PERFORMANCE ASSESSMENT OF PLANETARY MISSIONS AS LAUNCHED FROM AN ORBITING SPACE STATION

PRESENTED BY

ALAN FRIEDLANDER
SPACE SCIENCES DEPARTMENT
SCIENCE APPLICATIONS, INC.
SCHAUMBURG, ILLINOIS

TO

SPACE SCIENCE BOARD
NATIONAL RESEARCH COUNCIL

AT

SUMMER STUDY RETREAT
SNOWMASS, COLORADO

27 JULY 1982

N84-22594#

INTRODUCTION

WOULD DEVELOPMENT OF A LOW EARTH-ORBIT SPACE STATION ENABLE NEW PLANETARY EXPLORATION OPPORTUNITIES?............

........ALTERNATIVELY, WOULD THE EXISTENCE OF A LOW EARTH-ORBIT SPACE STATION AND ITS MANDATED USE ADVERSELY AFFECT PLANETARY EXPLORATION OPPORTUNITIES?

APPROACH AND SCOPE OF ANALYSIS

- DESCRIBE THE BASIC CHARACTERISTICS AND MANEUVER STRATEGIES FOR LAUNCHING PLANETARY MISSIONS FROM A SPACE STATION IN EARTH ORBIT.

- QUANTIFY THE "INHERENT" PROS AND CONS IN TERMS OF:

  INJECTED MASS CAPABILITY OF SELECTED UPPER STAGES
  PLANE CHANGE PENALTIES
  LAUNCH TIMING PENALTIES

- COMPARE STATION-LAUNCHED AND STANDARD SHUTTLE-LAUNCHED PERFORMANCE FOR A WIDE RANGE OF PLANETARY MISSION OPPORTUNITIES OVER LAUNCH ENERGY AND INJECTED MASS SPACE.
  - MARS GEOCHEMICAL ORBITER (LOW ENERGY, MODERATE MASS)
  - MARS SAMPLE RETURN (LOW ENERGY, LARGE MASS)
  - MULTIPLE ASTEROID RENDEZVOUS (LOW ENERGY, LARGE MASS)
  - ANTEROS RENDEZVOUS (MODERATE ENERGY, MODERATE MASS)
  - MERCURY ORBITER (MODERATE ENERGY, LARGE MASS)
  - TITAN PROBE (HIGH ENERGY, SMALL MASS)
  - URANUS/NEPTUNE PROBES (HIGH ENERGY, MODERATE MASS)
  - SATURN ORBITER/PROBE (HIGH ENERGY, MODERATE MASS)
  - GANYMEDE ORBITER (HIGH ENERGY, MODERATE MASS)
  - COMET RENDEZVOUS (HIGH ENERGY, MODERATE MASS)

GROUND RULES AND ASSUMPTIONS

	RATIONALE
• STATION ORBIT PARAMETERS	
ALTITUDE 200 NM, CIRCULAR INCLINATION 28.3° NODAL POSITION ANY AND ALL	MOST PROBABLE PLACEMENT WITH MAXIMUM UTILIZATION OF SHUTTLE CARGO CAPACITY; YIELDS CONSERVATIVE PLANETARY PERFORMANCE CONCLUSIONS
• UPPER STAGE SELECTION	
IUS(II) WIDE BODY CENTAUR OTV (MSFC 18' OTV) STAR 48 AS NEEDED	SET HAS WELL-DEFINED PERFORMANCE PARAMETERS OVER A RANGE OF CAPABILITY; OTV ADDS OPPORTUNITY FOR EXTENDED DEPARTURE MANEUVERS AND REUSABILITY
• SPACECRAFT PROPULSION	
EARTH-STORABLES SOLIDS	UTILIZES PRESENT PROPULSION TECHNOLOGY YIELDING CONSERVATIVE PERFORMANCE RESULTS
• STATION DEPARTURE	
ON TIME (0^{d} WINDOW)	COMPARABLE TO SHUTTLE UPPER-STAGE CRITERIA; PERFORMANCE CONSEQUENCE OF DEPARTURE DELAYS IS EXAMINED

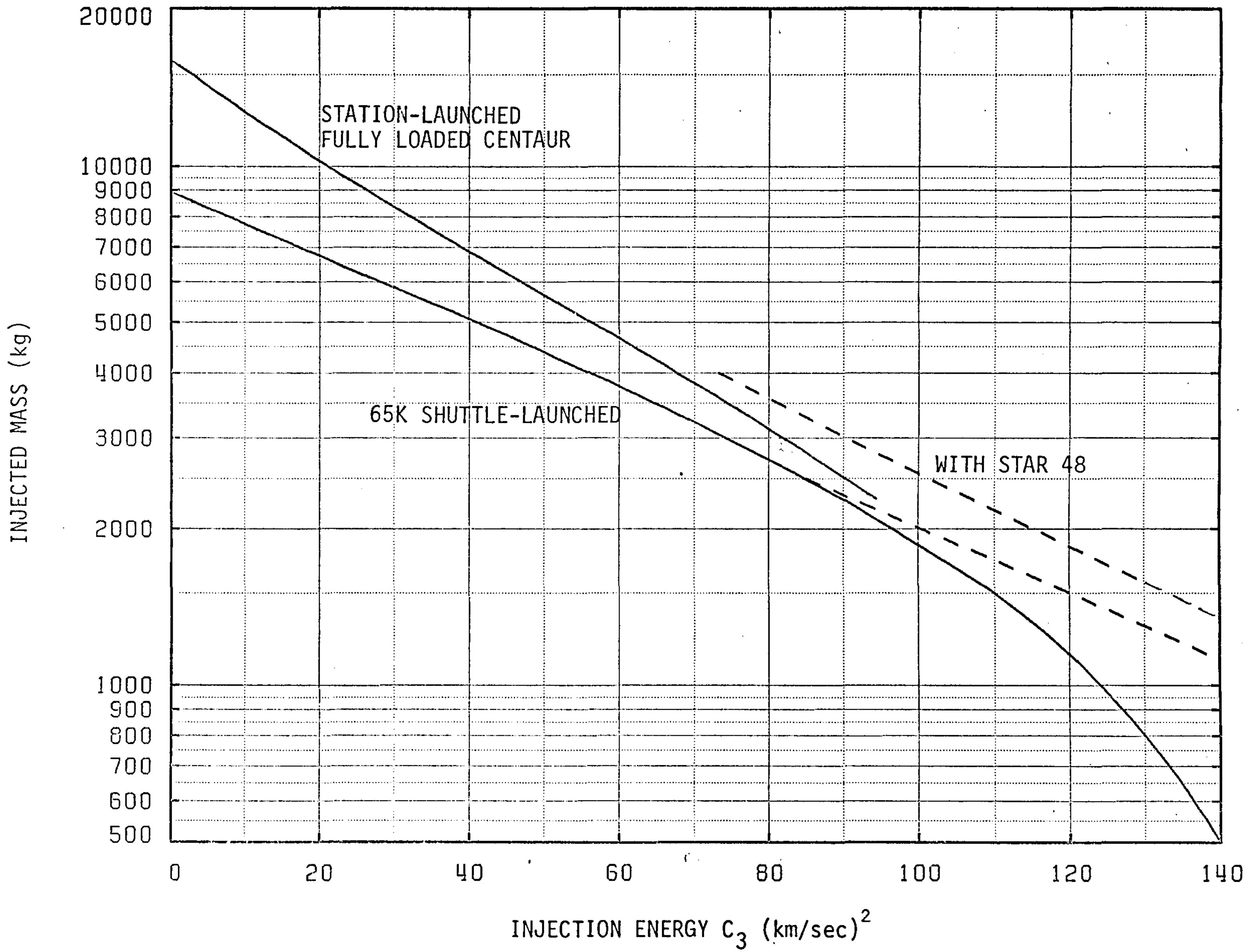
SPACE STATION PROS & CONS - QUALITATIVE ASSESSMENT

PROS

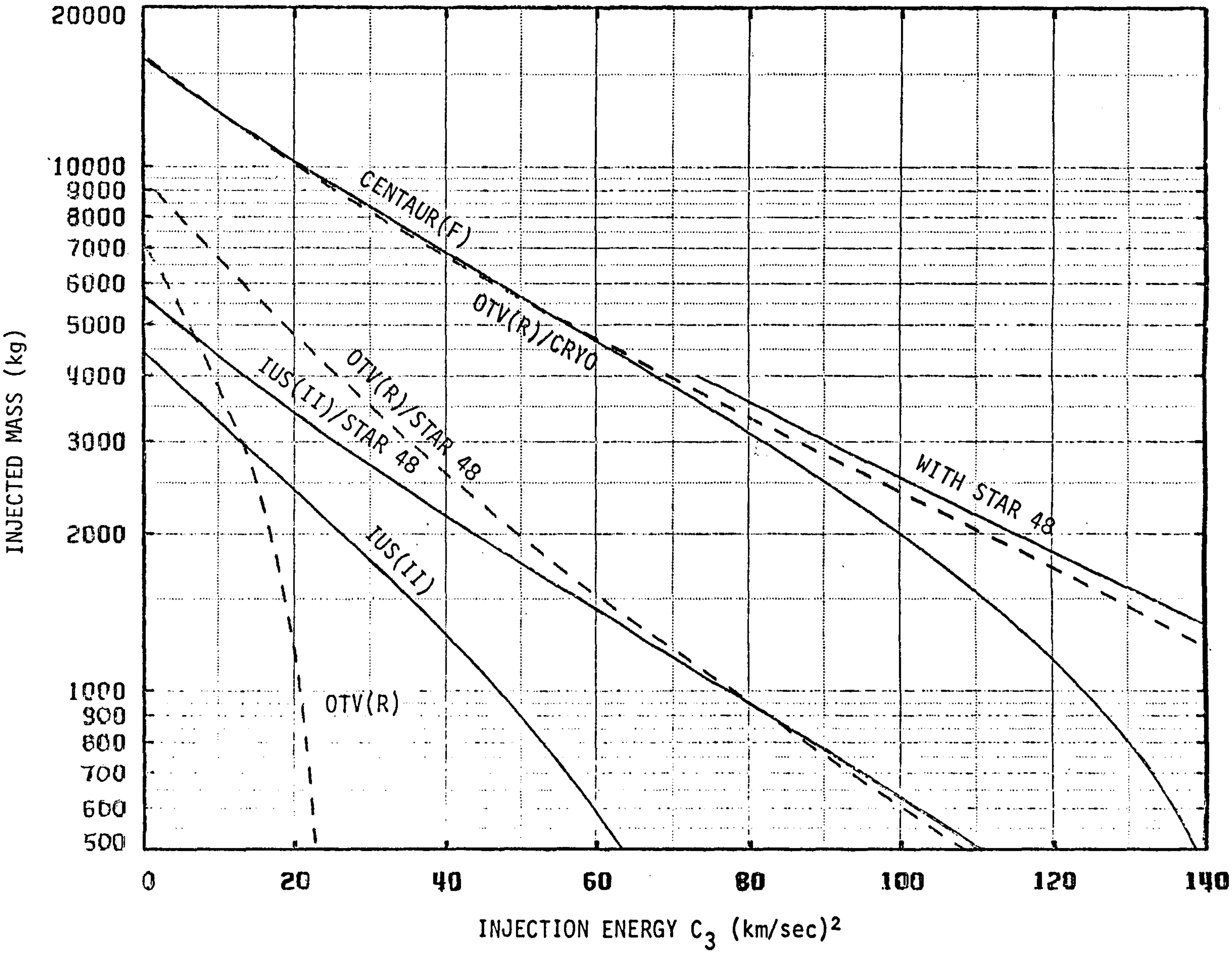
- MAXIMIZES SHUTTLE UTILIZATION
- ALLEVIATES SHUTTLE MANIFESTING THROUGH EARLY AND/OR FRACTIONAL LAUNCHES OF PAYLOAD
- ALLOWS FINAL CHECK-OUT AND ASSEMBLY IN SPACE ENVIRONMENT AFTER LAUNCH
- ASSURES FULLY LOADED STAGES
- POTENTIAL FOR "BEST-TIME" PLANETARY LAUNCHES (NO LAUNCH WINDOWS REQUIRED)
- ENHANCES REUSABLE STAGE OPTION

