	CONT end steer
2453526.52404440	50605.	3437.	2310.12	90.00	END beta meteor

CIDA EXPERIMENT

JD, CALDATE, TFL, I-ANG (deg), COMMENT

2451236.64904440	990227.	33437.	20.25	90.01	START tracking
2451270.06571107	990401.	133437.	53.67	110.02	CONT FOV
2451361.56571107	990702.	13437.	145.17	145.51	END 1/4 FOV
2451418.60737773	990828.	23437.	202.21	160.00	MAX 0 FOV
2451956.60737773	10216.	23437.	740.21	90.01	START tracking
2451995.77404440	10327.	63437.	779.38	110.01	CONT FOV
2452132.35737773	10810.	203437.	915.96	145.51	END 1/4 FOV
2452228.39904440	11114.	213437.	1012.00	160.00	MAX 0 FOV
2452877.06571107	30825.	133437.	1660.67	90.02	START tracking
2452916.19071107	31003.	163437.	1699.79	110.00	CONT FOV
2453051.77404440	40216.	63437.	1835.38	145.51	END 1/4 FOV
2453146.35737773	40520.	203437.	1929.96	160.00	MAX 0 FOV

Table 11-2 Time Ordered Event Listing

CALDATE		TFL	DESCRIPTION	VALUE	JD
990206.	213437.	0.00	START LAUNCH		2451216.39904440
990206.	213437.	0.00	LAUNCH		2451216.39904440
990207.	223437.	1.04	max SPE angle (deg)	96.77	2451217.44071107
990208.	3437.	1.12	min SEP angle (deg)	83.03	2451217.52404440
990209.	123437.	2.62	min Solar range (AU)	0.99	2451219.02404440
990221.	213437.	15.00	tcm 1		2451231.39904440
990227.	33437.	20.25	START CIDA: TRACKIN		2451236.64904440
990308.	213437.	30.00	END LAUNCH		2451246.39904440
990401.	133437.	53.67	cont CIDA: FOV		2451270.06571107
990430.	43437.	82.29	max SEP angle (deg)	179.95	2451298.69071107
990430.	43437.	82.29	min SPE angle (deg)	0.04	2451298.69071107
990702.	13437.	145.17	END CIDA: 1/4 FOV		2451361.56571107
990731.	93437.	174.50	max SPE angle (deg)	34.09	2451390.89904440
990828.	23437.	202.21	MAX CIDA: 0 FOV		2451418.60737773
128.	113437.	355.58	START ISP: SHADOWED		2451571.98237773
204.	143437.	362.71	inb SEP = 3 deg	3.00	2451579.10737773
209.	223437.	368.04	max Solar range (AU)	2.19	2451584.44071107
210.	53437.	368.33	min SEP angle (deg)	0.00	2451584.73237773
210.	53437.	368.33	min SPE angle (deg)	0.00	2451584.73237773
211.	83437.	369.46	max Earth range (AU)	3.18	2451585.85737773
215.	203437.	373.96	outb SEP = 3 deg	3.00	2451590.35737773
224.	103437.	382.54	cont ISP: end shadow		2451598.94071107
310.	0.	397.10	tcm 2a		2451613.50000000
310.	0.	397.10	DSM 1-1		2451613.50000000
312.	0.	399.10	tcm 2b		2451615.50000000
312.	0.	399.10	DSM 1-2		2451615.50000000
314.	0.	401.10	tcm 2c		2451617.50000000
314.	0.	401.10	DSM 1-3		2451617.50000000
413.	0.	431.10	tcm 3		2451647.50000000
504.	3437.	452.12	cont ISP: end steer		2451668.52404440
521.	123437.	469.62	END ISP: BETA METEOR		2451686.02404440
831.	163437.	571.79	max SPE angle (deg)	35.22	2451788.19071107
1116.	110124.	648.56	START EGA		2451864.95930640
1116.	110124.	648.56	tcm 4		2451864.95930640
1205.	113437.	667.58	max SEP angle (deg)	179.98	2451883.98237773
1205.	113437.	667.58	min SPE angle (deg)	0.01	2451883.98237773
10105.	110124.	698.56	tcm 5		2451914.95930640
10115.	103437.	708.54	min Earth range (AU)	0.00	2451924.94071107

10115.	110124.	708.56	EGA		2451924.95930640
10115.	113437.	708.58	min SEP angle (deg)	47.10	2451924.98237773
10115.	113437.	708.58	max SPE angle (deg)	132.89	2451924.98237773
10115.	113437.	708.58	min Solar range (AU)	0.98	2451924.98237773
10214.	110124.	738.56	END EGA		2451954.95930640
10214.	110124.	738.56	tcm 6		2451954.95930640
10216.	23437.	740.21	START CIDA: TRACKIN		2451956.60737773
10327.	63437.	779.38	cont CIDA: FOV		2451995.77404440
10329.	3437.	781.12	max SEP angle (deg)	164.97	2451997.52404440
10329.	203437.	781.96	min SPE angle (deg)	11.54	2451998.35737773
10623.	113437.	867.58	max SPE angle (deg)	31.74	2452083.98237773
10810.	203437.	915.96	END CIDA: 1/4 FOV		2452132.35737773
11114.	213437.	1012.00	MAX CIDA: 0 FOV		2452228.39904440
11220.	203437.	1047.96	inb SEP = 3 deg	3.01	2452264.35737773
11225.	123437.	1052.62	min SPE angle (deg)	0.36	2452269.02404440
11225.	123437.	1052.62	min SEP angle (deg)	0.96	2452269.02404440
11230.	43437.	1057.29	outb SEP = 3 deg	3.01	2452273.69071107
20106.	233437.	1065.08	max Earth range (AU)	3.59	2452281.48237773
20313.	73127.	1130.41	DSM 2		2452346.81350700
20313.	73127.	1130.41	tcm 7		2452346.81350700
20418.	53437.	1166.33	max Solar range (AU)	2.72	2452382.73237773
20510.	63437.	1188.38	max SPE angle (deg)	21.83	2452404.77404440
20727.	113437.	1266.58	START ISP: SHADOWED		2452482.98237773
20802.	103437.	1272.54	min SPE angle (deg)	0.58	2452488.94071107
20802.	103437.	1272.54	max SEP angle (deg)	178.51	2452488.94071107
20808.	193437.	1278.92	min Earth range (AU)	1.59	2452495.31571107
20831.	183437.	1301.88	cont ISP: end shadow		2452518.27404440
21031.	133437.	1362.67	max SPE angle (deg)	24.84	2452579.06571107
21122.	143437.	1384.71	cont ISP: end steer		2452601.10737773
21210.	93437.	1402.50	END ISP: BETA METEOR		2452618.89904440
30130.	83437.	1453.46	max Earth range (AU)	2.74	2452669.85737773
30402.	13437.	1515.17	inb SEP = 3 deg	3.00	2452731.56571107
30409.	63437.	1522.38	min SPE angle (deg)	1.44	2452738.77404440
30409.	143437.	1522.71	min SEP angle (deg)	2.13	2452739.10737773
30418.	53437.	1531.33	outb SEP = 3 deg	3.00	2452747.73237773
30602.	203437.	1576.96	max SEP angle (deg)	7.63	2452793.35737773
30610.	103437.	1584.54	max SPE angle (deg)	6.93	2452800.94071107

Table 11-2 Time Ordered Event Listing (cont)

CALDATE		TFL	DESCRIPTION	VALUE	JD
30704.	0.	1608.10	tcm 8a		2452824.50000000
30704.	0.	1608.10	DSM 3-1		2452824.50000000
30706.	0.	1610.10	tcm 8b		2452826.50000000
30706.	0.	1610.10	DSM 3-2		2452826.50000000
30713.	0.	1617.10	tcm 9		2452833.50000000
30720.	233437.	1625.08	min Earth range (AU)	2.00	2452841.48237773
30722.	123437.	1626.62	min Solar range (AU)	0.98	2452843.02404440
30724.	63437.	1628.38	inb SEP = 3 deg	3.00	2452844.77404440
30817.	63437.	1652.38	min SEP angle (deg)	0.93	2452868.77404440
30817.	153437.	1652.75	min SPE angle (deg)	0.91	2452869.14904440
30825.	133437.	1660.67	START CIDA: TRACKIN		2452877.06571107
30924.	192000.	1690.91	START ENCOUN		2452907.30555560
31003.	163437.	1699.79	cont CIDA: FOV		2452916.19071107
31006.	193437.	1702.92	outb SEP = 3 deg	3.00	2452919.31571107
31203.	192000.	1760.91	tcm 10		2452977.30555560
31223.	192000.	1780.91	tcm 11		2452997.30555560
31227.	133437.	1784.67	max Earth range (AU)	2.61	2453001.06571107
31231.	192000.	1788.91	tcm 12		2453005.30555560
40102.	12000.	1790.16	tcm 13		2453006.55555560
40102.	132000.	1790.66	tcm 14		2453007.05555560
40102.	192000.	1790.91	WILD-2		2453007.30555560
40201.	192000.	1820.91	DSM 4		2453037.30555560
40201.	192000.	1820.91	tcm 15		2453037.30555560
40216.	63437.	1835.38	END CIDA: 1/4 FOV		2453051.77404440
40221.	192000.	1840.91	END ENCOUN		2453057.30555560
40324.	83437.	1872.46	max SPE angle (deg)	25.94	2453088.85737773
40520.	203437.	1929.96	MAX CIDA: 0 FOV		2453146.35737773
40617.	3437.	1957.12	min Earth range (AU)	1.53	2453173.52404440
40624.	113437.	1964.58	max SEP angle (deg)	177.76	2453180.98237773
40624.	113437.	1964.58	min SPE angle (deg)	0.89	2453180.98237773
40916.	3437.	2048.12	max SPE angle (deg)	22.08	2453264.52404440
41001.	0.	2063.10	tcm 16		2453279.50000004
41017.	113437.	2079.58	max Solar range (AU)	2.68	2453295.98237773
50118.	233437.	2173.08	max Earth range (AU)	3.57	2453389.48237773
50124.	3437.	2178.12	START ISP: SHADOWED		2453394.52404440
50125.	93437.	2179.50	inb SEP = 3 deg	3.00	2453395.89904440
50130.	43437.	2184.29	min SEP angle (deg)	0.69	2453400.69071107
50130.	43437.	2184.29	min SPE angle (deg)	0.26	2453400.69071107

50204.	3437.	2189.12	outb SEP = 3 deg	2.99	2453405.52404440
50227.	53437.	2212.33	cont ISP: end shadow		2453428.73237773
50518.	143437.	2292.71	cont ISP: end steer		2453509.10737773
50605.	3437.	2310.12	END ISP: BETA METEOR		2453526.52404440
50804.	133437.	2370.67	max SPE angle (deg)	31.91	2453587.06571107
51017.	95807.	2444.52	START RETURN		2453660.91536000
51028.	103437.	2455.54	min SPE angle (deg)	11.45	2453671.94071107
51029.	43437.	2456.29	max SEP angle (deg)	164.95	2453672.69071107
51116.	95807.	2474.52	tcm 17		2453690.91536000
60102.	95807.	2521.52	tcm 18		2453737.91536000
60113.	113437.	2532.58	min Solar range (AU)	0.98	2453748.98237773
60114.	73437.	2533.42	min SEP angle (deg)	88.76	2453749.81571107
60114.	95807.	2533.52	tcm 19		2453749.91536000
60114.	103437.	2533.54	max SPE angle (deg)	91.00	2453749.94071107
60115.	55807.	2534.35	tcm 20		2453750.74869333
60115.	93437.	2534.50	max Solar range (AU)	0.98	2453750.89904440
60115.	93437.	2534.50	min SPE angle (deg)	56.47	2453750.89904440
60115.	93437.	2534.50	max SEP angle (deg)	123.52	2453750.89904440
60115.	93437.	2534.50	min Earth range (AU)	0.00	2453750.89904440
60115.	95807.	2534.52	RETURN		2453750.91536000
60116.	95807.	2535.52	END RETURN		2453751.91536000

