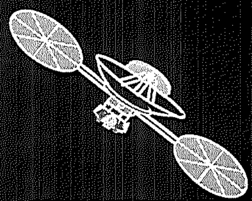

Aerospace Engineering Space Mission Concept Feasibility Study: A Neptune Mission Design Example

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Short Course Prepared for the Department of Aerospace and Mechanical Engineering

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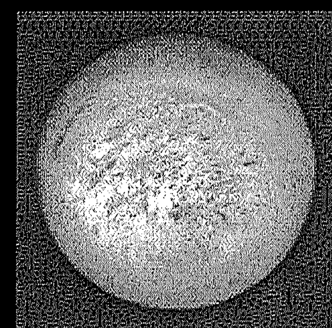
INTRODUCTION

- The outer solar system remains largely unexplored by robotic spacecraft

- Future technological advances promise to enable routine exploration affordably (within CY2000 Discovery Program constraints)

- Neptune and Triton are high-priority scientific targets

NEPTUNE & TRITON



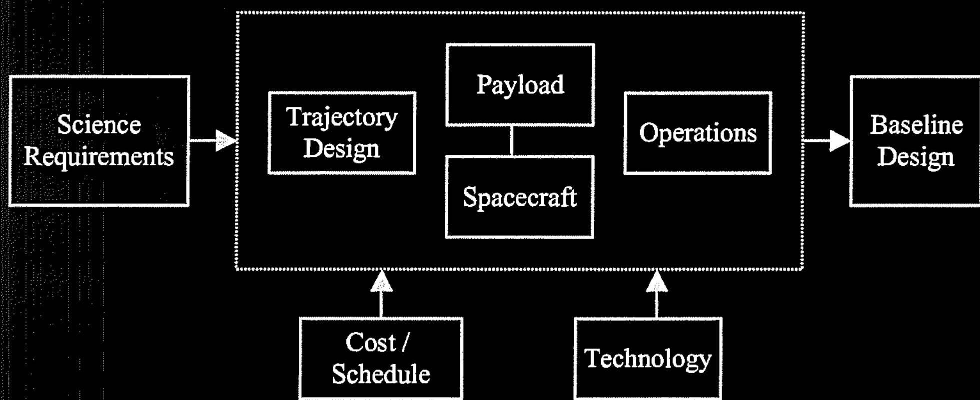
SCIENCE INSTRUMENTS & SELECT MEASUREMENTS

- UV, VIS, IR Camera / Spectrometer:
  - Mapping and morphology
  - Atmospheres and composition
  - Neptune's rings and small satellites

- Particles and Fields Package:
  - Magnetospheres
  - Ionospheres
  - Plasma density, structure, composition, origin

DESIGN METHODOLOGY

- Complete systems engineering approach



- Multivariable
- Iterative

TRAJECTORY COMPUTATION

• Analytical approximation method.