CONS

- HIGH PROBABILITY OF MISSING OPTIMUM LAUNCH DATE DUE TO NODAL MISALIGNMENT
- HIGHER SENSITIVITY TO DLA-INCURRED PERFORMANCE PENALTIES
- MAXIMIZED PERFORMANCE IMPLIES MORE SHUTTLE LAUNCHES
- ADDED COST FOR ON-ORBIT PAYLOAD STORAGE, CHECK-OUT AND ASSEMBLY



WIDE BODY CENTAUR LAUNCH PERFORMANCE



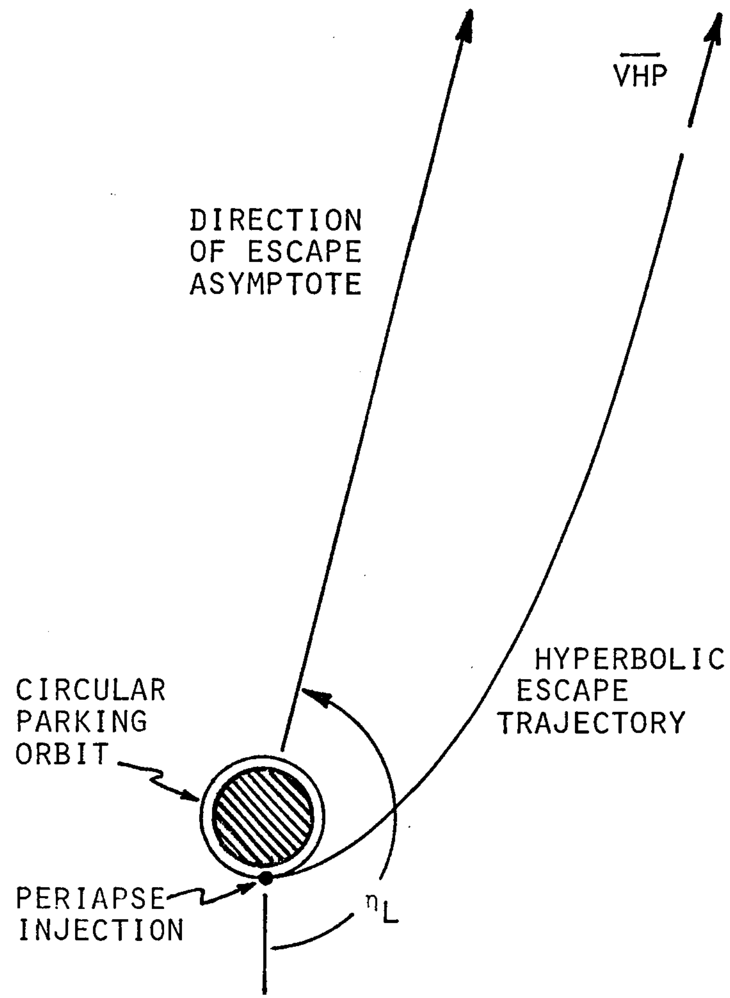
SPACE STATION-LAUNCHED UPPER STAGE PERFORMANCE

DESCRIPTION

CHARACTERISTICS OF PLANETARY ESCAPE

$E = \frac{mv^2}{2}$

$\frac{2E}{m} = v^2$



$$C_3 = |\overline{VHP}|^2$$

$$\eta_L = \cos^{-1}\left[\frac{-\mu}{\mu + R_p C_3}\right]$$

WHERE: μ = EARTH'S GRAVITATIONAL PARAMETER

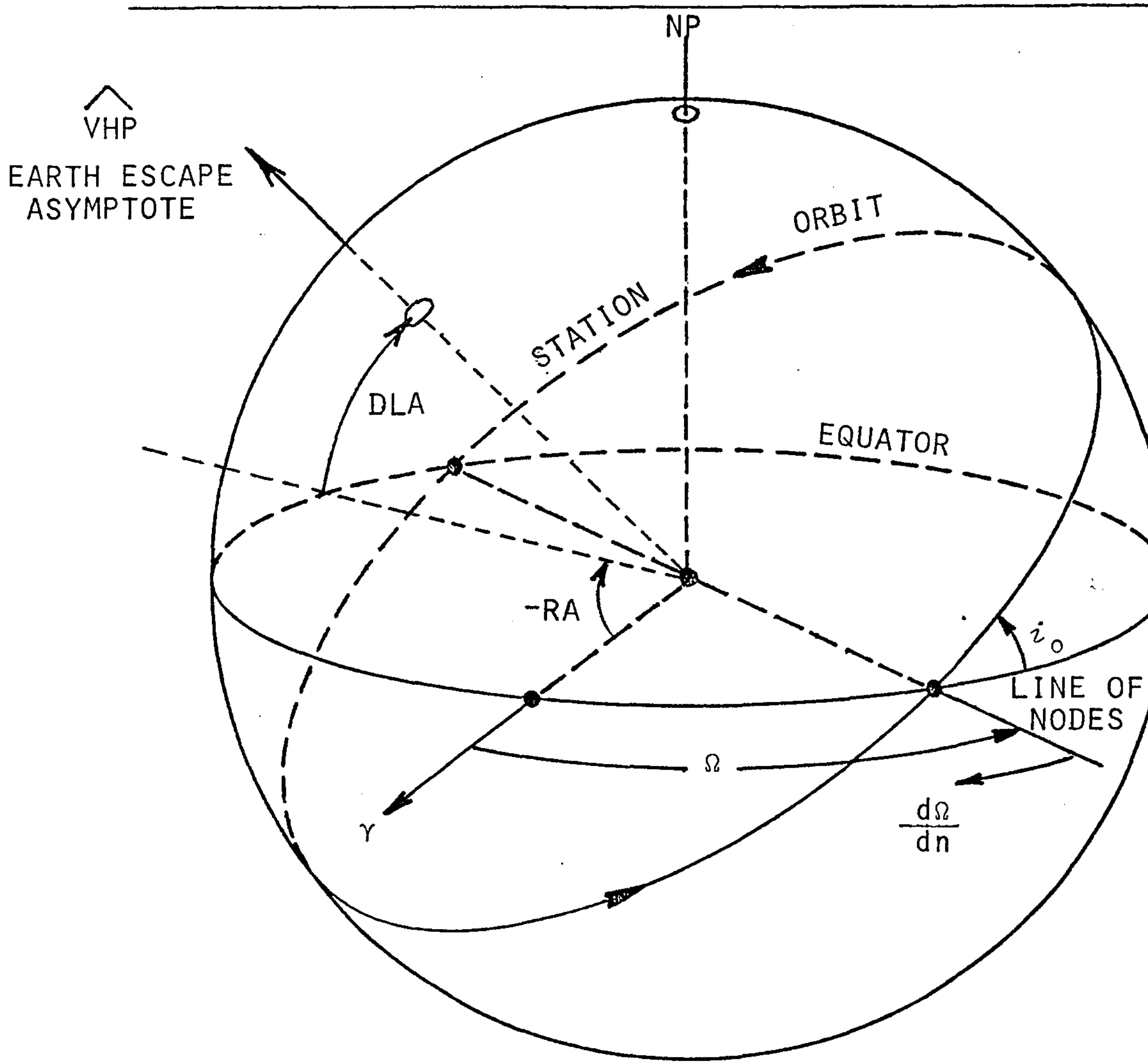
R_p = PERIAPSE RADIUS

C_3 = VIS VIVA INJECTION ENERGY

$\eta_L = 180^\circ$ WHEN $C_3 = 0$ (PARABOLIC ESCAPE)

$\eta_L = 90^\circ$ WHEN $C_3 = \infty$

SPACE STATION ORBITAL GEOMETRY



ORBIT PARAMETERS:

ALTITUDE, h = 200nm (CIRCULAR)