SECTION 12.0

APPENDIX D

ISP COLLECTION

AND

CIDA EXPERIMENT

TABLES

Table 12-1 ISP #1 Collection Period Characteristics

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	collector angle (deg)	grid exposure	beta angle (deg)
403.000	11.724	0.000	8.237	157.582	157.569	141.145	1.000	35.802
404.000	11.656	0.000	8.471	157.655	157.642	141.782	1.000	36.423
405.000	11.590	0.000	8.704	157.726	157.713	142.425	1.000	37.051
406.000	11.524	0.000	8.938	157.794	157.783	143.076	1.000	37.686
407.000	11.460	0.000	9.170	157.862	157.850	143.733	1.000	38.328
408.000	11.396	0.000	9.403	157.927	157.916	144.397	1.000	38.978
409.000	11.333	0.000	9.635	157.991	157.980	145.068	1.000	39.635
410.000	11.271	0.000	9.867	158.053	158.042	145.745	1.000	40.299
411.000	11.211	0.000	10.098	158.113	158.103	146.430	1.000	40.970
412.000	11.151	0.000	10.330	158.172	158.162	147.122	1.000	41.649
413.000	11.092	0.000	10.560	158.229	158.219	147.820	1.000	42.335
414.000	11.035	0.000	10.791	158.284	158.275	148.526	1.000	43.028
415.000	10.978	0.000	11.021	158.338	158.329	149.238	1.000	43.729
416.000	10.923	0.000	11.250	158.391	158.382	149.957	1.000	44.437
417.000	10.869	0.000	11.480	158.442	158.433	150.684	1.000	45.152
418.000	10.816	0.000	11.708	158.491	158.482	151.417	1.000	45.874
419.000	10.764	0.000	11.937	158.539	158.530	152.157	1.000	46.603
420.000	10.713	0.000	12.165	158.585	158.576	152.904	1.000	47.340
421.000	10.663	0.000	12.392	158.629	158.621	153.658	1.000	48.084
422.000	10.615	0.000	12.620	158.673	158.664	154.419	1.000	48.835
423.000	10.568	0.000	12.846	158.714	158.706	155.187	1.000	49.592
424.000	10.523	0.000	13.072	158.754	158.747	155.961	1.000	50.357
425.000	10.478	0.000	13.298	158.793	158.785	156.742	1.000	51.129
426.000	10.435	0.000	13.523	158.830	158.823	157.530	1.000	51.907
427.000	10.394	0.000	13.748	158.866	158.859	158.324	1.000	52.692
428.000	10.353	0.000	13.972	158.900	158.893	159.125	1.000	53.484
429.000	10.315	0.000	14.195	158.933	158.926	159.932	1.000	54.282
430.000	10.277	0.000	14.418	158.965	158.958	160.745	1.000	55.086
431.000	10.241	0.000	14.641	158.995	158.988	161.565	1.000	55.897
432.000	10.207	0.000	14.863	159.024	159.017	162.390	1.000	56.714
433.000	10.174	0.000	15.084	159.051	159.045	163.222	1.000	57.538
434.000	10.142	0.000	15.305	159.077	159.071	164.059	1.000	58.367
435.000	10.112	0.000	15.525	159.101	159.095	164.902	1.000	59.201
436.000	10.084	0.000	15.745	159.124	159.119	165.751	1.000	60.042
437.000	10.057	0.000	15.964	159.146	159.140	166.605	1.000	60.888
438.000	10.032	0.000	16.183	159.166	159.161	167.464	1.000	61.739
439.000	10.008	0.000	16.401	159.185	159.180	168.328	1.000	62.595
440.000	9.986	0.000	16.618	159.203	159.198	169.197	1.000	63.456
441.000	9.966	0.000	16.835	159.219	159.214	170.070	1.000	64.322
442.000	9.947	0.000	17.051	159.234	159.229	170.948	1.000	65.192
443.000	9.930	0.000	17.267	159.247	159.242	171.830	1.000	66.066
444.000	9.915	0.000	17.482	159.259	159.254	172.717	1.000	66.945
445.000	9.901	0.000	17.697	159.270	159.265	173.607	1.000	67.827
446.000	9.889	0.000	17.910	159.279	159.275	174.500	1.000	68.713
447.000	9.879	0.000	18.124	159.287	159.282	175.397	1.000	69.602
448.000	9.871	0.000	18.336	159.293	159.289	176.297	1.000	70.494
449.000	9.864	0.000	18.548	159.298	159.294	177.199	1.000	71.389
450.000	9.860	0.000	18.760	159.302	159.298	178.105	1.000	72.287
451.000	9.857	0.000	18.970	159.304	159.300	179.012	1.000	73.187
452.000	9.856	0.000	19.180	159.305	159.301	179.922	1.000	74.089
453.000	9.856	0.000	19.389	159.304	159.300	179.167	1.000	74.992
453.000	9.856	0.833	20.171	159.304	159.300	180.000	1.000	74.992
454.000	9.859	1.746	21.240	159.302	159.298	180.000	1.000	75.897
455.000	9.863	2.660	22.313	159.298	159.295	180.000	1.000	76.804
456.000	9.870	3.575	23.389	159.293	159.290	180.000	1.000	77.711
457.000	9.878	4.491	24.469	159.286	159.283	180.000	1.000	78.619
458.000	9.888	5.407	25.550	159.278	159.275	180.000	1.000	79.527
459.000	9.900	6.323	26.632	159.269	159.266	180.000	1.000	80.436
460.000	9.914	7.239	27.716	159.258	159.255	180.000	1.000	81.344
461.000	9.929	8.154	28.799	159.245	159.242	180.000	1.000	82.252
462.000	9.947	9.069	29.883	159.231	159.228	180.000	1.000	83.159
463.000	9.967	9.983	30.966	159.215	159.213	180.000	1.000	84.065
464.000	9.988	10.895	32.048	159.198	159.196	180.000	1.000	84.969
465.000	10.011	11.806	33.129	159.179	159.177	180.000	1.000	85.872
466.000	10.037	12.715	34.208	159.159	159.156	180.000	1.000	86.773
467.000	10.064	13.622	35.284	159.137	159.134	180.000	1.000	87.673
468.000	10.093	14.527	36.358	159.113	159.111	180.000	1.000	88.569
469.000	10.123	15.429	37.430	159.087	159.086	180.000	1.000	89.463

1. Collector fully stowed at 0 deg, fully deployed at 180 deg.

Table 12-2 ISP #2 Collection Period Characteristics

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	collector angle (deg)	grid exposure	beta angle (deg)
1267.000	14.845	0.000	2.782	165.725	158.130	117.128	0.493	14.733
1268.000	14.779	0.000	2.307	168.380	158.254	117.419	0.508	14.984
1269.000	14.713	0.000	1.836	172.350	158.376	117.714	0.524	15.239
1270.000	14.647	0.000	1.377	178.945	158.496	118.010	0.540	15.497
1271.000	14.581	0.000	0.951	168.327	158.615	118.310	0.556	15.758
1272.000	14.515	0.000	0.633	139.785	158.731	118.612	0.572	16.024
1273.000	14.450	0.000	0.625	86.923	158.845	118.916	0.588	16.293
1274.000	14.384	0.000	0.936	116.550	158.958	119.223	0.605	16.565
1275.000	14.318	0.000	1.364	129.729	159.068	119.533	0.621	16.841
1276.000	14.253	0.000	1.828	136.496	159.177	119.846	0.637	17.121
1277.000	14.188	0.000	2.307	140.537	159.284	120.161	0.654	17.404
1278.000	14.122	0.000	2.793	143.220	159.390	120.479	0.671	17.691
1279.000	14.057	0.000	3.282	145.137	159.494	120.800	0.687	17.982
1280.000	13.992	0.000	3.772	146.583	159.596	121.124	0.704	18.276
1281.000	13.927	0.000	4.262	147.719	159.696	121.450	0.721	18.573
1282.000	13.862	0.000	4.751	148.640	159.795	121.780	0.737	18.874
1283.000	13.798	0.000	5.239	149.405	159.893	122.113	0.754	19.179
1284.000	13.733	0.000	5.725	150.056	159.989	122.448	0.770	19.488
1285.000	13.669	0.000	6.209	150.619	160.083	122.787	0.787	19.800
1286.000	13.604	0.000	6.690	151.112	160.176	123.129	0.803	20.116
1287.000	13.540	0.000	7.168	151.550	160.267	123.474	0.819	20.435
1288.000	13.476	0.000	7.642	151.943	160.357	123.822	0.835	20.758
1289.000	13.412	0.000	8.113	152.300	160.446	124.173	0.851	21.085
1290.000	13.348	0.000	8.579	152.626	160.533	124.528	0.866	21.416
1291.000	13.285	0.000	9.042	152.926	160.619	124.886	0.881	21.750
1292.000	13.222	0.000	9.499	153.203	160.704	125.248	0.896	22.088
1293.000	13.158	0.000	9.952	153.462	160.787	125.613	0.910	22.431
1294.000	13.095	0.000	10.400	153.704	160.869	125.981	0.924	22.776
1295.000	13.032	0.000	10.842	153.932	160.949	126.353	0.937	23.126
1296.000	12.970	0.000	11.279	154.147	161.029	126.728	0.950	23.480
1297.000	12.907	0.000	11.711	154.350	161.107	127.107	0.962	23.838
1298.000	12.845	0.000	12.136	154.544	161.184	127.490	0.973	24.199
1299.000	12.783	0.000	12.555	154.728	161.259	127.877	0.982	24.565
1300.000	12.721	0.000	12.968	154.905	161.334	128.267	0.991	24.935
1301.000	12.659	0.000	13.375	155.074	161.407	128.661	0.997	25.309
1302.000	12.597	0.000	13.775	155.236	161.479	129.059	1.000	25.687
1303.000	12.536	0.000	14.168	155.392	161.550	129.461	1.000	26.069
1304.000	12.475	0.000	14.554	155.542	161.620	129.867	1.000	26.456
1305.000	12.414	0.000	14.934	155.687	161.689	130.277	1.000	26.847
1306.000	12.354	0.000	15.306	155.828	161.756	130.691	1.000	27.242
1307.000	12.293	0.000	15.671	155.963	161.823	131.109	1.000	27.641
1308.000	12.233	0.000	16.029	156.095	161.889	131.532	1.000	28.045
1309.000	12.173	0.000	16.379	156.223	161.953	131.959	1.000	28.453
1310.000	12.114	0.000	16.722	156.347	162.016	132.390	1.000	28.866
1311.000	12.055	0.000	17.057	156.468	162.079	132.825	1.000	29.283
1312.000	11.996	0.000	17.385	156.585	162.140	133.265	1.000	29.705
1313.000	11.937	0.000	17.705	156.700	162.200	133.710	1.000	30.132
1314.000	11.879	0.000	18.017	156.811	162.260	134.159	1.000	30.563
1315.000	11.821	0.000	18.322	156.920	162.318	134.612	1.000	30.999
1316.000	11.763	0.000	18.619	157.027	162.376	135.070	1.000	31.440
1317.000	11.706	0.000	18.909	157.131	162.432	135.533	1.000	31.886
1318.000	11.649	0.000	19.191	157.233	162.488	136.001	1.000	32.337
1319.000	11.592	0.000	19.465	157.332	162.542	136.474	1.000	32.792
1320.000	11.536	0.000	19.732	157.430	162.596	136.952	1.000	33.253
1321.000	11.480	0.000	19.991	157.525	162.648	137.434	1.000	33.718
1322.000	11.424	0.000	20.242	157.619	162.700	137.922	1.000	34.189
1323.000	11.369	0.000	20.487	157.711	162.751	138.414	1.000	34.665
1324.000	11.314	0.000	20.723	157.801	162.801	138.912	1.000	35.146
1325.000	11.260	0.000	20.952	157.890	162.850	139.415	1.000	35.633
1326.000	11.206	0.000	21.174	157.976	162.898	139.924	1.000	36.125
1327.000	11.152	0.000	21.389	158.062	162.946	140.437	1.000	36.622
1328.000	11.099	0.000	21.596	158.146	162.992	140.957	1.000	37.124
1329.000	11.047	0.000	21.797	158.228	163.038	141.481	1.000	37.632
1330.000	10.994	0.000	21.990	158.309	163.082	142.011	1.000	38.146
1331.000	10.943	0.000	22.176	158.389	163.126	142.547	1.000	38.665
1332.000	10.892	0.000	22.355	158.467	163.169	143.088	1.000	39.190
1333.000	10.841	0.000	22.527	158.544	163.212	143.635	1.000	39.720
1334.000	10.791	0.000	22.692	158.620	163.253	144.187	1.000	40.257
1335.000	10.741	0.000	22.850	158.695	163.293	144.746	1.000	40.799
1336.000	10.692	0.000	23.002	158.769	163.333	145.310	1.000	41.346
1337.000	10.644	0.000	23.146	158.841	163.372	145.880	1.000	41.900
1338.000	10.596	0.000	23.285	158.912	163.410	146.456	1.000	42.460

1. Collector fully stowed at 0 deg, fully deployed at 180 deg.

Table 12-2 ISP #2 Collection Period Characteristics (cont)