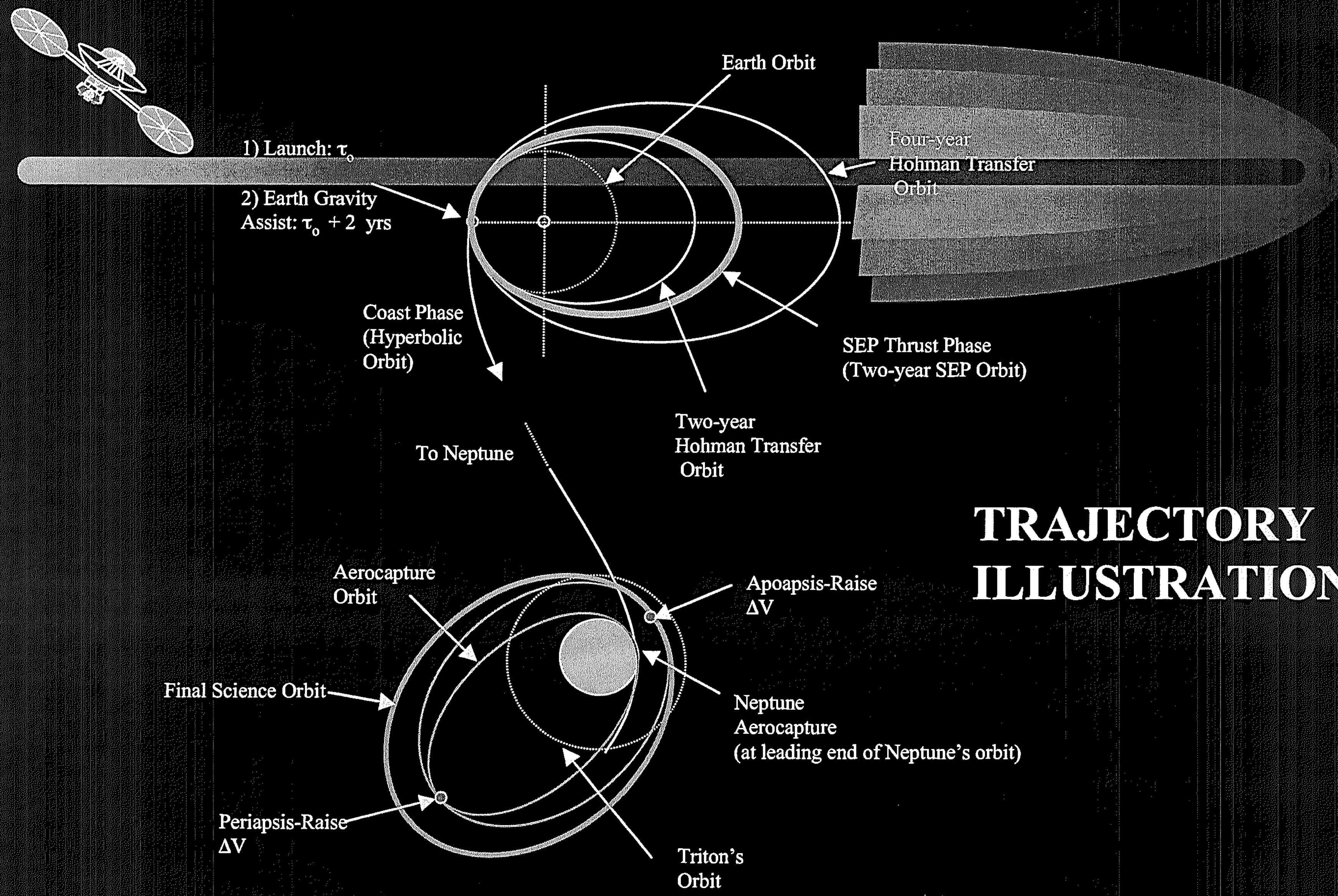
• SEP system used to gain energy equivalent to a 4-year Hohman Transfer orbit. Launch on a 2-year Hohman Transfer.

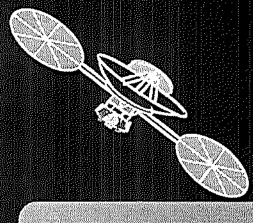
• Earth Gravity assist after two years with non-zero flight path angle. Injects spacecraft into a 6.7-year hyperbolic trajectory to Neptune.

•Aerocapture maneuver at Neptune, 500 km entry interface.

• Total Flight time = 8.7 years.