INCLINATION, i_o = 28.3°

ASCENDING NODE, Ω = VARIABLE

NODAL REGRESSION, $\frac{d\Omega}{dt}$ = 0.46°/REV

= 7.2°/DAY

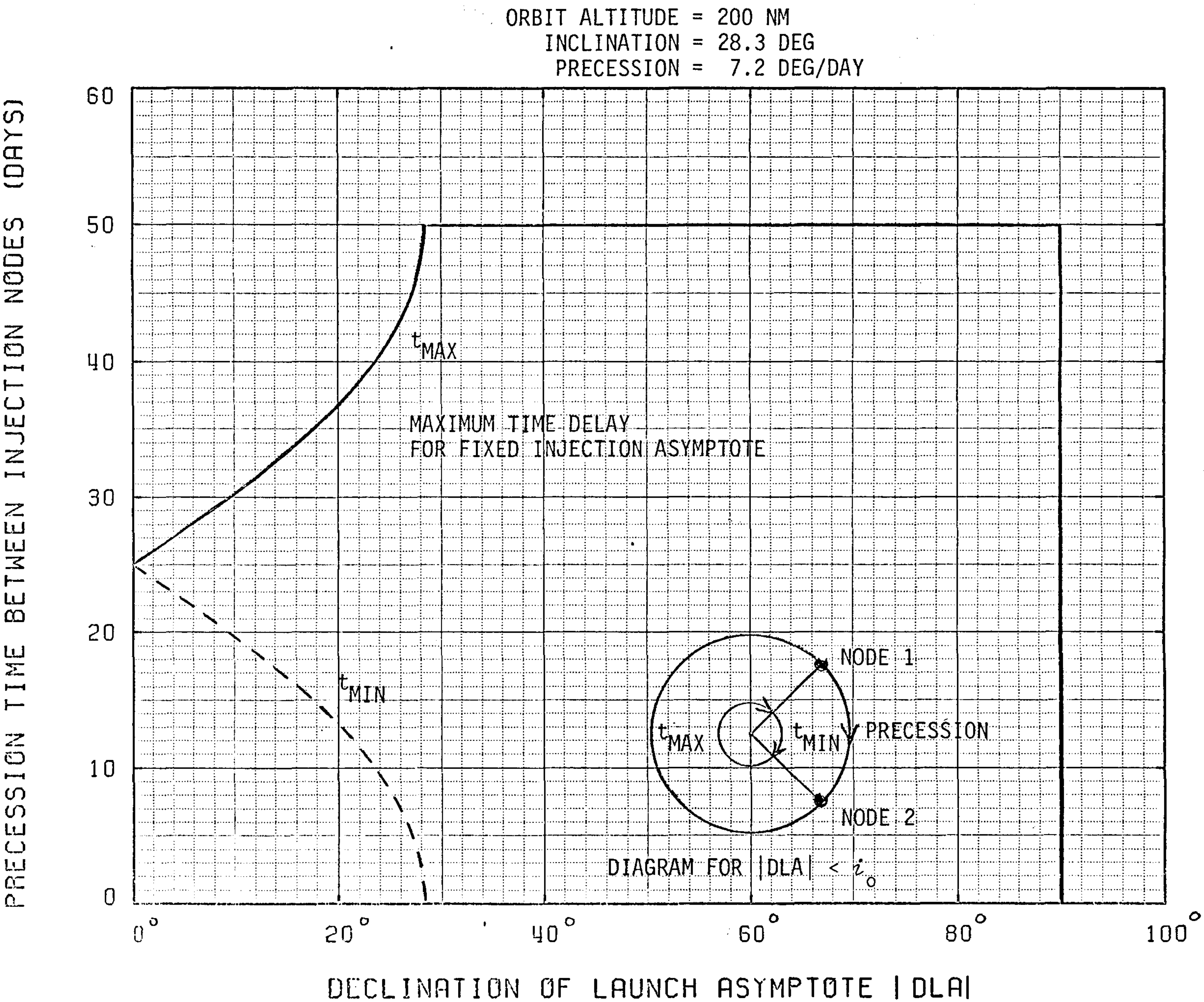
- WHEN A PLANETARY MISSION OPPORTUNITY OCCURS, THE DIRECTION OF EARTH ESCAPE ($\widehat{VHP}$) IS RELATIVELY CONSTANT ACROSS THE LAUNCH WINDOW, WHICH TYPICALLY LAST 20 - 40 DAYS DEPENDING ON THE TARGET.

- CONVERSELY, THE STATION ORBIT PLANE IS CONSTANTLY PRECESSING DUE TO THE OBLATENESS OF THE EARTH; FOR THE ASSUMED ORBIT (200 NM CIRCULAR AT 28.3° INCLINATION) THE NODAL PRECESSION IS 7.2°/DAY IN THE OPPOSITE DIRECTION TO THE STATION'S ORBITAL MOTION.

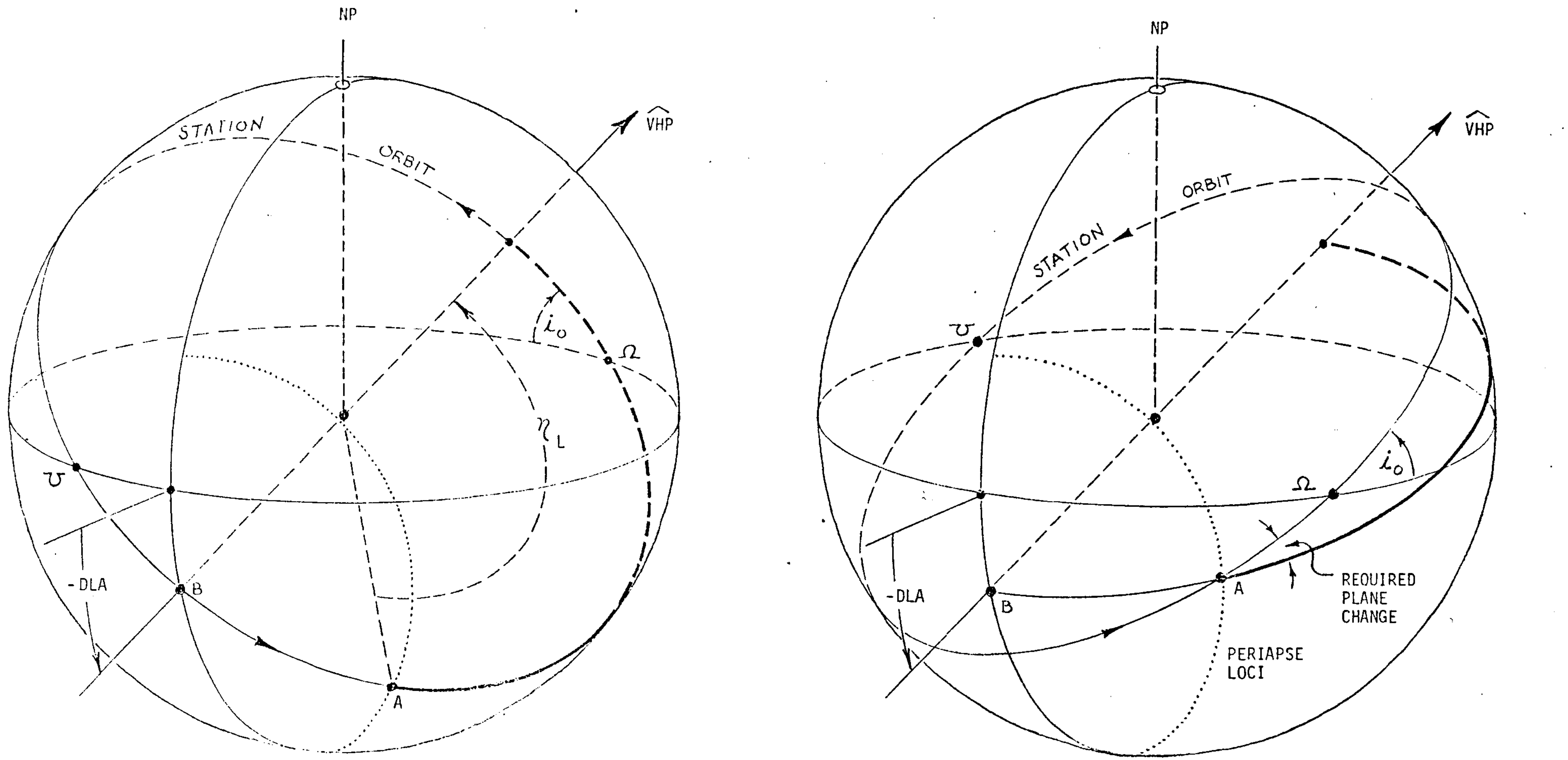
- ASSUMING THE ANGLE (DECLINATION, DLA) OF VHP TO THE EARTH'S EQUATOR IS LESS THAN THE ORBIT INCLINATION, THERE WILL, THEREFORE, BE ONLY TWO TIMES EVERY 50 DAYS (360°/7.2) WHEN $\widehat{VHP}$ LIES IN THE STATION ORBIT PLANE, WHICH IS THE CONDITION FOR OPTIMUM COPLANAR ESCAPE. AT ALL OTHER TIMES A PLANE CHANGE (AND PERFORMANCE LOSS) IS REQUIRED TO ACHIEVE THE CORRECT ESCAPE CONDITIONS.

- IF THE DECLINATION OF $\widehat{VHP}$ IS GREATER THAN THE ORBIT INCLINATION, AT NO TIME WILL $\widehat{VHP}$ BECOME COPLANAR WITH THE STATION ORBIT PLANE, AND ONLY ONCE EVERY 50 DAYS WILL IT COME CLOSEST TO THE PLANE MINIMIZING THE REQUIRED PLANE CHANGE (AND PERFORMANCE LOSSES).

- SINCE THESE CONDITIONS FOR OPTIMUM STATION DEPARTURE WILL NOT, IN GENERAL, COINCIDE WITH THE TIME OF MINIMUM C_3 ($C_3 = |\overline{VHP}|^2$) A TRADE-OFF EXISTS BETWEEN THE AMOUNT OF PLANE CHANGE REQUIRED AND THE C_3 OF OFF-OPTIMAL LAUNCH DATES.