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	collector angle (deg)	grid exposure	beta angle (deg)
1339.000	10.549	0.000	23.416	158.983	163.448	147.037	1.000	43.025
1340.000	10.502	0.000	23.541	159.052	163.484	147.625	1.000	43.596
1341.000	10.456	0.000	23.660	159.120	163.520	148.219	1.000	44.174
1342.000	10.411	0.000	23.773	159.187	163.555	148.819	1.000	44.757
1343.000	10.366	0.000	23.879	159.253	163.589	149.425	1.000	45.347
1344.000	10.322	0.000	23.979	159.319	163.622	150.037	1.000	45.943
1345.000	10.278	0.000	24.073	159.383	163.655	150.656	1.000	46.545
1346.000	10.236	0.000	24.162	159.447	163.686	151.280	1.000	47.153
1347.000	10.194	0.000	24.244	159.509	163.717	151.911	1.000	47.767
1348.000	10.153	0.000	24.321	159.571	163.747	152.548	1.000	48.387
1349.000	10.112	0.000	24.392	159.632	163.777	153.191	1.000	49.014
1350.000	10.073	0.000	24.457	159.693	163.805	153.841	1.000	49.647
1351.000	10.034	0.000	24.517	159.752	163.833	154.496	1.000	50.286
1352.000	9.996	0.000	24.572	159.811	163.860	155.158	1.000	50.931
1353.000	9.958	0.000	24.621	159.868	163.887	155.827	1.000	51.583
1354.000	9.922	0.000	24.666	159.925	163.912	156.502	1.000	52.240
1355.000	9.886	0.000	24.705	159.982	163.937	157.182	1.000	52.904
1356.000	9.852	0.000	24.739	160.037	163.961	157.870	1.000	53.575
1357.000	9.818	0.000	24.768	160.092	163.984	158.563	1.000	54.251
1358.000	9.785	0.000	24.792	160.147	164.006	159.263	1.000	54.933
1359.000	9.754	0.000	24.812	160.200	164.028	159.969	1.000	55.622
1360.000	9.723	0.000	24.826	160.253	164.049	160.681	1.000	56.317
1361.000	9.693	0.000	24.836	160.305	164.069	161.399	1.000	57.018
1362.000	9.664	0.000	24.842	160.356	164.088	162.123	1.000	57.724
1363.000	9.636	0.000	24.842	160.407	164.107	162.854	1.000	58.437
1364.000	9.609	0.000	24.839	160.457	164.125	163.590	1.000	59.156
1365.000	9.583	0.000	24.831	160.507	164.142	164.332	1.000	59.880
1366.000	9.559	0.000	24.818	160.556	164.158	165.080	1.000	60.610
1367.000	9.535	0.000	24.802	160.604	164.173	165.834	1.000	61.346
1368.000	9.513	0.000	24.781	160.651	164.188	166.593	1.000	62.088
1369.000	9.492	0.000	24.756	160.698	164.202	167.358	1.000	62.835
1370.000	9.471	0.000	24.727	160.745	164.214	168.129	1.000	63.587
1371.000	9.452	0.000	24.694	160.790	164.227	168.905	1.000	64.345
1372.000	9.435	0.000	24.657	160.835	164.238	169.686	1.000	65.108
1373.000	9.418	0.000	24.617	160.880	164.249	170.473	1.000	65.876
1374.000	9.403	0.000	24.573	160.924	164.258	171.265	1.000	66.649
1375.000	9.389	0.000	24.525	160.967	164.267	172.061	1.000	67.426
1376.000	9.376	0.000	24.473	161.010	164.275	172.862	1.000	68.209
1377.000	9.365	0.000	24.418	161.052	164.282	173.668	1.000	68.996
1378.000	9.355	0.000	24.360	161.094	164.289	174.479	1.000	69.787
1379.000	9.346	0.000	24.298	161.135	164.294	175.294	1.000	70.583
1380.000	9.339	0.000	24.233	161.175	164.299	176.113	1.000	71.382
1381.000	9.333	0.000	24.164	161.215	164.303	176.936	1.000	72.186
1382.000	9.328	0.000	24.093	161.255	164.305	177.763	1.000	72.993
1383.000	9.325	0.000	24.018	161.293	164.307	178.593	1.000	73.804
1384.000	9.323	0.000	23.940	161.332	164.309	179.427	1.000	74.618
1385.000	9.323	0.000	23.859	161.369	164.309	179.736	1.000	75.435
1385.000	9.323	0.264	23.609	161.369	164.309	180.000	1.000	75.435
1386.000	9.324	1.105	22.731	161.406	164.308	180.000	1.000	76.256
1387.000	9.327	1.948	21.850	161.443	164.306	180.000	1.000	77.079
1388.000	9.331	2.794	20.967	161.479	164.304	180.000	1.000	77.904
1389.000	9.337	3.643	20.083	161.514	164.300	180.000	1.000	78.732
1390.000	9.344	4.494	19.199	161.549	164.296	180.000	1.000	79.562
1391.000	9.353	5.346	18.315	161.583	164.290	180.000	1.000	80.394
1392.000	9.363	6.201	17.432	161.617	164.284	180.000	1.000	81.228
1393.000	9.375	7.058	16.553	161.650	164.276	180.000	1.000	82.063
1394.000	9.389	7.915	15.678	161.683	164.268	180.000	1.000	82.900
1395.000	9.404	8.774	14.809	161.715	164.258	180.000	1.000	83.737
1396.000	9.421	9.634	13.948	161.746	164.247	180.000	1.000	84.575
1397.000	9.439	10.495	13.098	161.777	164.236	180.000	1.000	85.414
1398.000	9.459	11.356	12.263	161.807	164.223	180.000	1.000	86.253
1399.000	9.481	12.217	11.447	161.837	164.209	180.000	1.000	87.093
1400.000	9.504	13.079	10.654	161.866	164.194	180.000	1.000	87.932
1401.000	9.529	13.940	9.891	161.894	164.178	180.000	1.000	88.771
1402.000	9.555	14.801	9.167	161.922	164.161	180.000	1.000	89.609

1. Collector fully stowed at 0 deg, fully deployed at 180 deg.

Table 12-3 ISP #1 Spacecraft Attitude [EME'2000]

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
403.000	-1.978	61.650	-78.052	161.045	11.778	151.237
404.000	-1.862	61.853	-78.154	160.768	11.694	151.467
405.000	-1.747	62.056	-78.255	160.494	11.610	151.697
406.000	-1.635	62.260	-78.356	160.221	11.526	151.927
407.000	-1.524	62.466	-78.455	159.951	11.441	152.157
408.000	-1.416	62.671	-78.553	159.682	11.356	152.387
409.000	-1.309	62.878	-78.651	159.415	11.271	152.617
410.000	-1.204	63.086	-78.748	159.151	11.186	152.847
411.000	-1.101	63.294	-78.844	158.889	11.100	153.078
412.000	-1.001	63.503	-78.939	158.628	11.014	153.308
413.000	-0.901	63.712	-79.034	158.370	10.928	153.538
414.000	-0.804	63.923	-79.128	158.114	10.842	153.769
415.000	-0.709	64.134	-79.221	157.860	10.755	154.000
416.000	-0.615	64.346	-79.313	157.609	10.668	154.230
417.000	-0.524	64.559	-79.405	157.359	10.581	154.461
418.000	-0.434	64.772	-79.497	157.112	10.494	154.692
419.000	-0.345	64.987	-79.588	156.867	10.406	154.923
420.000	-0.259	65.201	-79.678	156.624	10.318	155.154
421.000	-0.174	65.417	-79.768	156.383	10.230	155.386
422.000	-0.091	65.633	-79.858	156.145	10.142	155.617
423.000	-0.010	65.850	-79.947	155.909	10.053	155.849
424.000	0.069	66.068	-80.036	155.675	9.964	156.080
425.000	0.147	66.287	-80.124	155.443	9.875	156.312
426.000	0.223	66.506	-80.212	155.214	9.785	156.544
427.000	0.297	66.726	-80.300	154.988	9.695	156.777
428.000	0.370	66.947	-80.388	154.764	9.605	157.009
429.000	0.440	67.168	-80.475	154.542	9.515	157.242
430.000	0.510	67.390	-80.562	154.323	9.424	157.475
431.000	0.577	67.613	-80.649	154.106	9.333	157.708
432.000	0.643	67.836	-80.735	153.892	9.242	157.941
433.000	0.707	68.060	-80.822	153.680	9.151	158.174
434.000	0.769	68.285	-80.908	153.472	9.059	158.408
435.000	0.830	68.511	-80.994	153.265	8.967	158.642
436.000	0.889	68.737	-81.080	153.062	8.874	158.876
437.000	0.946	68.964	-81.167	152.861	8.782	159.110
438.000	1.002	69.192	-81.253	152.664	8.689	159.345
439.000	1.056	69.420	-81.339	152.469	8.596	159.579
440.000	1.108	69.649	-81.425	152.277	8.502	159.815
441.000	1.159	69.879	-81.511	152.088	8.409	160.050
442.000	1.208	70.109	-81.597	151.902	8.314	160.286
443.000	1.255	70.340	-81.683	151.720	8.220	160.521
444.000	1.301	70.572	-81.770	151.540	8.125	160.758
445.000	1.345	70.804	-81.856	151.364	8.030	160.994
446.000	1.387	71.038	-81.943	151.191	7.935	161.231
447.000	1.427	71.271	-82.030	151.022	7.840	161.468
448.000	1.466	71.506	-82.117	150.856	7.744	161.705
449.000	1.503	71.741	-82.204	150.694	7.648	161.943
450.000	1.538	71.977	-82.292	150.536	7.551	162.181
451.000	1.571	72.214	-82.380	150.382	7.454	162.419
452.000	1.603	72.451	-82.468	150.231	7.357	162.658
453.000	1.527	71.862	-82.557	150.085	7.283	162.058
454.000	1.443	71.195	-82.646	149.944	7.210	161.378
455.000	1.358	70.527	-82.735	149.806	7.135	160.697
456.000	1.275	69.858	-82.825	149.673	7.060	160.016
457.000	1.193	69.189	-82.915	149.545	6.983	159.335
458.000	1.111	68.520	-83.006	149.422	6.904	158.654
459.000	1.031	67.851	-83.097	149.305	6.825	157.974
460.000	0.951	67.183	-83.189	149.192	6.744	157.295
461.000	0.873	66.516	-83.281	149.086	6.661	156.618
462.000	0.795	65.849	-83.374	148.985	6.578	155.941
463.000	0.719	65.184	-83.467	148.890	6.492	155.266
464.000	0.644	64.521	-83.562	148.802	6.406	154.594
465.000	0.571	63.860	-83.656	148.721	6.318	153.923
466.000	0.498	63.201	-83.752	148.646	6.228	153.255
467.000	0.427	62.544	-83.848	148.580	6.137	152.590
468.000	0.357	61.891	-83.945	148.521	6.044	151.928
469.000	0.289	61.240	-84.043	148.471	5.950	151.270

Table 12-4 ISP #2 Spacecraft Attitude [EME'2000]