TRAJECTORY ILLUSTRATION

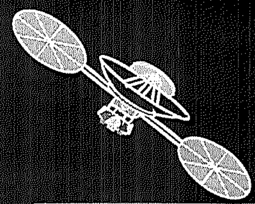


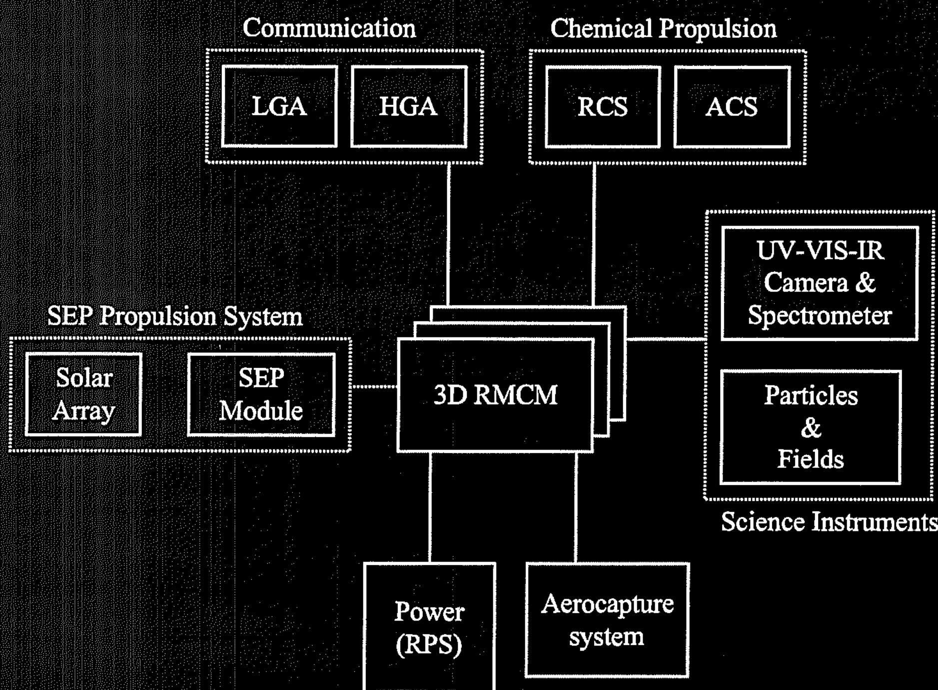


TRAJECTORY& AEROCAPTURE PARAMETER SUMMARY

SEEGA		**Aerocapture**	
Launch Energy, C_3 (km^2/sec^2)	25.7	Neptune-Centered Arrival Velocity (km/sec)	30.1
SEP on-board ΔV (km/sec)	2.9	B-Plane Offset (km)	25,264
Vehicle Injected Mass (kg)	77	Entry Interface Altitude (km)	500
Taurus Performance for C_3 (kg)	115	Desired ΔV at Aerocapture (km/sec)	7.1
First Leg Duration (years)	2	Entry Flight Path Angle (degrees)	-1.0
Flight Path Angle at Earth Swing-by (degrees)	9.2	Lift / Drag	0.1295
Heliocentric ΔV gained (km/sec)	7.8	Atmospheric Scale Height (km)	39.6
		Maximum Aerodynamic Load (g)	2
Hyperbolic Trajectory		Pull-up Altitude (km)	200– 400
Flight Time (years)	6.7	Total Heat Load (Joules)	1.7×10^8
Excess Hyperbolic Velocity at Neptune (km/sec)	19.2	Maximum Body Average Heating Rate ($watts/m^2$)	9.4×10^6

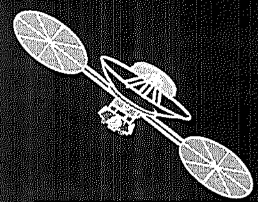
SPACECRAFT DESIGN





- Subsystem and system integration
- Sharing of resources
- Advanced technology use

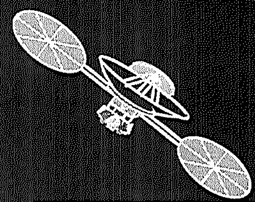
CHEMICAL PROPULSION SYSTEM



• Hydroxylammonium Nitrate (HAN) based monopropellant.

• Provides advantages for a deep space mission in the areas of safety, performance, density, and thermal management.