LAUNCH TIMING EFFECT OF SPACE STATION ORBIT PRECESION



NOTE: DLA < i_o
A ≡ ESCAPE IMPULSE POINT

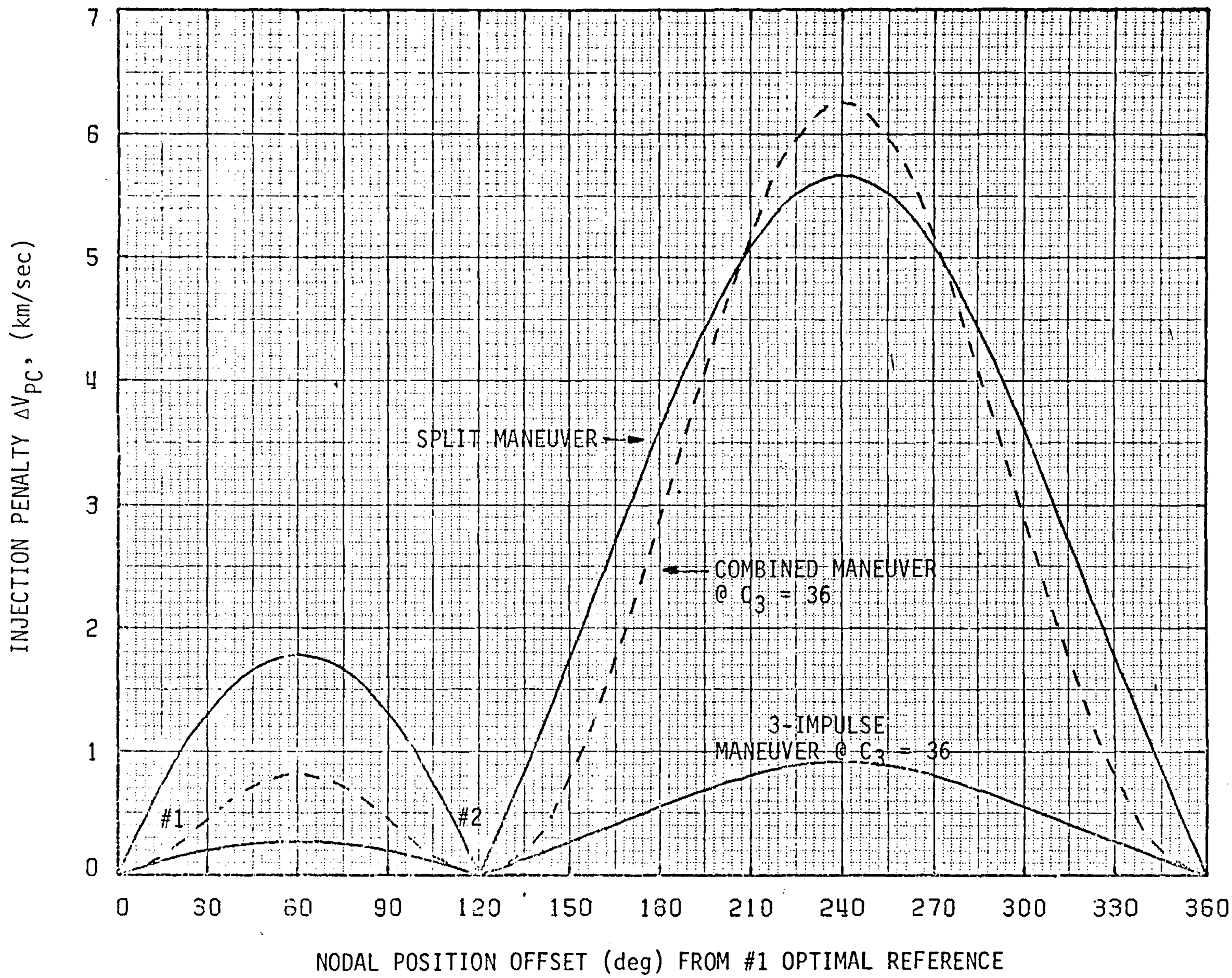
CASE A
OPTIMUM STATION ORBIT ORIENTATION

CASE B
OFF-OPTIMUM STATION ORBIT ORIENTATION
(COMBINED MANEUVER STRATEGY SHOWN)

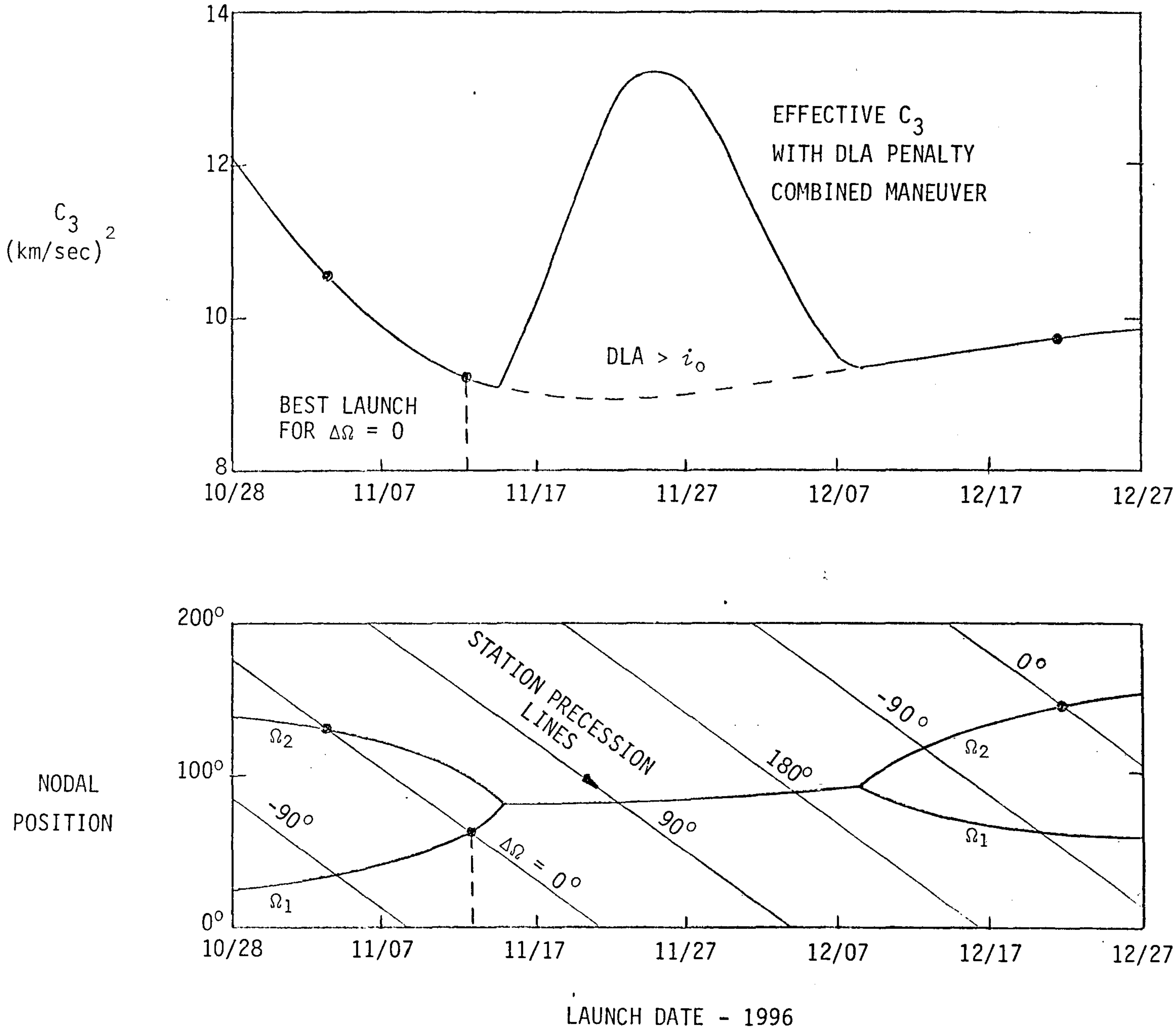
PLANETARY LAUNCH SITUATIONS WITH SPACE STATION

SPACE STATION/PLANETARY INJECTION STRATEGIES

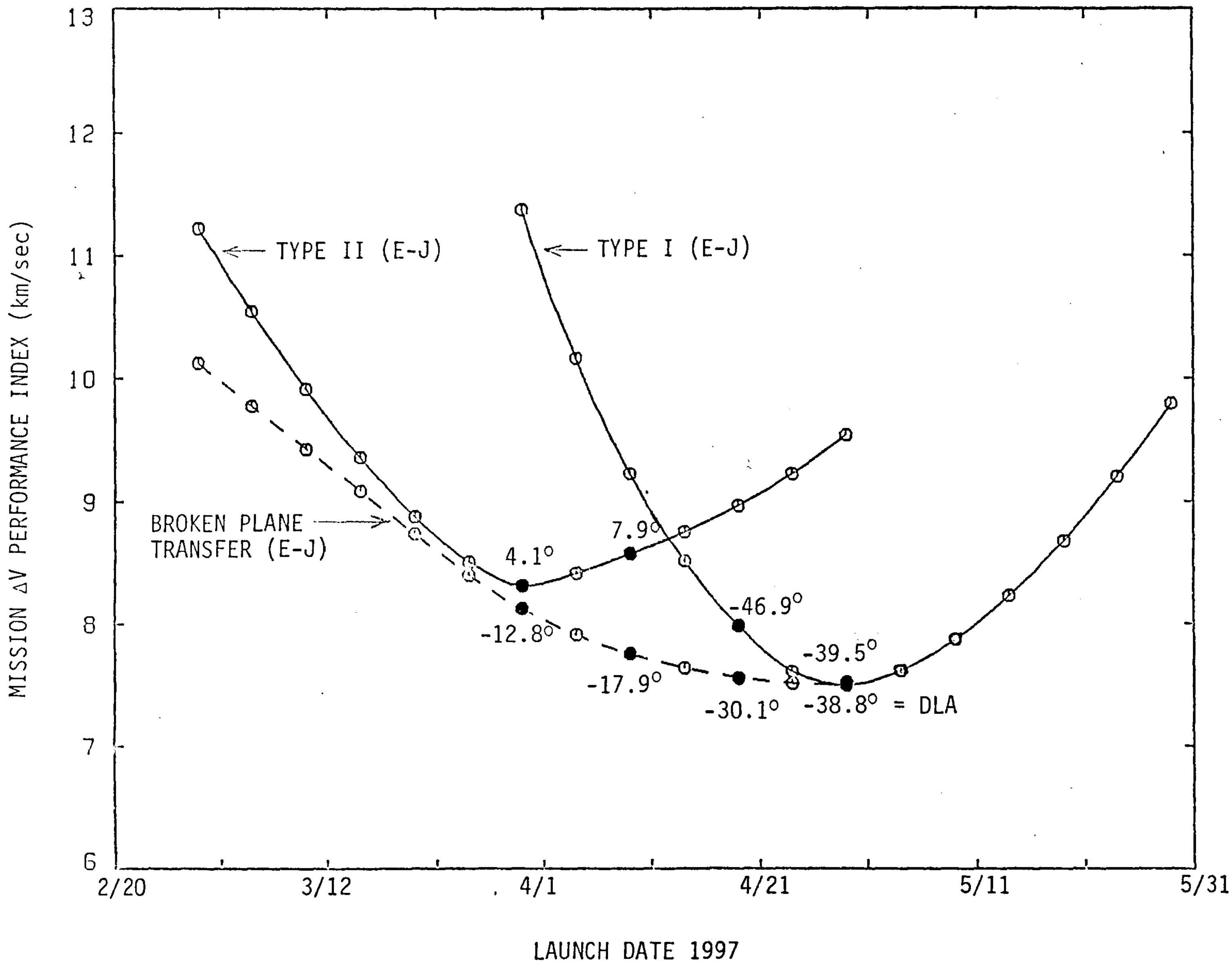
	UTILIZATION PRIORITIES
• ACTIVE (PROPULSIVE PLANE CHANGES)	
o EARTH-ORBITAL	AS NEEDED FOR DLA TARGETING & LAUNCH DELAYS
– SPLIT MANEUVER	– STATION ORBIT REALIGNMENT: EXPENSIVE
– COMBINED MANEUVER	– NON-PLANAR ESCAPE: LESS EXPENSIVE
– THREE-IMPULSE MANEUVER	– APOAPSE PLANE CHANGE: LEAST EXPENSIVE (BUT REQUIRES 24^h INTERMEDIATE ORBIT)
o INTERPLANETARY	
– BROKEN PLANE TRANSFERS	VERY EFFECTIVE ON SOME MISSIONS IN REDUCING DLA PENALTIES AND IN IMPROVING OFF-OPTIMAL ESCAPE REQUIREMENTS FOR PASSIVE STRATEGY (SEE BELOW)
• PASSIVE (LAUNCH DATE TIMING)	BASELINE SOLUTION
– STATION ORBIT PRECESSION	WAITS FOR ORBIT REALIGNMENT, ACCEPTING SOME PERFORMANCE LOSS FROM RESULTING OFF-OPTIMAL LAUNCH DATE