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
1267.000	-9.487	44.919	-68.749	160.367	18.833	131.652
1268.000	-9.317	45.031	-68.862	160.141	18.797	131.830
1269.000	-9.150	45.144	-68.974	159.916	18.762	132.008
1270.000	-8.984	45.258	-69.084	159.693	18.726	132.186
1271.000	-8.820	45.374	-69.192	159.471	18.690	132.365
1272.000	-8.658	45.490	-69.299	159.251	18.654	132.544
1273.000	-8.497	45.607	-69.404	159.033	18.617	132.723
1274.000	-8.338	45.726	-69.508	158.816	18.580	132.902
1275.000	-8.181	45.845	-69.610	158.600	18.543	133.081
1276.000	-8.026	45.966	-69.711	158.386	18.506	133.261
1277.000	-7.872	46.087	-69.810	158.174	18.469	133.440
1278.000	-7.720	46.210	-69.909	157.963	18.431	133.620
1279.000	-7.569	46.333	-70.006	157.753	18.393	133.800
1280.000	-7.420	46.457	-70.101	157.545	18.355	133.981
1281.000	-7.273	46.583	-70.196	157.339	18.317	134.161
1282.000	-7.126	46.709	-70.289	157.133	18.278	134.342
1283.000	-6.982	46.836	-70.381	156.930	18.239	134.523
1284.000	-6.839	46.964	-70.472	156.728	18.200	134.705
1285.000	-6.697	47.093	-70.562	156.527	18.161	134.886
1286.000	-6.556	47.223	-70.651	156.328	18.121	135.068
1287.000	-6.417	47.354	-70.738	156.130	18.082	135.250
1288.000	-6.279	47.486	-70.825	155.933	18.042	135.432
1289.000	-6.143	47.619	-70.911	155.738	18.001	135.615
1290.000	-6.008	47.752	-70.995	155.545	17.961	135.797
1291.000	-5.874	47.887	-71.079	155.353	17.920	135.980
1292.000	-5.741	48.022	-71.162	155.162	17.879	136.164
1293.000	-5.610	48.158	-71.244	154.972	17.838	136.347
1294.000	-5.480	48.296	-71.325	154.785	17.796	136.531
1295.000	-5.351	48.433	-71.405	154.598	17.754	136.715
1296.000	-5.223	48.572	-71.484	154.413	17.712	136.899
1297.000	-5.097	48.712	-71.562	154.229	17.670	137.084
1298.000	-4.971	48.852	-71.640	154.047	17.628	137.269
1299.000	-4.847	48.994	-71.717	153.866	17.585	137.454
1300.000	-4.724	49.136	-71.793	153.686	17.542	137.639
1301.000	-4.602	49.279	-71.868	153.508	17.499	137.825
1302.000	-4.481	49.423	-71.943	153.331	17.455	138.011
1303.000	-4.361	49.567	-72.017	153.155	17.411	138.197
1304.000	-4.242	49.713	-72.090	152.981	17.367	138.383
1305.000	-4.124	49.859	-72.163	152.808	17.323	138.570
1306.000	-4.008	50.006	-72.234	152.637	17.278	138.757
1307.000	-3.892	50.154	-72.306	152.467	17.233	138.945
1308.000	-3.777	50.303	-72.376	152.298	17.188	139.132
1309.000	-3.664	50.452	-72.446	152.131	17.143	139.321
1310.000	-3.551	50.603	-72.516	151.964	17.097	139.509
1311.000	-3.439	50.754	-72.585	151.800	17.051	139.698
1312.000	-3.329	50.906	-72.653	151.636	17.005	139.887
1313.000	-3.219	51.058	-72.721	151.474	16.958	140.076
1314.000	-3.110	51.212	-72.788	151.313	16.912	140.266
1315.000	-3.002	51.366	-72.855	151.154	16.865	140.456
1316.000	-2.895	51.522	-72.921	150.996	16.817	140.646
1317.000	-2.789	51.678	-72.987	150.839	16.770	140.836
1318.000	-2.684	51.834	-73.052	150.683	16.722	141.027
1319.000	-2.580	51.992	-73.117	150.529	16.673	141.219
1320.000	-2.476	52.150	-73.181	150.376	16.625	141.411
1321.000	-2.374	52.310	-73.245	150.224	16.576	141.603
1322.000	-2.272	52.470	-73.309	150.074	16.527	141.795
1323.000	-2.172	52.630	-73.372	149.925	16.478	141.988
1324.000	-2.072	52.792	-73.435	149.777	16.428	142.181
1325.000	-1.973	52.955	-73.497	149.631	16.378	142.375
1326.000	-1.875	53.118	-73.559	149.486	16.328	142.568
1327.000	-1.777	53.282	-73.621	149.342	16.277	142.763
1328.000	-1.681	53.447	-73.682	149.200	16.226	142.957
1329.000	-1.585	53.612	-73.743	149.058	16.175	143.152
1330.000	-1.491	53.779	-73.804	148.919	16.124	143.348
1331.000	-1.397	53.946	-73.864	148.780	16.072	143.544
1332.000	-1.303	54.114	-73.925	148.643	16.020	143.740
1333.000	-1.211	54.283	-73.985	148.507	15.967	143.937
1334.000	-1.120	54.453	-74.044	148.372	15.914	144.134
1335.000	-1.029	54.624	-74.104	148.239	15.861	144.331
1336.000	-0.939	54.795	-74.163	148.107	15.808	144.529
1337.000	-0.850	54.967	-74.222	147.976	15.754	144.727
1338.000	-0.761	55.140	-74.280	147.847	15.700	144.926

Table 12-4 ISP #2 Spacecraft Attitude [EME'2000] (cont)

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
1339.000	-0.674	55.314	-74.339	147.719	15.646	145.125
1340.000	-0.587	55.489	-74.397	147.592	15.591	145.325
1341.000	-0.501	55.664	-74.455	147.467	15.536	145.525
1342.000	-0.416	55.841	-74.513	147.343	15.481	145.726
1343.000	-0.332	56.018	-74.571	147.220	15.425	145.927
1344.000	-0.248	56.196	-74.629	147.099	15.369	146.128
1345.000	-0.165	56.375	-74.686	146.979	15.313	146.330
1346.000	-0.083	56.555	-74.744	146.860	15.256	146.532
1347.000	-0.002	56.736	-74.801	146.743	15.199	146.735
1348.000	0.079	56.917	-74.858	146.627	15.141	146.938
1349.000	0.158	57.100	-74.915	146.513	15.084	147.142
1350.000	0.237	57.283	-74.972	146.399	15.026	147.347
1351.000	0.315	57.467	-75.029	146.288	14.967	147.551
1352.000	0.393	57.652	-75.086	146.177	14.908	147.757
1353.000	0.469	57.838	-75.143	146.069	14.849	147.962
1354.000	0.545	58.025	-75.200	145.961	14.790	148.169
1355.000	0.620	58.213	-75.257	145.855	14.730	148.376
1356.000	0.694	58.401	-75.313	145.751	14.669	148.583
1357.000	0.768	58.591	-75.370	145.647	14.609	148.791
1358.000	0.841	58.781	-75.427	145.546	14.548	148.999
1359.000	0.912	58.972	-75.484	145.446	14.486	149.208
1360.000	0.984	59.165	-75.541	145.347	14.424	149.418
1361.000	1.054	59.358	-75.597	145.250	14.362	149.628
1362.000	1.123	59.552	-75.654	145.154	14.300	149.838
1363.000	1.192	59.747	-75.711	145.060	14.237	150.049
1364.000	1.260	59.943	-75.768	144.968	14.173	150.261
1365.000	1.327	60.140	-75.825	144.877	14.110	150.473
1366.000	1.393	60.338	-75.883	144.788	14.046	150.686
1367.000	1.459	60.537	-75.940	144.700	13.981	150.900
1368.000	1.524	60.736	-75.997	144.614	13.916	151.114
1369.000	1.587	60.937	-76.055	144.530	13.851	151.329
1370.000	1.650	61.139	-76.113	144.447	13.785	151.544
1371.000	1.712	61.342	-76.170	144.366	13.719	151.760
1372.000	1.774	61.545	-76.229	144.287	13.652	151.976
1373.000	1.834	61.750	-76.287	144.209	13.585	152.193
1374.000	1.894	61.956	-76.345	144.133	13.518	152.411
1375.000	1.952	62.163	-76.404	144.060	13.450	152.630
1376.000	2.010	62.370	-76.463	143.988	13.382	152.849
1377.000	2.067	62.579	-76.522	143.917	13.313	153.068
1378.000	2.123	62.789	-76.581	143.849	13.244	153.289
1379.000	2.178	63.000	-76.640	143.783	13.174	153.510
1380.000	2.233	63.212	-76.700	143.719	13.104	153.732
1381.000	2.286	63.425	-76.760	143.656	13.034	153.954
1382.000	2.338	63.639	-76.821	143.596	12.963	154.177
1383.000	2.390	63.854	-76.881	143.538	12.892	154.401
1384.000	2.440	64.070	-76.942	143.482	12.820	154.626
1385.000	2.431	64.029	-77.004	143.428	12.759	154.580
1386.000	2.295	63.427	-77.065	143.377	12.722	153.945
1387.000	2.159	62.822	-77.128	143.328	12.684	153.309
1388.000	2.023	62.216	-77.190	143.281	12.644	152.670
1389.000	1.887	61.609	-77.253	143.236	12.602	152.031
1390.000	1.751	60.999	-77.316	143.194	12.558	151.390
1391.000	1.615	60.389	-77.380	143.155	12.513	150.748
1392.000	1.480	59.778	-77.444	143.118	12.466	150.105
1393.000	1.344	59.165	-77.509	143.084	12.416	149.462
1394.000	1.210	58.553	-77.574	143.053	12.365	148.818
1395.000	1.076	57.940	-77.639	143.024	12.312	148.174
1396.000	0.942	57.326	-77.706	142.998	12.257	147.531
1397.000	0.809	56.713	-77.772	142.976	12.200	146.888
1398.000	0.677	56.100	-77.840	142.956	12.141	146.246
1399.000	0.546	55.488	-77.907	142.939	12.080	145.605
1400.000	0.415	54.877	-77.976	142.926	12.017	144.965
1401.000	0.286	54.266	-78.045	142.916	11.952	144.327
1402.000	0.157	53.657	-78.115	142.910	11.884	143.690

Table 12-5 CIDA #1 Collection Period Characteristics

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	+x-off ISP (deg)	fov exposure
45.000	58.692	15.238	60.064	176.360	176.470	0.000	0.766
46.000	58.575	15.805	59.347	176.343	176.453	0.000	0.766
47.000	58.454	16.368	58.625	176.325	176.436	0.000	0.766
48.000	58.331	16.927	57.897	176.306	176.418	0.000	0.766
49.000	58.205	17.482	57.165	176.286	176.399	0.000	0.766
50.000	58.075	18.032	56.428	176.266	176.380	0.000	0.766
51.000	57.943	18.579	55.687	176.245	176.360	0.000	0.766
52.000	57.809	19.122	54.943	176.223	176.340	0.000	0.766
53.000	57.671	19.660	54.195	176.200	176.319	0.000	0.766
54.000	57.531	20.000	53.250	176.177	176.298	0.195	0.764
55.000	57.389	20.000	51.967	176.153	176.276	0.725	0.758
56.000	57.245	20.000	50.687	176.127	176.253	1.251	0.752
57.000	57.098	20.000	49.409	176.101	176.230	1.774	0.746
58.000	56.949	20.000	48.135	176.074	176.206	2.292	0.740
59.000	56.798	20.000	46.864	176.046	176.182	2.806	0.734
60.000	56.646	20.000	45.598	176.017	176.157	3.317	0.728
61.000	56.491	20.000	44.337	175.987	176.132	3.823	0.721
62.000	56.335	20.000	43.081	175.955	176.106	4.325	0.715
63.000	56.176	20.000	41.832	175.923	176.079	4.824	0.709
64.000	56.017	20.000	40.590	175.889	176.052	5.319	0.703
65.000	55.855	20.000	39.356	175.854	176.024	5.809	0.697
66.000	55.693	20.000	38.131	175.817	175.996	6.296	0.691
67.000	55.529	20.000	36.915	175.779	175.967	6.779	0.685
68.000	55.363	20.000	35.709	175.739	175.938	7.259	0.679
69.000	55.197	20.000	34.514	175.697	175.908	7.734	0.673
70.000	55.029	20.000	33.330	175.652	175.877	8.206	0.666
71.000	54.860	20.000	32.159	175.605	175.846	8.674	0.660
72.000	54.690	20.000	31.002	175.554	175.814	9.139	0.654
73.000	54.519	20.000	29.858	175.498	175.782	9.600	0.648
74.000	54.347	20.000	28.729	175.437	175.749	10.057	0.642
75.000	54.175	20.000	27.615	175.367	175.716	10.511	0.636
76.000	54.001	20.000	26.516	175.284	175.682	10.961	0.630
77.000	53.827	20.000	25.433	175.183	175.648	11.407	0.624
78.000	53.652	20.000	24.367	175.050	175.612	11.851	0.618
79.000	53.477	20.000	23.317	174.855	175.577	12.290	0.612
80.000	53.300	20.000	22.284	174.521	175.540	12.727	0.606
81.000	53.124	20.000	21.268	173.716	175.504	13.160	0.600
82.000	52.947	20.000	20.269	167.384	175.466	13.589	0.594
83.000	52.769	20.000	19.288	178.473	175.428	14.016	0.588
84.000	52.591	20.000	18.325	176.650	175.389	14.439	0.582
85.000	52.412	20.000	17.379	176.136	175.350	14.859	0.576
86.000	52.234	20.000	16.451	175.877	175.310	15.276	0.570
87.000	52.054	20.000	15.541	175.710	175.270	15.689	0.564
88.000	51.875	20.000	14.650	175.587	175.229	16.100	0.558
89.000	51.696	20.000	13.777	175.488	175.187	16.507	0.552
90.000	51.516	20.000	12.922	175.404	175.144	16.912	0.546
91.000	51.336	20.000	12.086	175.328	175.101	17.313	0.540
92.000	51.156	20.000	11.268	175.258	175.058	17.712	0.534
93.000	50.976	20.000	10.470	175.193	175.013	18.107	0.528
94.000	50.796	20.000	9.690	175.130	174.969	18.500	0.523
95.000	50.616	20.000	8.931	175.070	174.923	18.890	0.517
96.000	50.435	20.000	8.191	175.011	174.877	19.277	0.511
97.000	50.255	20.000	7.472	174.953	174.830	19.661	0.505
98.000	50.075	20.000	6.775	174.895	174.782	20.042	0.499
99.000	49.895	20.000	6.100	174.838	174.734	20.421	0.494
100.000	49.715	20.000	5.450	174.781	174.685	20.797	0.488
101.000	49.535	20.000	4.826	174.724	174.635	21.171	0.482
102.000	49.355	20.000	4.233	174.667	174.584	21.541	0.477
103.000	49.176	20.000	3.675	174.610	174.533	21.910	0.471
104.000	48.996	20.000	3.163	174.553	174.481	22.276	0.465
105.000	48.817	20.000	2.709	174.496	174.429	22.639	0.460
106.000	48.638	20.000	2.335	174.438	174.375	23.000	0.454
107.000	48.459	20.000	2.073	174.380	174.321	23.358	0.448
108.000	48.281	20.000	1.952	174.322	174.266	23.714	0.443
109.000	48.103	20.000	1.986	174.263	174.211	24.067	0.437
110.000	47.925	20.000	2.157	174.203	174.154	24.419	0.432
111.000	47.747	20.000	2.427	174.143	174.097	24.768	0.426
112.000	47.569	20.000	2.759	174.083	174.039	25.114	0.421
113.000	47.392	20.000	3.127	174.021	173.980	25.459	0.415
114.000	47.215	20.000	3.514	173.959	173.920	25.801	0.410
115.000	47.039	20.000	3.909	173.897	173.859	26.141	0.404
116.000	46.863	20.000	4.308	173.834	173.798	26.479	0.399
117.000	46.687	20.000	4.704	173.770	173.735	26.815	0.394
118.000	46.512	20.000	5.096	173.705	173.672	27.148	0.388