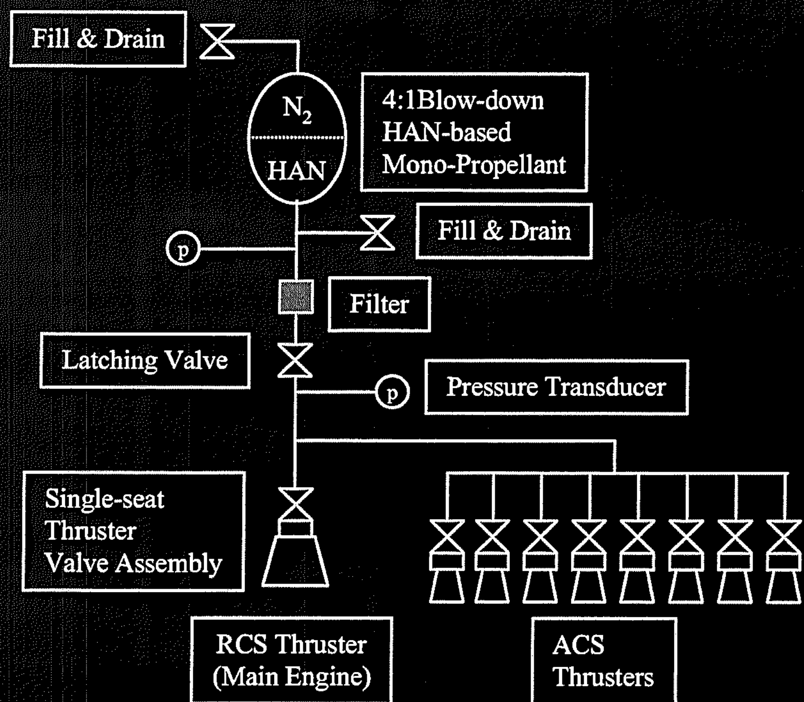
- Operating temperature: -33° C to 65° C
- Operating Power Requirement: ~ 1 watt
- Operating Modes: Continuous and Pulsed
- Specific Impulse: 260 seconds



CHEMICAL PROPULSION SYSTEM SIZING

CHEM Propulsion system sizing input	
Science Orbit Period (days)	11.8
Periapsis Raise ΔV (m/sec)	81
Apoapsis Lower ΔV (m/sec)	31
Trajectory Corrections and Orbital Maneuvering (m/sec)	223
Total CHEM on-board ΔV (m/sec)	335
CHEM System Parameters	
Monopropellant I_{sp} (sec)	260
Propellant Mass (kg)	5
Tank Mass (kg)	1
Main Engine Mass (kg)	0.6
Main Engine Thrust (Newton)	80

CHEMICAL PROPULSION SYSTEM SCHEMATIC



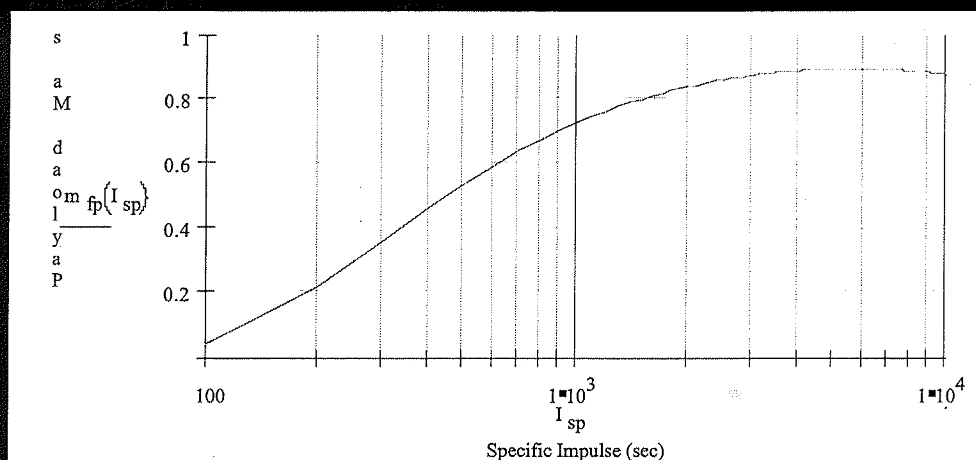
- Same system for RCS and ACS
- Simple Design

SOLAR ELECTRIC PROPULSION (SEP)

- Used payload mass-fraction-optimization

$$m_{fp}(I_{sp}) := \exp\left(\frac{-\Delta V_{SEPm}}{g_{em} \cdot I_{sp}}\right) - \left(1 - \exp\left(\frac{-\Delta V_{SEPm}}{g_{em} \cdot I_{sp}}\right)\right) \cdot \frac{\beta_{Tm} \cdot (g_{em} \cdot I_{sp})^2}{2 \cdot \eta_T \cdot \tau_{SEPs}}$$

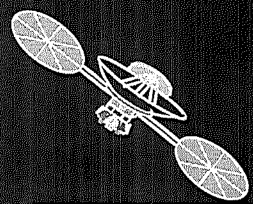
β_{Tm} => Prop sys specific mass = 0.01 kg/watt
η_T => Prop sys efficiency = 0.589



SEP SYSTEM CHARACTERISTICS

Optimum Specific Impulse (Isp) is above 3000 seconds.
Choose Isp = 3,300 based on NSTAR derivative.