STATION ORBIT INJECTION TO |DLA| = 15° WITH CORRECTION OF NODAL POSITION OFFSET



SELECTION OF LAUNCH DATE VIA PRECESION - 1996 MARS SAMPLE RETURN



ADVANTAGE OF BROKEN-PLANE TRANSFERS - 1997 J/S SATURN ORBITER/PROBE MISSION

EXAMPLE
RESULTS

CHARACTERISTICS OF EXAMPLE MISSIONS

MISSION	LAUNCH YEAR	FLIGHT MODE/OPTION	NOMINAL PAYLOAD*	COMMENTS
MARS GEOCHEMICAL ORBITER	1992	300km CIRCULAR ORBIT	505 KG	$T_F = 0.9^y$
MARS SAMPLE RETURN	1996	a) ORBIT RENDEZVOUS b) DIRECT RETURN	5 MODULES SEE BREAKDOWN	$T_F = 2.7^y$ AEROCAPTURE TECH.
MERCURY ORBITER	1994	a) HI-LO ORBITER b) DUAL ORBITERS	725 KG IN 12^h ORBIT** 1050 KG IN 12^h ORBIT**	VENUS SWINGBY (2) $T_F = 2.4^y$
ANTEROS RENDEZVOUS	1997 1999	a) GOOD OPPORTUNITY b) POOR OPPORTUNITY	600 KG	$T_F = 1.2^y$ $T_F = 1.1^y$, HIGH DLA
ASTEROID MULTIPLE RENDEZVOUS	1992	MARS SWINGBY	600 KG	$T_F = 4.5^y$, 2 TARGETS
COMET TEMPEL 2 RENDEZVOUS	1994	DIRECT	600 KG	$T_F = 5^y$
TITAN PROBE	1995	DIRECT, SATURN FLYBY	250 KG PROBE 580 KG BUS	$T_F = 3.5^y$
URANUS/NEPTUNE PROBES	1992	DIRECT, TANDEM LAUNCH JUPITER SWINGBY	235 KG PROBE (x2) 560 KG BUS (x2)	$T_F = 6.7^y$ $T_F = 10^y$
SATURN ORBITER/PROBE	1997 1998	a) FAIR J/S OPP. b) GOOD J/S OPP.	250 KG PROBE 650 KG ORBITER	$T_{F_U} = 5.5^y$, HIGH DLA $T_{F_U} = 5.5^y$
GANYMEDE ORBITER	2000	DIRECT	650 KG	$T_F = 3.5 - 4.3^y$ WITH SATELLITE G/A TOUR