Table 12-5 CIDA #1 Collection Period Characteristics (cont)

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	+x-off ISP (deg)	fov exposure
119.000	46.337	20.000	5.482	173.639	173.608	27.480	0.383
120.000	46.162	20.000	5.861	173.573	173.543	27.809	0.378
121.000	45.988	20.000	6.232	173.505	173.477	28.137	0.372
122.000	45.814	20.000	6.594	173.437	173.410	28.463	0.367
123.000	45.640	20.000	6.948	173.368	173.342	28.786	0.362
124.000	45.467	20.000	7.292	173.298	173.273	29.108	0.357
125.000	45.295	20.000	7.627	173.226	173.203	29.428	0.351
126.000	45.122	20.000	7.953	173.154	173.132	29.746	0.346
127.000	44.951	20.000	8.269	173.081	173.061	30.062	0.341
128.000	44.779	20.000	8.576	173.007	172.988	30.376	0.336
129.000	44.608	20.000	8.874	172.932	172.914	30.688	0.331
130.000	44.438	20.000	9.162	172.856	172.838	30.999	0.326
131.000	44.268	20.000	9.442	172.779	172.762	31.308	0.320
132.000	44.098	20.000	9.712	172.700	172.685	31.615	0.315
133.000	43.929	20.000	9.974	172.621	172.606	31.921	0.310
134.000	43.760	20.000	10.227	172.540	172.527	32.225	0.305
135.000	43.592	20.000	10.472	172.459	172.446	32.527	0.300
136.000	43.424	20.000	10.709	172.376	172.364	32.828	0.295
137.000	43.257	20.000	10.937	172.292	172.281	33.127	0.290
138.000	43.090	20.000	11.158	172.207	172.196	33.424	0.285
139.000	42.924	20.000	11.370	172.120	172.110	33.720	0.280
140.000	42.758	20.000	11.576	172.033	172.023	34.014	0.275
141.000	42.593	20.000	11.773	171.944	171.935	34.307	0.270
142.000	42.428	20.000	11.964	171.853	171.845	34.598	0.266
143.000	42.263	20.000	12.148	171.762	171.754	34.888	0.261
144.000	42.099	20.000	12.324	171.669	171.661	35.177	0.256

Table 12-6 CIDA #2 Collection Period Characteristics

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	+x-off ISP (deg)	fov exposure
769.000	57.051	15.411	29.552	130.290	177.372	0.000	0.766
770.000	56.958	15.874	28.940	127.721	177.362	0.000	0.766
771.000	56.863	16.333	28.336	124.943	177.352	0.000	0.766
772.000	56.767	16.787	27.739	121.942	177.341	0.000	0.766
773.000	56.669	17.237	27.152	118.710	177.330	0.000	0.766
774.000	56.569	17.683	26.573	115.243	177.319	0.000	0.766
775.000	56.468	18.124	26.004	111.542	177.307	0.000	0.766
776.000	56.366	18.562	25.444	107.619	177.295	0.000	0.766
777.000	56.263	18.995	24.895	103.491	177.283	0.000	0.766
778.000	56.158	19.424	24.356	99.191	177.271	0.000	0.766
779.000	56.052	19.848	23.827	94.758	177.259	0.000	0.766
780.000	55.945	20.000	23.079	89.760	177.246	0.269	0.763
781.000	55.837	20.000	22.220	94.305	177.233	0.686	0.758
782.000	55.728	20.000	21.379	98.822	177.220	1.099	0.754
783.000	55.618	20.000	20.559	103.256	177.207	1.508	0.749
784.000	55.507	20.000	19.759	107.557	177.193	1.913	0.744
785.000	55.395	20.000	18.981	111.685	177.180	2.314	0.739
786.000	55.282	20.000	18.223	115.610	177.166	2.712	0.735
787.000	55.169	20.000	17.487	119.314	177.152	3.105	0.730
788.000	55.055	20.000	16.773	122.786	177.138	3.496	0.725
789.000	54.940	20.000	16.081	126.024	177.123	3.882	0.721
790.000	54.825	20.000	15.412	129.032	177.108	4.265	0.716
791.000	54.709	20.000	14.767	131.820	177.093	4.645	0.711
792.000	54.593	20.000	14.146	134.399	177.078	5.021	0.707
793.000	54.476	20.000	13.549	136.782	177.063	5.393	0.702
794.000	54.359	20.000	12.977	138.984	177.048	5.762	0.698
795.000	54.241	20.000	12.430	141.019	177.032	6.128	0.693
796.000	54.123	20.000	11.910	142.900	177.016	6.491	0.688
797.000	54.005	20.000	11.418	144.640	177.000	6.850	0.684
798.000	53.886	20.000	10.953	146.253	176.984	7.206	0.679
799.000	53.767	20.000	10.517	147.748	176.968	7.559	0.675
800.000	53.647	20.000	10.111	149.137	176.951	7.909	0.670
801.000	53.528	20.000	9.735	150.429	176.934	8.256	0.666
802.000	53.408	20.000	9.390	151.633	176.918	8.600	0.661
803.000	53.288	20.000	9.077	152.755	176.901	8.940	0.657
804.000	53.168	20.000	8.796	153.804	176.883	9.278	0.652
805.000	53.048	20.000	8.548	154.786	176.866	9.613	0.648
806.000	52.927	20.000	8.332	155.705	176.848	9.945	0.644
807.000	52.807	20.000	8.149	156.569	176.831	10.274	0.639
808.000	52.686	20.000	7.997	157.380	176.813	10.601	0.635
809.000	52.566	20.000	7.876	158.143	176.794	10.925	0.630
810.000	52.445	20.000	7.786	158.863	176.776	11.246	0.626
811.000	52.324	20.000	7.724	159.542	176.758	11.564	0.622
812.000	52.203	20.000	7.689	160.184	176.739	11.880	0.617
813.000	52.083	20.000	7.678	160.791	176.720	12.193	0.613
814.000	51.962	20.000	7.691	161.366	176.701	12.504	0.609
815.000	51.842	20.000	7.725	161.911	176.682	12.812	0.604
816.000	51.721	20.000	7.777	162.429	176.663	13.118	0.600
817.000	51.600	20.000	7.846	162.921	176.644	13.421	0.596
818.000	51.480	20.000	7.929	163.389	176.624	13.722	0.592
819.000	51.360	20.000	8.025	163.835	176.604	14.020	0.588
820.000	51.240	20.000	8.131	164.260	176.584	14.316	0.583
821.000	51.120	20.000	8.247	164.666	176.564	14.610	0.579
822.000	51.000	20.000	8.370	165.054	176.544	14.901	0.575
823.000	50.880	20.000	8.499	165.425	176.523	15.191	0.571
824.000	50.760	20.000	8.633	165.779	176.503	15.478	0.567
825.000	50.641	20.000	8.770	166.119	176.482	15.763	0.563
826.000	50.521	20.000	8.909	166.444	176.461	16.045	0.559
827.000	50.402	20.000	9.050	166.756	176.440	16.326	0.554
828.000	50.283	20.000	9.191	167.056	176.419	16.605	0.550
829.000	50.165	20.000	9.333	167.343	176.397	16.881	0.546
830.000	50.046	20.000	9.473	167.620	176.376	17.156	0.542
831.000	49.928	20.000	9.613	167.885	176.354	17.428	0.538
832.000	49.810	20.000	9.750	168.141	176.332	17.698	0.534
833.000	49.692	20.000	9.885	168.387	176.310	17.967	0.530

834.000	49.574	20.000	10.017	168.623	176.287	18.234	0.526
835.000	49.457	20.000	10.146	168.852	176.265	18.498	0.523
836.000	49.340	20.000	10.272	169.071	176.242	18.761	0.519
837.000	49.223	20.000	10.394	169.284	176.219	19.022	0.515
838.000	49.106	20.000	10.513	169.488	176.196	19.282	0.511
839.000	48.990	20.000	10.627	169.686	176.173	19.539	0.507
840.000	48.874	20.000	10.737	169.876	176.150	19.795	0.503
841.000	48.758	20.000	10.843	170.060	176.126	20.049	0.499
842.000	48.642	20.000	10.945	170.238	176.103	20.301	0.495

Table 12-6 CIDA #2 Collection Period Characteristics (cont)

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	+x-off ISP (deg)	fov exposure
843.000	48.527	20.000	11.043	170.410	176.079	20.552	0.492
844.000	48.412	20.000	11.136	170.577	176.055	20.800	0.488
845.000	48.297	20.000	11.224	170.738	176.030	21.048	0.484
846.000	48.182	20.000	11.308	170.893	176.006	21.293	0.480
847.000	48.068	20.000	11.388	171.044	175.981	21.537	0.477
848.000	47.954	20.000	11.463	171.190	175.957	21.780	0.473
849.000	47.841	20.000	11.534	171.331	175.932	22.021	0.469
850.000	47.727	20.000	11.601	171.468	175.907	22.260	0.465
851.000	47.614	20.000	11.663	171.601	175.881	22.498	0.462
852.000	47.501	20.000	11.721	171.730	175.856	22.735	0.458
853.000	47.389	20.000	11.774	171.854	175.830	22.969	0.454
854.000	47.277	20.000	11.823	171.975	175.804	23.203	0.451
855.000	47.165	20.000	11.868	172.093	175.778	23.435	0.447
856.000	47.053	20.000	11.909	172.206	175.752	23.666	0.444
857.000	46.942	20.000	11.945	172.317	175.725	23.895	0.440
858.000	46.831	20.000	11.977	172.424	175.698	24.123	0.436
859.000	46.720	20.000	12.006	172.528	175.672	24.349	0.433
860.000	46.610	20.000	12.030	172.628	175.645	24.575	0.429
861.000	46.500	20.000	12.049	172.726	175.617	24.798	0.426
862.000	46.390	20.000	12.065	172.821	175.590	25.021	0.422
863.000	46.281	20.000	12.077	172.913	175.562	25.242	0.419
864.000	46.171	20.000	12.085	173.003	175.534	25.462	0.415
865.000	46.062	20.000	12.089	173.090	175.506	25.681	0.412
866.000	45.954	20.000	12.089	173.174	175.478	25.899	0.408
867.000	45.846	20.000	12.085	173.256	175.449	26.115	0.405
868.000	45.738	20.000	12.078	173.335	175.421	26.330	0.401
869.000	45.630	20.000	12.066	173.412	175.392	26.544	0.398
870.000	45.523	20.000	12.051	173.487	175.363	26.757	0.395
871.000	45.416	20.000	12.032	173.560	175.333	26.969	0.391
872.000	45.309	20.000	12.010	173.630	175.304	27.179	0.388
873.000	45.202	20.000	11.984	173.699	175.274	27.389	0.384
874.000	45.096	20.000	11.955	173.765	175.244	27.597	0.381
875.000	44.990	20.000	11.923	173.830	175.214	27.804	0.378
876.000	44.885	20.000	11.887	173.893	175.183	28.010	0.374
877.000	44.780	20.000	11.848	173.953	175.152	28.215	0.371
878.000	44.675	20.000	11.806	174.012	175.121	28.419	0.368
879.000	44.570	20.000	11.761	174.069	175.090	28.622	0.365
880.000	44.466	20.000	11.712	174.125	175.059	28.824	0.361
881.000	44.362	20.000	11.661	174.178	175.027	29.025	0.358
882.000	44.258	20.000	11.606	174.230	174.995	29.225	0.355
883.000	44.154	20.000	11.549	174.281	174.963	29.424	0.351
884.000	44.051	20.000	11.489	174.330	174.931	29.622	0.348
885.000	43.948	20.000	11.426	174.377	174.898	29.819	0.345
886.000	43.846	20.000	11.360	174.423	174.865	30.015	0.342
887.000	43.743	20.000	11.292	174.467	174.832	30.211	0.339
888.000	43.641	20.000	11.220	174.510	174.799	30.405	0.335
889.000	43.540	20.000	11.146	174.551	174.765	30.598	0.332
890.000	43.438	20.000	11.069	174.591	174.731	30.791	0.329
891.000	43.337	20.000	10.990	174.630	174.697	30.982	0.326
892.000	43.236	20.000	10.908	174.667	174.663	31.173	0.323
893.000	43.135	20.000	10.823	174.703	174.628	31.363	0.320
894.000	43.035	20.000	10.736	174.738	174.593	31.552	0.316
895.000	42.935	20.000	10.647	174.771	174.558	31.740	0.313
896.000	42.835	20.000	10.554	174.803	174.522	31.927	0.310
897.000	42.736	20.000	10.460	174.834	174.487	32.113	0.307
898.000	42.637	20.000	10.363	174.864	174.451	32.299	0.304
899.000	42.538	20.000	10.263	174.893	174.414	32.484	0.301
900.000	42.439	20.000	10.162	174.920	174.377	32.668	0.298
901.000	42.341	20.000	10.058	174.946	174.341	32.851	0.295
902.000	42.242	20.000	9.952	174.972	174.303	33.034	0.292
903.000	42.145	20.000	9.844	174.996	174.266	33.216	0.289
904.000	42.047	20.000	9.733	175.019	174.228	33.397	0.286
905.000	41.950	20.000	9.621	175.041	174.190	33.577	0.283
906.000	41.853	20.000	9.507	175.061	174.151	33.756	0.280
907.000	41.756	20.000	9.390	175.081	174.112	33.935	0.277