*NET SPACECRAFT MASS EXCLUDING PROPULSION

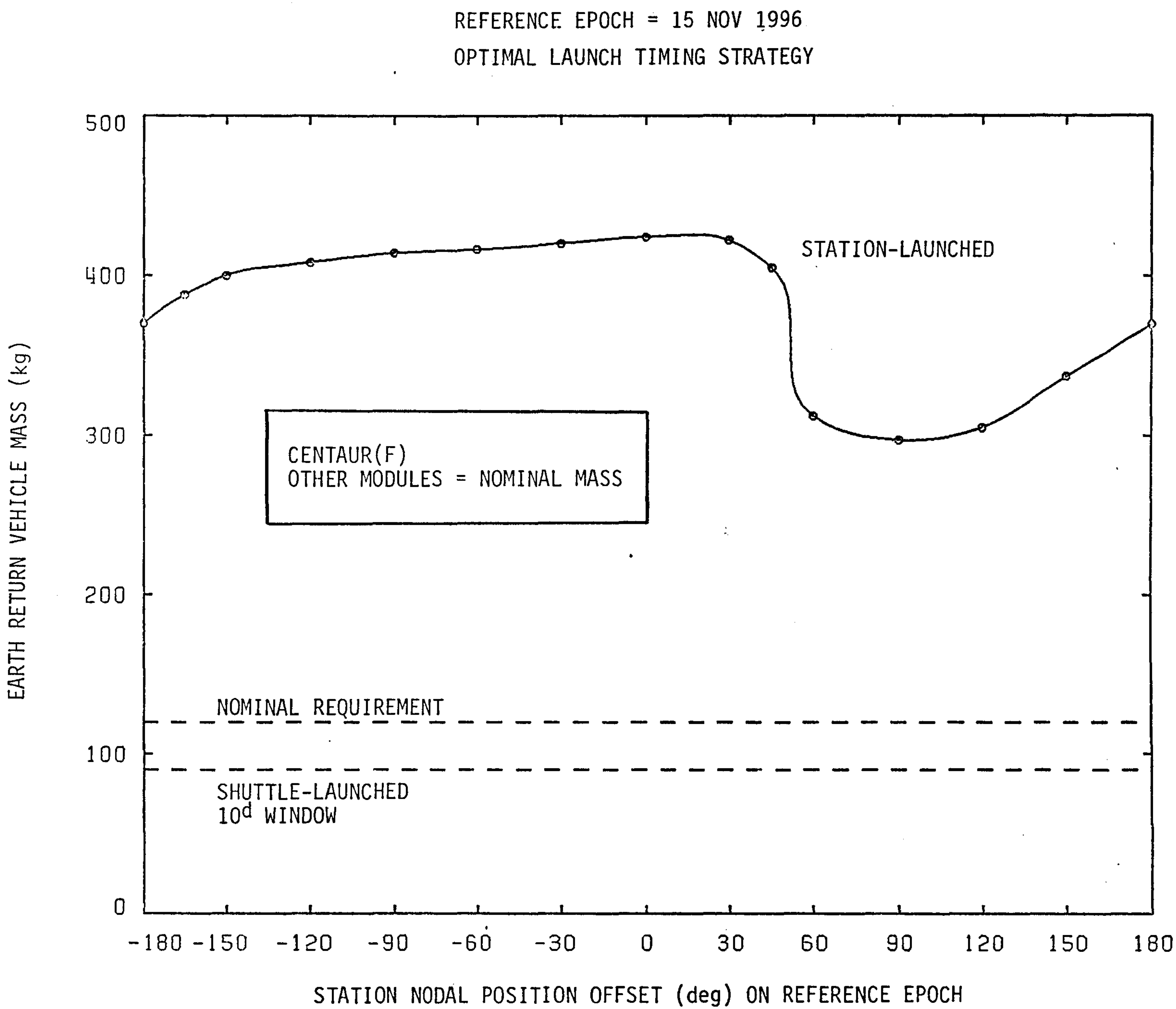
**MERCURY ORBITERS INCLUDES PROPULSION FOR CIRCULARIZATION

SAI SPACE SCIENCES

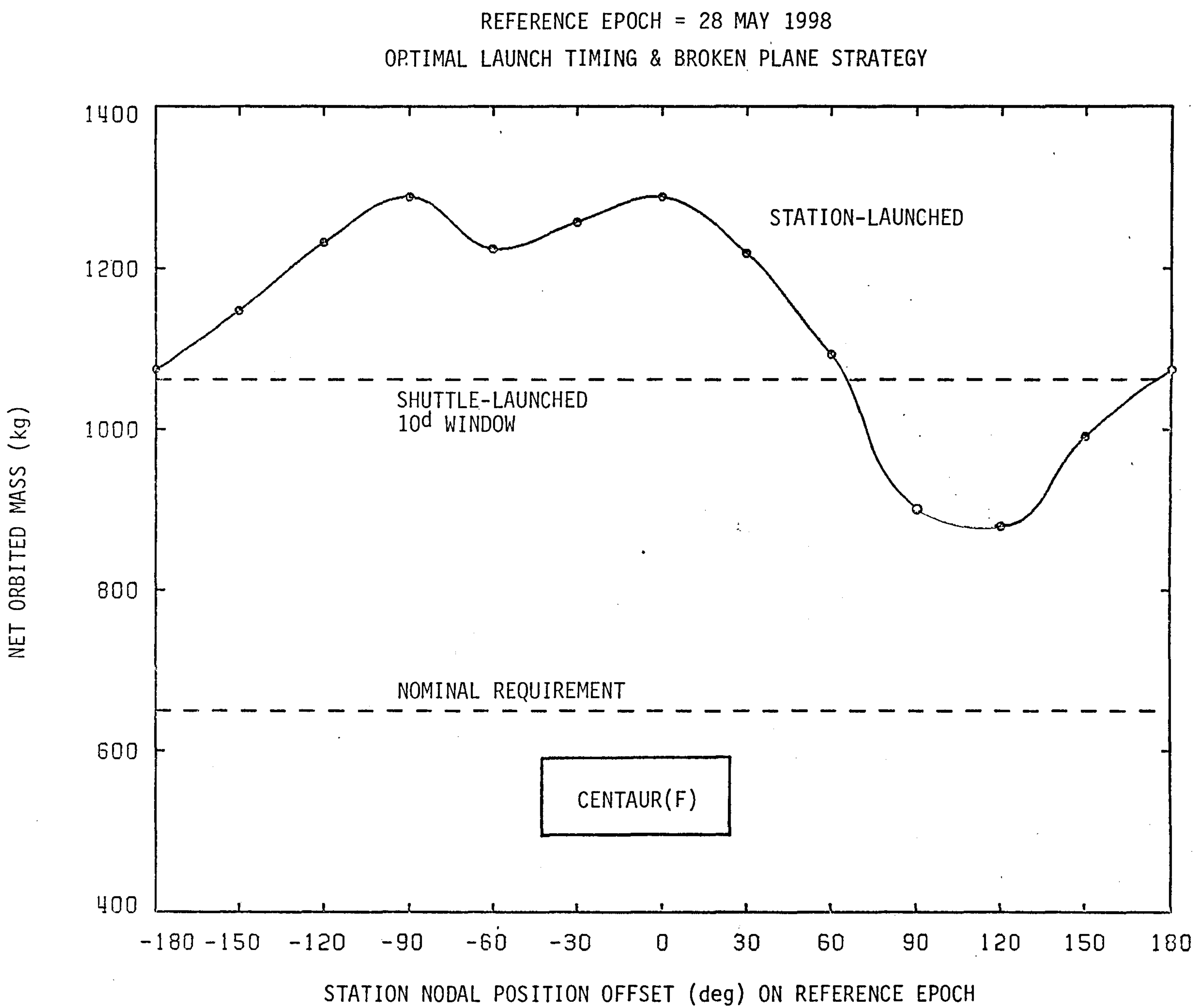
1996 MARS SAMPLE RETURN MISSION - MASS DEFINITION

SYSTEM MASS ELEMENT	--- NOMINAL VALUE (KG) ---	
	DIRECT RETURN MODE	MOR MODE
AEROCAPTURE/ENTRY	1500	1500
ORBITER	-	550
LANDER (W/ROVER)	650	650
ASCENT VEHICLE SUBSYSTEMS	-	95
EARTH RETURN VEHICLE	120	-
SAMPLE CAPSULE	30	30
SAMPLE	5	5
SUBTOTAL W/O PROPULSION	2305	2830
INJECTED MASS REQUIREMENT		
SHUTTLE-LAUNCHED	8320	5555
STATION-LAUNCHED*	8345 - 9085	5515 - 5910

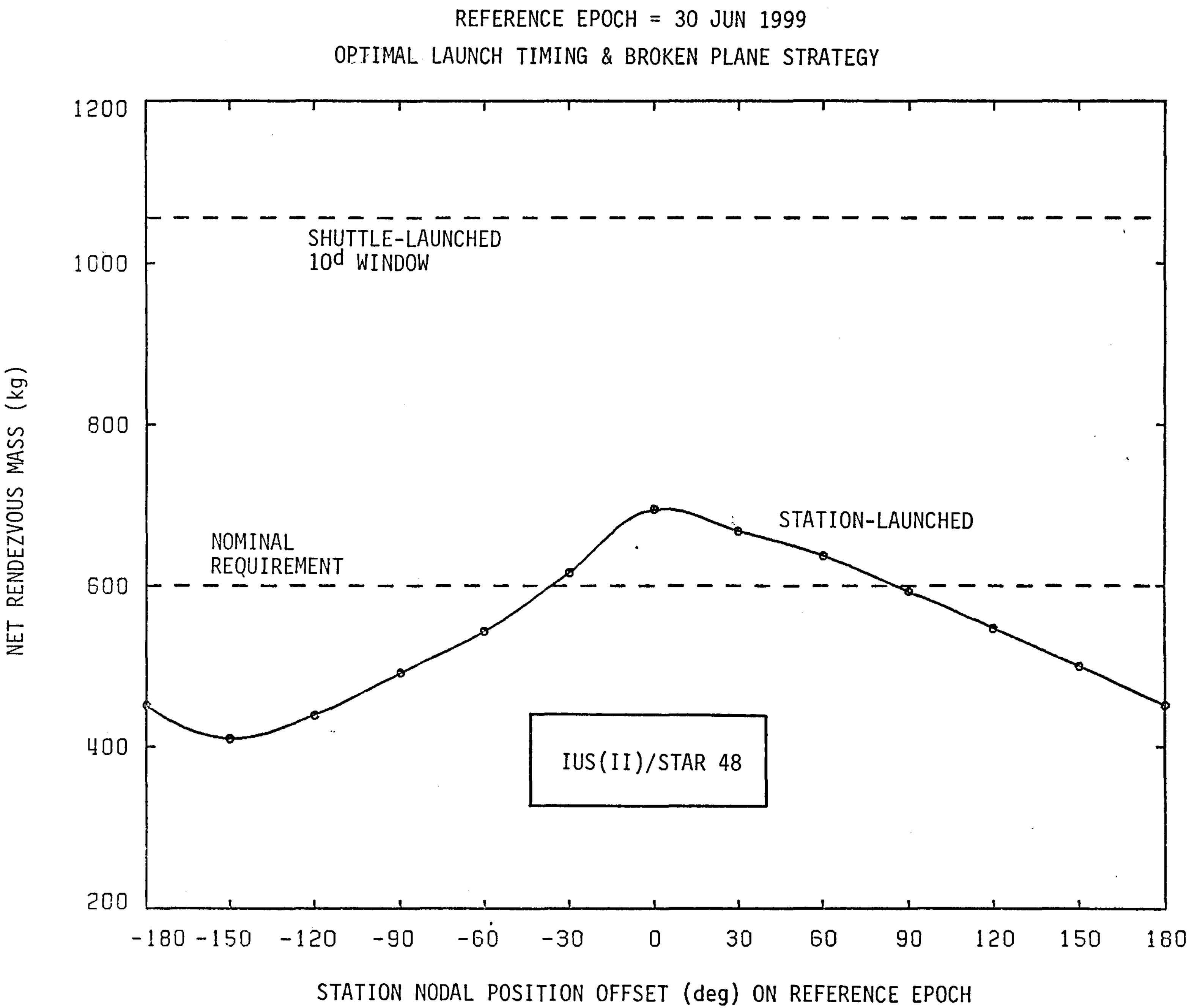
*RANGE OVER ALL POSSIBLE NODAL POSITIONS OF SPACE STATION



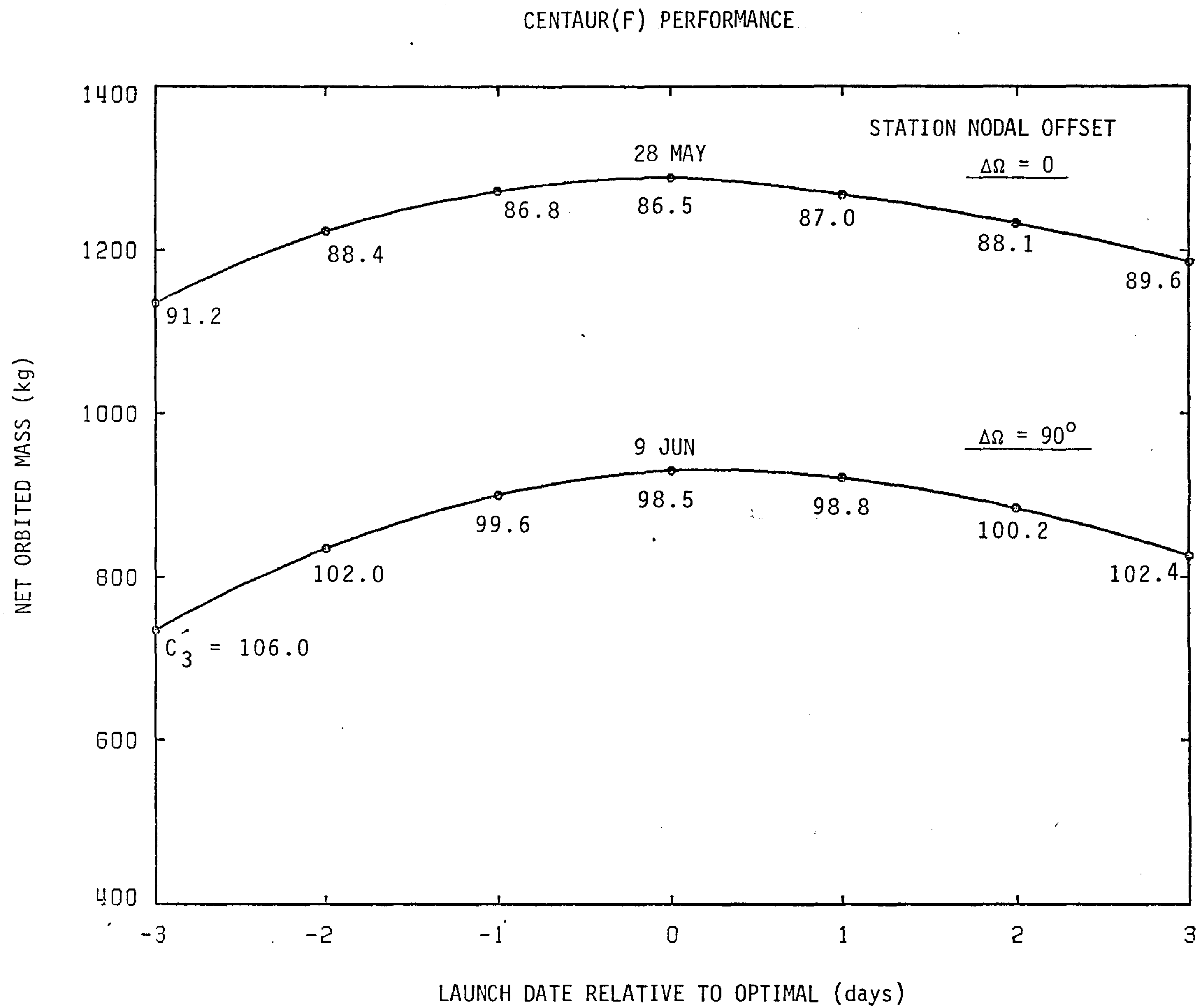
PERFORMANCE COMPARISON FOR 1996 MARS SAMPLE RETURN - DIRECT RETURN MODE



PERFORMANCE COMPARISON FOR 1998 J/S SATURN ORBITER (250 KG PROBE)



PERFORMANCE COMPARISON FOR 1999 ANTEROS RENDEZVOUS



LAUNCH ON-TIME PENALTY - 1998 J/S SATURN ORBITER/PROBE MISSION

SUMMARY
OF RESULTS

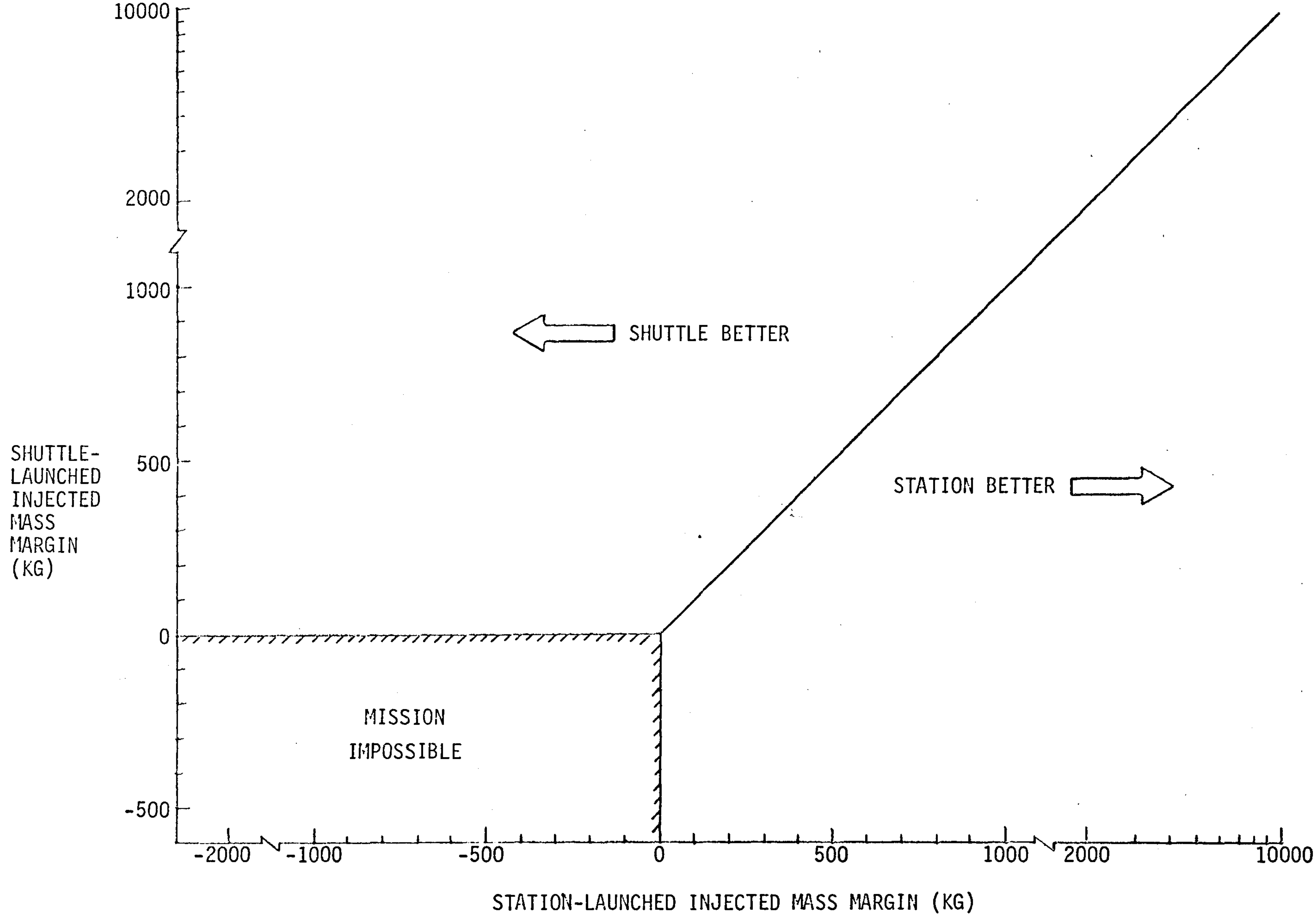
CRITERIA FOR PERFORMANCE COMPARISON

- FOR SPECIFIED NOMINAL PAYLOAD MASS, EXPRESS PERFORMANCE IN TERMS OF INJECTED MASS MARGIN. POSITIVE MARGIN IS MEASURE OF 'SAFETY' OR PAYLOAD GROWTH.

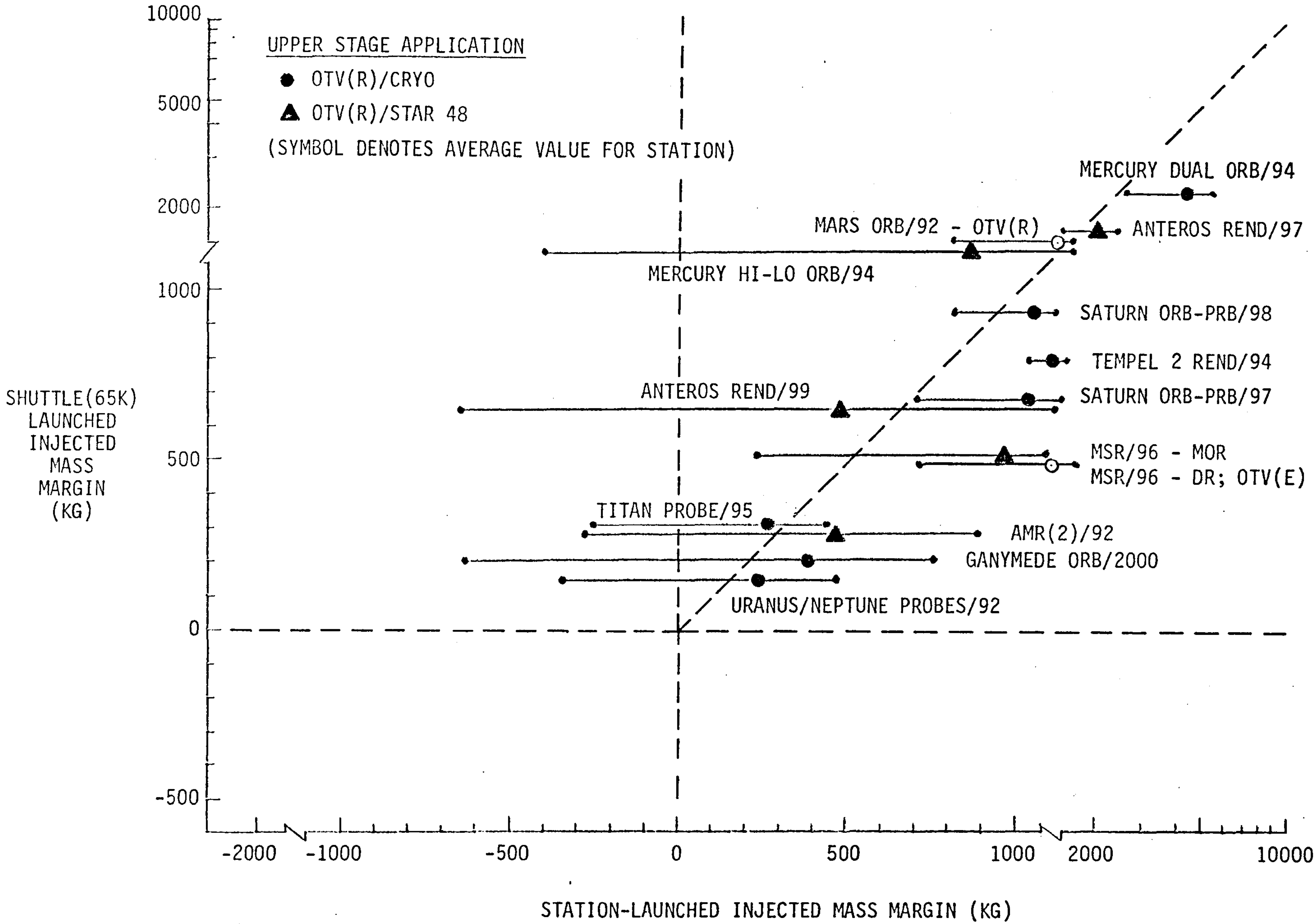
- FOR EACH MISSION, SELECT MINIMUM CAPABILITY UPPER STAGE THAT CAPTURES MISSION WITH SHUTTLE LAUNCH. IF MISSION CANNOT BE CAPTURED, SELECT MAXIMUM CAPABILITY STAGE.

- APPLY SAME UPPER STAGE FOR STATION-LAUNCHED MISSION.