908.000	41.659	20.000	9.272	175.100	174.073	34.113	0.274
909.000	41.563	20.000	9.152	175.118	174.034	34.291	0.271
910.000	41.467	20.000	9.030	175.134	173.994	34.467	0.268
911.000	41.371	20.000	8.906	175.150	173.954	34.643	0.265
912.000	41.276	20.000	8.780	175.165	173.914	34.819	0.262
913.000	41.180	20.000	8.653	175.179	173.873	34.993	0.259
914.000	41.085	20.000	8.523	175.192	173.832	35.167	0.256

Table 12-7 CIDA #3 Collection Period Characteristics

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	+x-off ISP (deg)	fov exposure
1703.000	55.649	20.000	21.719	135.705	177.214	1.338	0.751
1704.000	55.538	20.000	21.839	137.565	177.201	1.746	0.746
1705.000	55.426	20.000	21.961	139.329	177.187	2.149	0.741
1706.000	55.313	20.000	22.086	141.000	177.173	2.549	0.737
1707.000	55.199	20.000	22.213	142.581	177.159	2.946	0.732
1708.000	55.085	20.000	22.342	144.077	177.145	3.338	0.727
1709.000	54.970	20.000	22.474	145.492	177.130	3.727	0.723
1710.000	54.854	20.000	22.608	146.830	177.116	4.113	0.718
1711.000	54.738	20.000	22.744	148.095	177.101	4.495	0.713
1712.000	54.621	20.000	22.882	149.292	177.086	4.873	0.709
1713.000	54.503	20.000	23.022	150.424	177.071	5.248	0.704
1714.000	54.386	20.000	23.164	151.495	177.055	5.620	0.699
1715.000	54.267	20.000	23.308	152.509	177.040	5.988	0.695
1716.000	54.148	20.000	23.454	153.469	177.024	6.353	0.690
1717.000	54.029	20.000	23.601	154.380	177.008	6.715	0.686
1718.000	53.910	20.000	23.751	155.243	176.992	7.073	0.681
1719.000	53.790	20.000	23.902	156.062	176.975	7.428	0.677
1720.000	53.670	20.000	24.055	156.839	176.959	7.781	0.672
1721.000	53.550	20.000	24.210	157.578	176.942	8.130	0.667
1722.000	53.429	20.000	24.366	158.280	176.925	8.476	0.663
1723.000	53.308	20.000	24.523	158.948	176.908	8.819	0.658
1724.000	53.187	20.000	24.682	159.583	176.891	9.159	0.654
1725.000	53.066	20.000	24.843	160.189	176.873	9.497	0.649
1726.000	52.945	20.000	25.004	160.766	176.856	9.831	0.645
1727.000	52.823	20.000	25.167	161.317	176.838	10.163	0.641
1728.000	52.702	20.000	25.332	161.843	176.820	10.491	0.636
1729.000	52.580	20.000	25.497	162.345	176.802	10.818	0.632
1730.000	52.459	20.000	25.664	162.825	176.783	11.141	0.627
1731.000	52.337	20.000	25.831	163.284	176.765	11.462	0.623
1732.000	52.215	20.000	26.000	163.723	176.746	11.780	0.619
1733.000	52.093	20.000	26.170	164.144	176.727	12.095	0.614
1734.000	51.972	20.000	26.341	164.548	176.708	12.408	0.610
1735.000	51.850	20.000	26.513	164.934	176.689	12.718	0.606
1736.000	51.729	20.000	26.686	165.306	176.670	13.026	0.601
1737.000	51.607	20.000	26.859	165.662	176.650	13.332	0.597
1738.000	51.486	20.000	27.034	166.005	176.631	13.635	0.593
1739.000	51.364	20.000	27.209	166.334	176.611	13.935	0.589
1740.000	51.243	20.000	27.386	166.650	176.591	14.234	0.584
1741.000	51.122	20.000	27.563	166.955	176.571	14.530	0.580
1742.000	51.001	20.000	27.741	167.248	176.550	14.823	0.576
1743.000	50.880	20.000	27.919	167.531	176.530	15.115	0.572
1744.000	50.759	20.000	28.098	167.803	176.509	15.404	0.568
1745.000	50.638	20.000	28.278	168.065	176.488	15.691	0.564
1746.000	50.518	20.000	28.459	168.318	176.467	15.976	0.560
1747.000	50.397	20.000	28.640	168.562	176.446	16.259	0.555

Table 12-8 CIDA #1 Spacecraft Attitude [EME'2000]

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
45.000	-19.837	262.129	-70.047	88.561	-2.061	352.873
46.000	-19.852	262.566	-70.053	88.378	-1.862	353.239
47.000	-19.865	263.000	-70.059	88.194	-1.664	353.601
48.000	-19.877	263.430	-70.064	88.011	-1.468	353.960
49.000	-19.887	263.856	-70.068	87.827	-1.272	354.316
50.000	-19.896	264.279	-70.072	87.643	-1.078	354.669
51.000	-19.903	264.698	-70.075	87.459	-0.884	355.018
52.000	-19.909	265.113	-70.078	87.274	-0.692	355.364
53.000	-19.913	265.525	-70.080	87.090	-0.501	355.706
54.000	-19.917	266.139	-70.081	86.905	-0.245	356.228
55.000	-19.918	267.108	-70.082	86.720	0.124	357.063
56.000	-19.911	268.068	-70.082	86.534	0.491	357.890
57.000	-19.899	269.020	-70.081	86.349	0.855	358.710
58.000	-19.879	269.964	-70.080	86.163	1.217	359.524
59.000	-19.854	270.899	-70.079	85.977	1.576	0.330
60.000	-19.822	271.827	-70.076	85.791	1.932	1.130
61.000	-19.784	272.746	-70.073	85.604	2.285	1.923
62.000	-19.740	273.656	-70.070	85.418	2.635	2.710
63.000	-19.691	274.558	-70.066	85.230	2.982	3.490
64.000	-19.636	275.452	-70.061	85.043	3.327	4.263
65.000	-19.576	276.337	-70.056	84.856	3.668	5.031
66.000	-19.510	277.214	-70.050	84.668	4.006	5.792
67.000	-19.439	278.082	-70.043	84.480	4.341	6.547
68.000	-19.364	278.942	-70.036	84.291	4.673	7.295
69.000	-19.283	279.793	-70.029	84.103	5.002	8.038
70.000	-19.198	280.636	-70.020	83.914	5.327	8.775
71.000	-19.108	281.470	-70.011	83.725	5.650	9.506
72.000	-19.014	282.296	-70.002	83.535	5.969	10.231
73.000	-18.915	283.114	-69.992	83.345	6.285	10.951
74.000	-18.812	283.923	-69.981	83.155	6.598	11.665
75.000	-18.705	284.724	-69.970	82.965	6.908	12.373
76.000	-18.595	285.517	-69.958	82.774	7.214	13.076
77.000	-18.480	286.302	-69.946	82.583	7.517	13.774
78.000	-18.362	287.078	-69.933	82.391	7.817	14.466
79.000	-18.240	287.847	-69.919	82.200	8.114	15.154
80.000	-18.115	288.607	-69.905	82.007	8.408	15.835
81.000	-17.986	289.359	-69.890	81.815	8.698	16.512
82.000	-17.854	290.104	-69.874	81.622	8.985	17.184
83.000	-17.719	290.840	-69.858	81.429	9.269	17.851
84.000	-17.581	291.569	-69.841	81.235	9.550	18.513
85.000	-17.440	292.290	-69.824	81.042	9.828	19.170
86.000	-17.296	293.003	-69.806	80.847	10.103	19.823
87.000	-17.149	293.709	-69.787	80.653	10.375	20.470
88.000	-17.000	294.407	-69.768	80.457	10.643	21.114
89.000	-16.848	295.098	-69.748	80.262	10.909	21.752
90.000	-16.694	295.782	-69.728	80.066	11.171	22.386
91.000	-16.537	296.458	-69.706	79.870	11.431	23.016
92.000	-16.378	297.127	-69.684	79.673	11.687	23.641
93.000	-16.216	297.789	-69.662	79.476	11.941	24.262
94.000	-16.053	298.443	-69.639	79.278	12.191	24.879
95.000	-15.887	299.091	-69.615	79.080	12.439	25.492
96.000	-15.719	299.732	-69.590	78.881	12.684	26.100
97.000	-15.550	300.366	-69.565	78.682	12.926	26.704
98.000	-15.378	300.993	-69.539	78.483	13.165	27.305
99.000	-15.205	301.614	-69.513	78.283	13.401	27.901
100.000	-15.029	302.228	-69.485	78.082	13.635	28.494
101.000	-14.852	302.835	-69.457	77.881	13.866	29.082
102.000	-14.674	303.437	-69.428	77.680	14.094	29.667
103.000	-14.493	304.031	-69.399	77.478	14.319	30.248
104.000	-14.312	304.620	-69.369	77.275	14.542	30.825
105.000	-14.128	305.202	-69.338	77.072	14.762	31.399
106.000	-13.943	305.778	-69.306	76.869	14.980	31.969
107.000	-13.757	306.348	-69.274	76.665	15.195	32.536
108.000	-13.569	306.912	-69.240	76.460	15.408	33.099
109.000	-13.380	307.471	-69.206	76.255	15.618	33.658
110.000	-13.189	308.023	-69.172	76.049	15.825	34.214
111.000	-12.998	308.570	-69.136	75.843	16.030	34.767
112.000	-12.805	309.110	-69.100	75.636	16.233	35.316
113.000	-12.611	309.646	-69.062	75.428	16.434	35.862
114.000	-12.415	310.176	-69.024	75.220	16.632	36.405
115.000	-12.219	310.700	-68.985	75.011	16.828	36.945
116.000	-12.021	311.219	-68.946	74.802	17.021	37.481
117.000	-11.822	311.732	-68.905	74.592	17.213	38.014
118.000	-11.622	312.241	-68.863	74.381	17.402	38.545
119.000	-11.421	312.744	-68.821	74.170	17.589	39.072

Table 12-8 CIDA #1 Spacecraft Attitude [EME'2000] (cont)

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
120.000	-11.219	313.242	-68.778	73.958	17.774	39.596
121.000	-11.016	313.734	-68.733	73.745	17.956	40.117
122.000	-10.812	314.222	-68.688	73.532	18.137	40.636
123.000	-10.607	314.705	-68.642	73.318	18.316	41.151
124.000	-10.401	315.183	-68.595	73.103	18.492	41.664
125.000	-10.194	315.656	-68.547	72.888	18.667	42.174
126.000	-9.986	316.125	-68.498	72.672	18.840	42.681
127.000	-9.777	316.588	-68.448	72.455	19.011	43.185
128.000	-9.567	317.047	-68.397	72.238	19.180	43.686
129.000	-9.356	317.502	-68.344	72.020	19.347	44.185
130.000	-9.145	317.952	-68.291	71.801	19.512	44.682
131.000	-8.932	318.397	-68.237	71.581	19.676	45.175
132.000	-8.719	318.838	-68.181	71.360	19.838	45.666
133.000	-8.504	319.274	-68.125	71.139	19.998	46.155
134.000	-8.289	319.706	-68.067	70.917	20.156	46.641
135.000	-8.073	320.134	-68.008	70.694	20.313	47.125
136.000	-7.856	320.558	-67.948	70.471	20.468	47.606
137.000	-7.637	320.977	-67.887	70.247	20.622	48.085
138.000	-7.418	321.392	-67.824	70.021	20.774	48.561
139.000	-7.199	321.803	-67.760	69.795	20.925	49.035
140.000	-6.978	322.210	-67.695	69.568	21.074	49.507
141.000	-6.756	322.613	-67.629	69.341	21.221	49.976
142.000	-6.533	323.012	-67.561	69.112	21.367	50.444
143.000	-6.310	323.407	-67.492	68.883	21.512	50.909
144.000	-6.085	323.798	-67.421	68.653	21.656	51.372