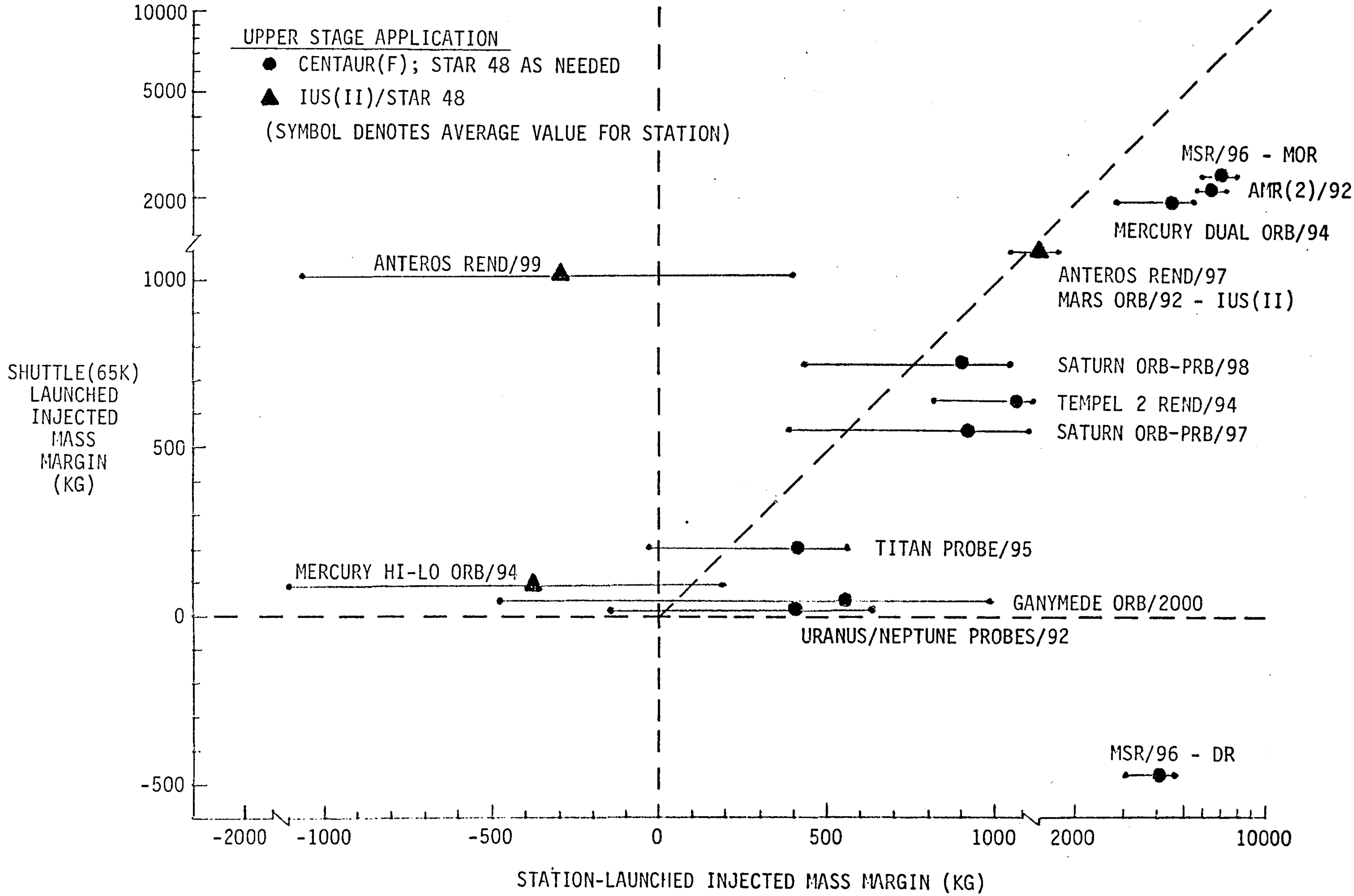
- SHUTTLE LAUNCH WINDOW = 10 DAYS
  STATION LAUNCH WINDOW ≡ 360° OF ALL POSSIBLE NODAL POSITIONS



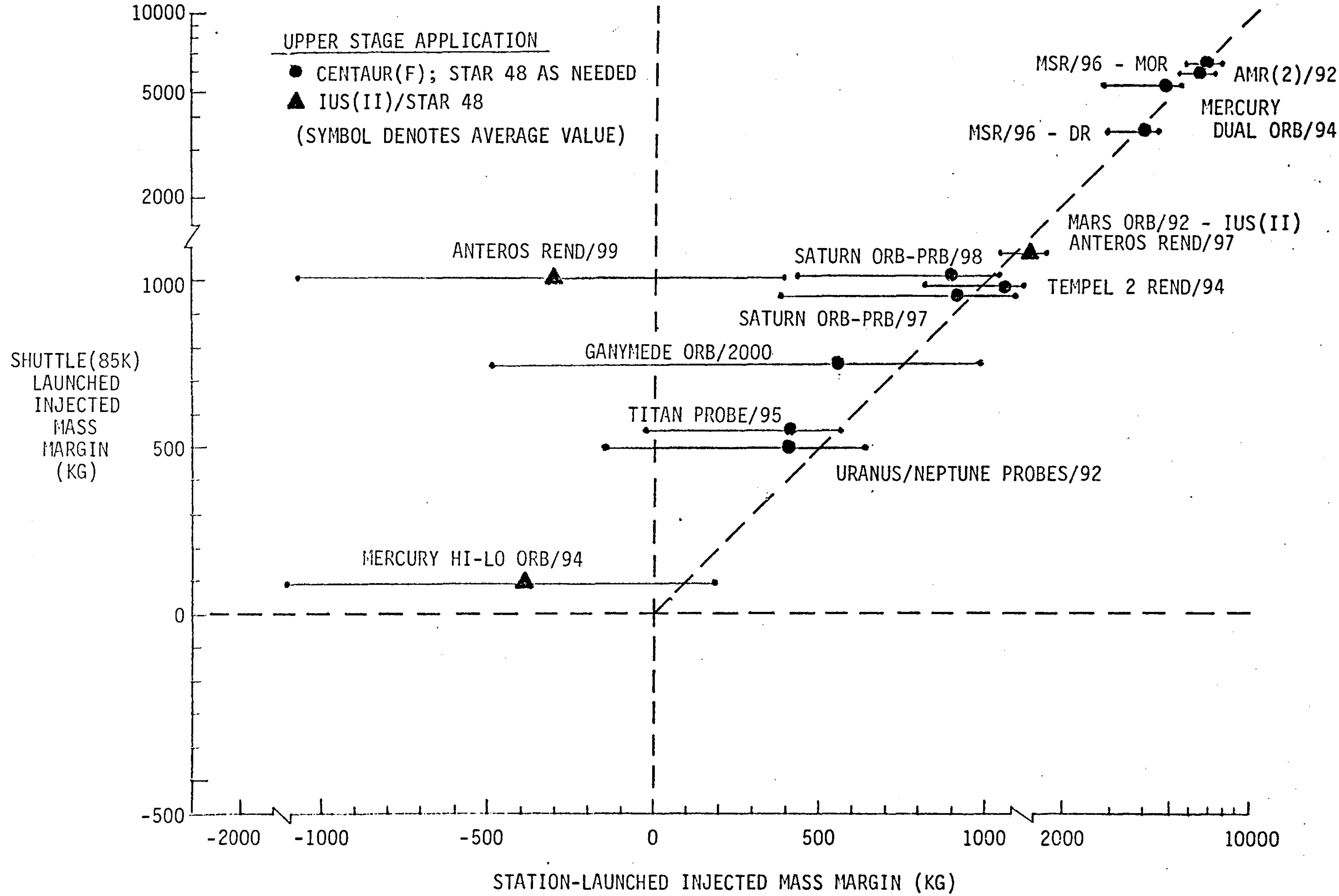
COMPARISON OF SHUTTLE AND SPACE STATION LAUNCHED MISSION PERFORMANCE



COMPARISON OF SHUTTLE(65K) AND SPACE STATION-LAUNCHED MISSION PERFORMANCE



COMPARISON OF SHUTTLE(65K) AND SPACE STATION-LAUNCHED MISSION PERFORMANCE



COMPARISON OF SHUTTLE(85K) AND SPACE STATION-LAUNCHED MISSION PERFORMANCE

CONCLUSIONS

- A FUNDAMENTAL TRADE-OFF EXISTS BETWEEN SHUTTLE-LAUNCHED AND STATION-LAUNCHED PLANETARY MISSIONS:
  - SHUTTLE LAUNCHES ARE FAVORED BY A MORE ADAPTIVE LAUNCH SITUATION WHICH, FOR A PROPELLANT-FIXED UPPER STAGE, WILL PRODUCE (ON AVERAGE) BETTER PAYLOAD PERFORMANCE
  - STATION LAUNCHES ARE FAVORED BY FREEDOM FROM STAGE PROPELLANT OFF-LOADING DUE TO SHUTTLE CARGO MASS CONSTRAINTS (WHICH MAY PRODUCE BETTER PERFORMANCE), AND BY AN ASSUMED LAUNCH-ON-TIME CAPABILITY
- FOR A BROAD RANGE OF MISSIONS, THESE TRADE-OFFS TEND TO FAVOR:
  - THE SHUTTLE FOR SMALLER PAYLOAD MISSIONS IMPLEMENTED WITH SMALLER UPPER STAGES (e.g. THE IUS(II))
  - THE SPACE STATION FOR LARGER PAYLOAD MISSIONS IMPLEMENTED WITH LARGER UPPER STAGES (e.g. THE WIDE-BODY CENTAUR) OR SPACE-BASED REUSABLE OTV'S
  - ASSUMING A 65K SHUTTLE, THE STATION IS ENABLING ONLY IN A NARROW SENSE FOR SOME MISSIONS (e.g. MSR-DIRECT RETURN MODE). FOR MOST MISSIONS OF INTEREST THE PAYLOAD MARGINS ARE QUITE SUFFICIENT WHETHER SHUTTLE OR STATION LAUNCHED.
- GIVEN THE AVAILABILITY OF AN UPRATED SHUTTLE (e.g. 85K), THE STATION OFFERS NO SIGNIFICANT PAYLOAD DELIVERY BENEFIT. THE ADVANTAGE SHIFTS SLIGHTLY IN FAVOR OF SHUTTLE-LAUNCHED MISSIONS.
- IN SUMMARY, PLANETARY MISSIONS CAN BE LAUNCHED FROM A SPACE STATION WITH NEITHER SIGNIFICANT PERFORMANCE BENEFIT NOR PENALTY.
- OTHER POTENTIAL NON-PERFORMANCE ADVANTAGES OF SPACE STATION (e.g. SHUTTLE MANIFESTING AND ORBIT CHECK-OUT) WILL BE SENSITIVE TO SPECIFIC DESIGN AND OPERATIONAL CHARACTERISTICS OF THE STATION AND ITS SHUTTLE INTERFACE.