Table 12-9 CIDA #2 Spacecraft Attitude [EME'2000]

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
769.000	-17.521	252.716	-70.458	99.910	-8.382	345.382
770.000	-17.572	253.063	-70.475	99.807	-8.244	345.692
771.000	-17.621	253.406	-70.491	99.704	-8.107	345.999
772.000	-17.669	253.745	-70.507	99.601	-7.971	346.302
773.000	-17.716	254.082	-70.522	99.498	-7.835	346.601
774.000	-17.762	254.414	-70.537	99.396	-7.701	346.897
775.000	-17.806	254.744	-70.552	99.293	-7.568	347.189
776.000	-17.849	255.070	-70.567	99.190	-7.436	347.478
777.000	-17.890	255.393	-70.581	99.087	-7.305	347.764
778.000	-17.931	255.712	-70.595	98.983	-7.174	348.046
779.000	-17.971	256.028	-70.609	98.880	-7.045	348.325
780.000	-18.043	256.622	-70.623	98.777	-6.833	348.859
781.000	-18.130	257.367	-70.636	98.674	-6.575	349.530
782.000	-18.213	258.105	-70.649	98.570	-6.318	350.193
783.000	-18.292	258.837	-70.661	98.467	-6.063	350.849
784.000	-18.366	259.562	-70.674	98.363	-5.810	351.498
785.000	-18.436	260.281	-70.686	98.260	-5.558	352.140
786.000	-18.502	260.993	-70.698	98.156	-5.308	352.774
787.000	-18.565	261.698	-70.709	98.052	-5.059	353.402
788.000	-18.623	262.398	-70.721	97.949	-4.812	354.023
789.000	-18.677	263.091	-70.732	97.845	-4.566	354.638
790.000	-18.728	263.777	-70.743	97.741	-4.323	355.246
791.000	-18.775	264.457	-70.754	97.637	-4.080	355.847
792.000	-18.819	265.131	-70.764	97.533	-3.840	356.442
793.000	-18.859	265.799	-70.774	97.428	-3.601	357.031
794.000	-18.896	266.461	-70.784	97.324	-3.364	357.614
795.000	-18.930	267.117	-70.794	97.220	-3.129	358.191
796.000	-18.960	267.766	-70.804	97.115	-2.896	358.762
797.000	-18.987	268.410	-70.813	97.010	-2.664	359.327
798.000	-19.011	269.048	-70.822	96.906	-2.434	359.887
799.000	-19.032	269.679	-70.831	96.801	-2.205	0.441
800.000	-19.050	270.306	-70.839	96.696	-1.979	0.989
801.000	-19.065	270.926	-70.848	96.591	-1.754	1.532
802.000	-19.078	271.540	-70.856	96.486	-1.531	2.070
803.000	-19.087	272.149	-70.864	96.380	-1.310	2.603
804.000	-19.094	272.753	-70.872	96.275	-1.090	3.130
805.000	-19.099	273.350	-70.880	96.169	-0.872	3.652
806.000	-19.101	273.943	-70.887	96.064	-0.656	4.170
807.000	-19.100	274.529	-70.894	95.958	-0.442	4.682
808.000	-19.097	275.111	-70.901	95.852	-0.229	5.190
809.000	-19.092	275.687	-70.908	95.746	-0.018	5.693
810.000	-19.084	276.258	-70.915	95.639	0.191	6.192
811.000	-19.074	276.824	-70.921	95.533	0.399	6.686
812.000	-19.062	277.384	-70.928	95.426	0.605	7.175
813.000	-19.048	277.940	-70.934	95.320	0.809	7.660
814.000	-19.032	278.490	-70.939	95.213	1.011	8.141
815.000	-19.013	279.035	-70.945	95.106	1.212	8.618
816.000	-18.993	279.576	-70.951	94.999	1.411	9.090
817.000	-18.971	280.111	-70.956	94.891	1.609	9.558
818.000	-18.947	280.642	-70.961	94.784	1.805	10.022
819.000	-18.921	281.168	-70.966	94.676	1.999	10.483
820.000	-18.893	281.690	-70.971	94.568	2.192	10.939
821.000	-18.863	282.206	-70.975	94.460	2.383	11.392
822.000	-18.832	282.718	-70.980	94.351	2.572	11.840
823.000	-18.799	283.226	-70.984	94.243	2.760	12.285
824.000	-18.765	283.729	-70.988	94.134	2.947	12.726
825.000	-18.728	284.227	-70.992	94.025	3.132	13.164
826.000	-18.691	284.721	-70.996	93.916	3.315	13.598
827.000	-18.652	285.211	-70.999	93.807	3.497	14.029
828.000	-18.611	285.696	-71.003	93.697	3.677	14.456
829.000	-18.569	286.178	-71.006	93.587	3.856	14.880
830.000	-18.526	286.655	-71.009	93.477	4.034	15.301
831.000	-18.481	287.128	-71.012	93.367	4.209	15.718
832.000	-18.435	287.596	-71.014	93.257	4.384	16.132
833.000	-18.387	288.061	-71.017	93.146	4.557	16.543
834.000	-18.339	288.522	-71.019	93.035	4.729	16.951
835.000	-18.289	288.979	-71.021	92.924	4.899	17.355
836.000	-18.237	289.431	-71.023	92.813	5.068	17.757
837.000	-18.185	289.880	-71.025	92.701	5.235	18.156
838.000	-18.132	290.326	-71.027	92.589	5.401	18.551
839.000	-18.077	290.767	-71.028	92.477	5.566	18.944
840.000	-18.021	291.205	-71.030	92.364	5.729	19.334
841.000	-17.965	291.639	-71.031	92.252	5.891	19.722
842.000	-17.907	292.069	-71.032	92.139	6.052	20.106
843.000	-17.848	292.496	-71.033	92.025	6.212	20.488

Table 12-9 CIDA #2 Spacecraft Attitude [EME'2000] (cont)

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
844.000	-17.788	292.919	-71.033	91.912	6.370	20.867
845.000	-17.727	293.339	-71.034	91.798	6.527	21.243
846.000	-17.666	293.756	-71.034	91.684	6.683	21.617
847.000	-17.603	294.168	-71.034	91.569	6.837	21.988
848.000	-17.539	294.578	-71.034	91.455	6.990	22.357
849.000	-17.475	294.984	-71.034	91.340	7.142	22.723
850.000	-17.410	295.387	-71.033	91.224	7.293	23.087
851.000	-17.343	295.787	-71.033	91.109	7.443	23.449
852.000	-17.276	296.183	-71.032	90.993	7.591	23.808
853.000	-17.209	296.576	-71.031	90.876	7.739	24.164
854.000	-17.140	296.967	-71.030	90.760	7.885	24.519
855.000	-17.071	297.354	-71.029	90.643	8.030	24.871
856.000	-17.001	297.737	-71.027	90.525	8.174	25.221
857.000	-16.930	298.118	-71.026	90.408	8.316	25.568
858.000	-16.858	298.496	-71.024	90.290	8.458	25.914
859.000	-16.786	298.871	-71.022	90.172	8.599	26.257
860.000	-16.713	299.243	-71.020	90.053	8.738	26.598
861.000	-16.639	299.613	-71.018	89.934	8.877	26.937
862.000	-16.565	299.979	-71.015	89.815	9.014	27.274
863.000	-16.490	300.342	-71.012	89.695	9.151	27.609
864.000	-16.414	300.703	-71.010	89.575	9.286	27.942
865.000	-16.338	301.061	-71.007	89.454	9.421	28.273
866.000	-16.261	301.416	-71.003	89.333	9.554	28.602
867.000	-16.184	301.769	-71.000	89.212	9.686	28.929
868.000	-16.106	302.119	-70.997	89.090	9.818	29.255
869.000	-16.027	302.466	-70.993	88.968	9.948	29.578
870.000	-15.948	302.811	-70.989	88.846	10.078	29.900
871.000	-15.868	303.153	-70.985	88.723	10.207	30.219
872.000	-15.788	303.492	-70.980	88.600	10.334	30.537
873.000	-15.707	303.830	-70.976	88.476	10.461	30.853
874.000	-15.625	304.164	-70.971	88.352	10.587	31.168
875.000	-15.543	304.496	-70.966	88.227	10.712	31.480
876.000	-15.461	304.826	-70.961	88.103	10.836	31.791
877.000	-15.378	305.153	-70.956	87.977	10.959	32.101
878.000	-15.295	305.478	-70.951	87.851	11.081	32.408
879.000	-15.211	305.801	-70.945	87.725	11.203	32.714
880.000	-15.126	306.121	-70.939	87.598	11.324	33.018
881.000	-15.042	306.439	-70.933	87.471	11.443	33.321
882.000	-14.956	306.755	-70.927	87.344	11.562	33.622
883.000	-14.870	307.069	-70.921	87.215	11.681	33.922
884.000	-14.784	307.380	-70.914	87.087	11.798	34.220
885.000	-14.697	307.689	-70.907	86.958	11.915	34.517
886.000	-14.610	307.996	-70.900	86.828	12.030	34.812
887.000	-14.523	308.301	-70.893	86.698	12.146	35.105
888.000	-14.435	308.604	-70.885	86.568	12.260	35.398
889.000	-14.346	308.905	-70.878	86.437	12.373	35.688
890.000	-14.257	309.203	-70.870	86.305	12.486	35.978
891.000	-14.168	309.500	-70.862	86.173	12.598	36.266
892.000	-14.078	309.794	-70.853	86.041	12.710	36.552
893.000	-13.988	310.087	-70.845	85.908	12.820	36.837
894.000	-13.898	310.378	-70.836	85.774	12.930	37.121
895.000	-13.807	310.666	-70.827	85.640	13.039	37.403
896.000	-13.716	310.953	-70.818	85.505	13.148	37.685
897.000	-13.624	311.238	-70.808	85.370	13.256	37.964
898.000	-13.532	311.520	-70.799	85.235	13.363	38.243
899.000	-13.440	311.801	-70.789	85.098	13.469	38.520
900.000	-13.347	312.081	-70.779	84.962	13.575	38.796
901.000	-13.253	312.358	-70.768	84.824	13.681	39.071
902.000	-13.160	312.633	-70.758	84.686	13.785	39.345
903.000	-13.066	312.907	-70.747	84.548	13.889	39.617
904.000	-12.972	313.179	-70.736	84.409	13.993	39.888
905.000	-12.877	313.449	-70.724	84.269	14.095	40.158
906.000	-12.782	313.717	-70.713	84.129	14.197	40.427
907.000	-12.686	313.984	-70.701	83.988	14.299	40.695
908.000	-12.590	314.249	-70.689	83.846	14.400	40.961
909.000	-12.494	314.512	-70.676	83.704	14.500	41.227
910.000	-12.398	314.774	-70.664	83.561	14.600	41.491
911.000	-12.301	315.033	-70.651	83.418	14.700	41.754
912.000	-12.203	315.292	-70.638	83.274	14.798	42.016
913.000	-12.106	315.548	-70.624	83.130	14.896	42.277
914.000	-12.008	315.803	-70.610	82.984	14.994	42.537

Table 12-10 CIDA #3 Spacecraft Attitude [EME'2000]

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
1703.000	-18.287	258.778	-70.652	98.539	-6.105	350.804
1704.000	-18.362	259.509	-70.664	98.435	-5.850	351.458
1705.000	-18.434	260.233	-70.676	98.331	-5.596	352.105
1706.000	-18.501	260.951	-70.688	98.227	-5.344	352.745
1707.000	-18.564	261.662	-70.700	98.123	-5.094	353.377
1708.000	-18.623	262.367	-70.711	98.019	-4.845	354.004
1709.000	-18.679	263.065	-70.723	97.914	-4.597	354.623
1710.000	-18.731	263.758	-70.734	97.810	-4.351	355.236
1711.000	-18.779	264.443	-70.744	97.705	-4.107	355.843
1712.000	-18.823	265.123	-70.755	97.601	-3.865	356.443
1713.000	-18.864	265.796	-70.765	97.496	-3.624	357.037
1714.000	-18.901	266.464	-70.775	97.391	-3.386	357.624
1715.000	-18.936	267.125	-70.785	97.286	-3.148	358.206
1716.000	-18.966	267.780	-70.794	97.181	-2.913	358.782
1717.000	-18.994	268.429	-70.804	97.076	-2.679	359.352
1718.000	-19.019	269.072	-70.813	96.971	-2.447	359.917
1719.000	-19.040	269.710	-70.821	96.866	-2.217	0.475
1720.000	-19.058	270.341	-70.830	96.760	-1.989	1.028
1721.000	-19.074	270.967	-70.839	96.655	-1.762	1.576
1722.000	-19.087	271.587	-70.847	96.549	-1.537	2.119
1723.000	-19.097	272.201	-70.855	96.443	-1.314	2.656
1724.000	-19.104	272.810	-70.863	96.337	-1.092	3.188
1725.000	-19.108	273.413	-70.870	96.231	-0.872	3.715
1726.000	-19.110	274.010	-70.878	96.125	-0.654	4.237
1727.000	-19.110	274.603	-70.885	96.018	-0.438	4.754
1728.000	-19.107	275.189	-70.892	95.912	-0.223	5.267
1729.000	-19.101	275.771	-70.899	95.805	-0.011	5.774
1730.000	-19.094	276.347	-70.905	95.698	0.200	6.277
1731.000	-19.084	276.918	-70.912	95.591	0.410	6.776
1732.000	-19.071	277.483	-70.918	95.484	0.618	7.270
1733.000	-19.057	278.044	-70.924	95.377	0.824	7.759
1734.000	-19.040	278.599	-70.930	95.269	1.028	8.244
1735.000	-19.022	279.150	-70.935	95.161	1.231	8.725
1736.000	-19.001	279.695	-70.941	95.053	1.432	9.202
1737.000	-18.979	280.236	-70.946	94.945	1.631	9.674
1738.000	-18.954	280.771	-70.951	94.837	1.829	10.143
1739.000	-18.928	281.302	-70.956	94.729	2.025	10.607
1740.000	-18.900	281.828	-70.961	94.620	2.219	11.068
1741.000	-18.870	282.350	-70.965	94.511	2.412	11.525
1742.000	-18.838	282.867	-70.970	94.402	2.604	11.978
1743.000	-18.804	283.379	-70.974	94.293	2.793	12.427
1744.000	-18.769	283.886	-70.978	94.184	2.981	12.872
1745.000	-18.733	284.390	-70.981	94.074	3.168	13.314
1746.000	-18.694	284.888	-70.985	93.964	3.353	13.753
1747.000	-18.655	285.383	-70.989	93.854	3.537	14.187

Table 12-11 CIDA #3 Solar Conjunction Characteristics

TFL (days)	impact velocity (km/s)	+z-off sun (deg)	+z-off earth (deg)	+y-off SEP-N (deg)	+y-off orbit-N (deg)	+x-off ISP (deg)	fov exposure
1658.000	58.572	1.607	1.987	96.575	177.534	0.000	0.766
1659.000	58.582	0.991	1.538	99.409	177.535	0.000	0.766
1660.000	58.588	0.380	1.192	101.851	177.535	0.000	0.766
1661.000	58.588	0.226	1.052	103.930	177.535	0.000	0.766
1662.000	58.584	0.828	1.193	105.675	177.535	0.000	0.766
1663.000	58.575	1.424	1.540	107.115	177.534	0.000	0.766
1664.000	58.562	2.016	1.988	108.276	177.533	0.000	0.766
1665.000	58.544	2.602	2.481	109.180	177.531	0.000	0.766
1666.000	58.522	3.184	2.998	109.849	177.529	0.000	0.766
1667.000	58.496	3.761	3.528	110.299	177.526	0.000	0.766
1668.000	58.465	4.333	4.065	110.545	177.523	0.000	0.766
1669.000	58.431	4.900	4.607	110.600	177.520	0.000	0.766
1670.000	58.393	5.461	5.152	110.472	177.516	0.000	0.766
1671.000	58.351	6.018	5.700	110.170	177.512	0.000	0.766
1672.000	58.305	6.570	6.248	109.700	177.507	0.000	0.766
1673.000	58.256	7.117	6.798	109.067	177.502	0.000	0.766
1674.000	58.204	7.659	7.347	108.273	177.497	0.000	0.766
1675.000	58.148	8.196	7.897	107.322	177.491	0.000	0.766
1676.000	58.089	8.728	8.448	106.215	177.485	0.000	0.766
1677.000	58.027	9.255	8.998	104.954	177.479	0.000	0.766
1678.000	57.963	9.777	9.548	103.540	177.472	0.000	0.766
1679.000	57.895	10.294	10.097	101.975	177.465	0.000	0.766
1680.000	57.824	10.807	10.646	100.261	177.458	0.000	0.766
1681.000	57.751	11.315	11.195	98.401	177.450	0.000	0.766
1682.000	57.676	11.817	11.743	96.400	177.442	0.000	0.766
1683.000	57.597	12.316	12.290	85.736	177.434	0.000	0.766
1684.000	57.517	12.809	12.837	88.001	177.425	0.000	0.766
1685.000	57.434	13.298	13.384	90.383	177.417	0.000	0.766
1686.000	57.349	13.782	13.929	92.872	177.408	0.000	0.766
1687.000	57.262	14.261	14.474	95.454	177.398	0.000	0.766
1688.000	57.173	14.736	15.018	98.112	177.388	0.000	0.766
1689.000	57.082	15.206	15.561	100.830	177.379	0.000	0.766
1690.000	56.989	15.672	16.103	103.588	177.368	0.000	0.766
1691.000	56.895	16.133	16.644	106.367	177.358	0.000	0.766
1692.000	56.799	16.590	17.184	109.147	177.347	0.000	0.766
1693.000	56.701	17.043	17.724	111.911	177.336	0.000	0.766
1694.000	56.602	17.491	18.262	114.639	177.325	0.000	0.766
1695.000	56.501	17.935	18.799	117.316	177.314	0.000	0.766
1696.000	56.398	18.374	19.335	119.927	177.302	0.000	0.766
1697.000	56.295	18.810	19.870	122.463	177.290	0.000	0.766
1698.000	56.190	19.241	20.404	124.912	177.278	0.000	0.766
1699.000	56.084	19.669	20.936	127.269	177.266	0.000	0.766
1700.000	55.977	20.000	21.376	129.528	177.253	0.092	0.765
1701.000	55.869	20.000	21.488	131.688	177.240	0.511	0.760
1702.000	55.759	20.000	21.602	133.747	177.227	0.927	0.756

Table 12-12 CIDA #3 Solar Conjunction Spacecraft Attitude [EME'2000]

TFL (days)	i-LAT (deg)	i-LNG (deg)	j-LAT (deg)	j-LNG (deg)	k-LAT (deg)	k-LNG (deg)
1658.000	-15.118	240.189	-69.738	103.150	-13.170	333.814
1659.000	-15.224	240.646	-69.769	103.049	-13.004	334.250
1660.000	-15.329	241.100	-69.798	102.948	-12.838	334.682
1661.000	-15.431	241.551	-69.827	102.847	-12.673	335.110
1662.000	-15.531	241.999	-69.856	102.746	-12.508	335.534
1663.000	-15.629	242.444	-69.883	102.645	-12.345	335.954
1664.000	-15.725	242.886	-69.911	102.544	-12.181	336.370
1665.000	-15.820	243.324	-69.938	102.442	-12.019	336.782
1666.000	-15.912	243.759	-69.964	102.341	-11.858	337.190
1667.000	-16.002	244.190	-69.990	102.239	-11.697	337.594
1668.000	-16.090	244.619	-70.015	102.138	-11.537	337.994
1669.000	-16.176	245.043	-70.040	102.036	-11.377	338.390
1670.000	-16.261	245.465	-70.064	101.934	-11.219	338.781
1671.000	-16.343	245.882	-70.088	101.832	-11.062	339.169
1672.000	-16.424	246.297	-70.112	101.730	-10.905	339.552
1673.000	-16.502	246.707	-70.135	101.628	-10.749	339.931
1674.000	-16.579	247.114	-70.157	101.526	-10.594	340.307
1675.000	-16.654	247.518	-70.179	101.424	-10.440	340.678
1676.000	-16.727	247.918	-70.201	101.321	-10.287	341.045
1677.000	-16.799	248.314	-70.222	101.219	-10.135	341.408
1678.000	-16.869	248.707	-70.243	101.117	-9.984	341.767
1679.000	-16.937	249.096	-70.264	101.014	-9.834	342.122
1680.000	-17.003	249.482	-70.284	100.912	-9.685	342.473
1681.000	-17.068	249.864	-70.304	100.809	-9.537	342.820
1682.000	-17.131	250.242	-70.323	100.707	-9.390	343.164
1683.000	-17.193	250.617	-70.342	100.604	-9.243	343.503
1684.000	-17.253	250.988	-70.360	100.501	-9.098	343.838
1685.000	-17.311	251.355	-70.379	100.399	-8.954	344.170
1686.000	-17.368	251.719	-70.397	100.296	-8.811	344.498
1687.000	-17.423	252.080	-70.414	100.193	-8.668	344.822
1688.000	-17.477	252.436	-70.431	100.090	-8.527	345.142
1689.000	-17.530	252.790	-70.448	99.987	-8.387	345.459
1690.000	-17.581	253.140	-70.465	99.884	-8.247	345.772
1691.000	-17.631	253.486	-70.481	99.781	-8.109	346.081
1692.000	-17.679	253.829	-70.497	99.678	-7.972	346.387
1693.000	-17.727	254.168	-70.512	99.574	-7.836	346.689
1694.000	-17.773	254.504	-70.528	99.471	-7.700	346.988
1695.000	-17.817	254.837	-70.543	99.368	-7.566	347.284
1696.000	-17.861	255.166	-70.557	99.265	-7.433	347.575
1697.000	-17.903	255.492	-70.572	99.161	-7.300	347.864
1698.000	-17.944	255.815	-70.586	99.058	-7.169	348.149
1699.000	-17.984	256.134	-70.599	98.954	-7.038	348.431
1700.000	-18.034	256.546	-70.613	98.850	-6.880	348.797
1701.000	-18.123	257.297	-70.626	98.747	-6.621	349.474
1702.000	-18.207	258.041	-70.639	98.643	-6.362	350.142

13.0 Appendix E: PRD Traceability Matrix

STARDUST Mission Plan Traceability Matrix

References:

Project Requirements Document, SD-30000-200
Mission Plan, SD-75000-100 (JPL D-300-1-Revision A)

Project Requirements Document	Mission Plan
1.3.2.1 Launch Phase	3.0 Launch Phase (L+0 to L+30 days)
1.3.2.2 Cruise Phase	4.0 Cruise Phases
1.3.2.3 Encounter Phase	6.0 Wild-2 Encounter Phase
1.3.2.4 Recovery Phase	7.0 Earth Return Phase (ER-14 to ER+1 day)
1.4 Design Margins	2.2.2.1 General Configuration [2.2.2 STARDUST Spacecraft] - Partial
3.1.1.1.1 Encounter Velocity	6.1 Overview [6.0 Wild-2 Encounter Phase]
3.1.1.1.2 Encounter Location	6.1 Overview [6.0 Wild-2 Encounter Phase]
3.1.1.1.3 Encounter Comet Distance	2.4.2 Comet Wild-2 Orbit, Nucleus and Coma, Dust Environment
3.1.1.1.4 Encounter sun Distance	2.3.1 Description [2.3 Mission Summary]
3.1.1.1.5 Encounter Earth Distance	2.3.1 Description [2.3 Mission Summary]
3.1.1.3.2 Nav Camera Pointing	6.2.5 Nucleus Tracking
3.1.3.1 Launch Opportunity	2.3.2.1 Nominal Launch Period
3.1.3.2 Launch Vehicle	2.2.1 Launch Vehicle
3.1.3.3 Launch C3	2.3.2.1 Nominal Launch Period
3.1.4.1.1 Trajectory Deterministic	2.3.2.2 ΔV Budget
3.1.4.1.2 Trajectory Corrections	2.3.2.2 ΔV Budget
3.1.4.2.1 Maximum Earth Distance	2.3.1 Description [2.3 Mission Summary]
3.1.4.2.2 Maximum sun Distance	2.3.1 Description [2.3 Mission Summary]
3.1.5.2 Return Location	7.2.2 Entry, Descent and Recovery Subphases
3.1.5.3 Earth Entry	7.2.1.1 Earth Entry Control
3.3.1.2.1.1 Flyby Velocity	2.2.2.1 General Configuration [2.2.2 STARDUST Spacecraft] 2.4.2.3 Wild-2 Dust Environment
3.3.1.2.3.1 Flight System Launch Environments	2.2.1 Launch Vehicle
3.3.1.2.3.2 Flight System Launch Mass	2.2.2.1 General Configuration [2.2.2 STARDUST Spacecraft]
3.3.1.7.1 Flight System Mission Life	2.2.2.1 General Configuration [2.2.2 STARDUST Spacecraft]
4.3.1.3.1 Launch Opportunity Verification	2.3.2.1 Nominal Launch Period
4.3.1.3.3 Launch C3 Verification	2.3.2.1 Nominal Launch Period