Specific Impulse (sec)	3,300
Payload Mass Fraction	0.882
Propellant Mass (kg)	6.4
Propellant Flow Rate (kg/sec)	2.2×10^{-7}
Electric Power Source (watts)	197
Thruster and PPU Mass (kg)	1.5
Tank and Feed System Mass (kg)	0.96
Solar Array Mass (kg)	2
SEP System Wet Mass (kg)	11



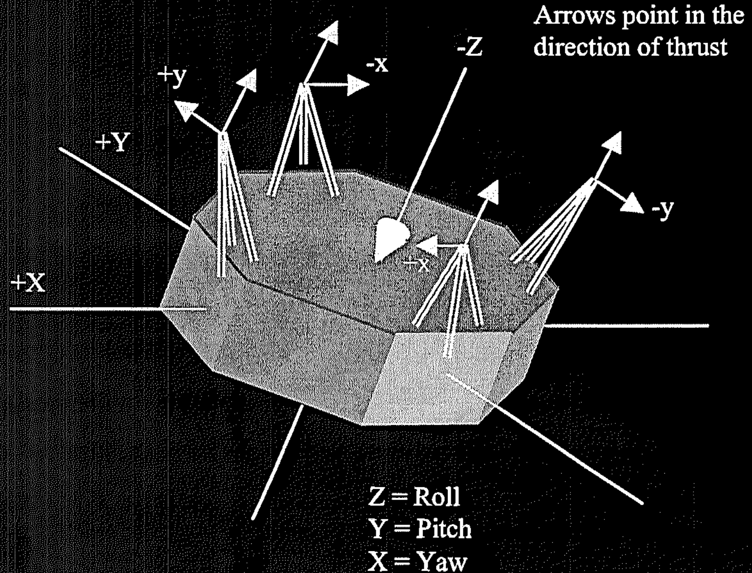
SOLAR ARRAY SIZING

- Solar Array sizing must include effects due to radiation, temperature, and distance from the Sun.

- Size array to provide 197 watts at 2.3 AU from the Sun (EOL).

  - Power at BOL = 305 watts
  - Array Area = 3.6 m2
  - Mass = 3.3 kg

ATTITUDE CONTROL



- 3-Axis Stabilization

Actuators: 8 (Redundant) Thrusters

- Sensors: Sun Sensors, Star Tracker, MEMS Gyroscopes

COMMUNICATIONS SYSTEM: DOWNLINK

Characteristics

Science data communications through a 2-meter diameter High Gain Antenna (HGA).

Transmit using Ka-band (35 GHz) to the DSN 70-meter antenna. Maximum RF output 5 watts.

- Bandwidth = 4000 Hz
- Data Rate = 7 kbps
- SNR = 3.8 dB

Science Data Return

Orbital tour duration of 2 years.

3:1 data compression ratio

33 % DSN usage per 11.8-day orbit

446 Gbits of science data returned

COMMUNICATIONS SYSTEM: UPLINK

Uplink at 8 GHz in the X-band

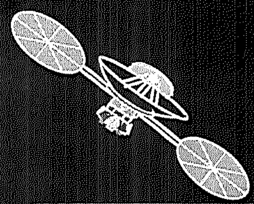
Use DSN 34-meter antenna with an RF output of 20,000 watts

- SNR = 10.8 dB

- Maximum Data Rate = 37 kbps

POWER SYSTEM

- Power required ~ 37 watts.
- Use a Radioactive Power Source.
- Scaled from current X2000 program development.
- Roughly a 30-fold mass reduction in PuO_2 content from Cassini RTG.
- Solar collector alternatives studied but not practical.



THERMAL SYSTEM

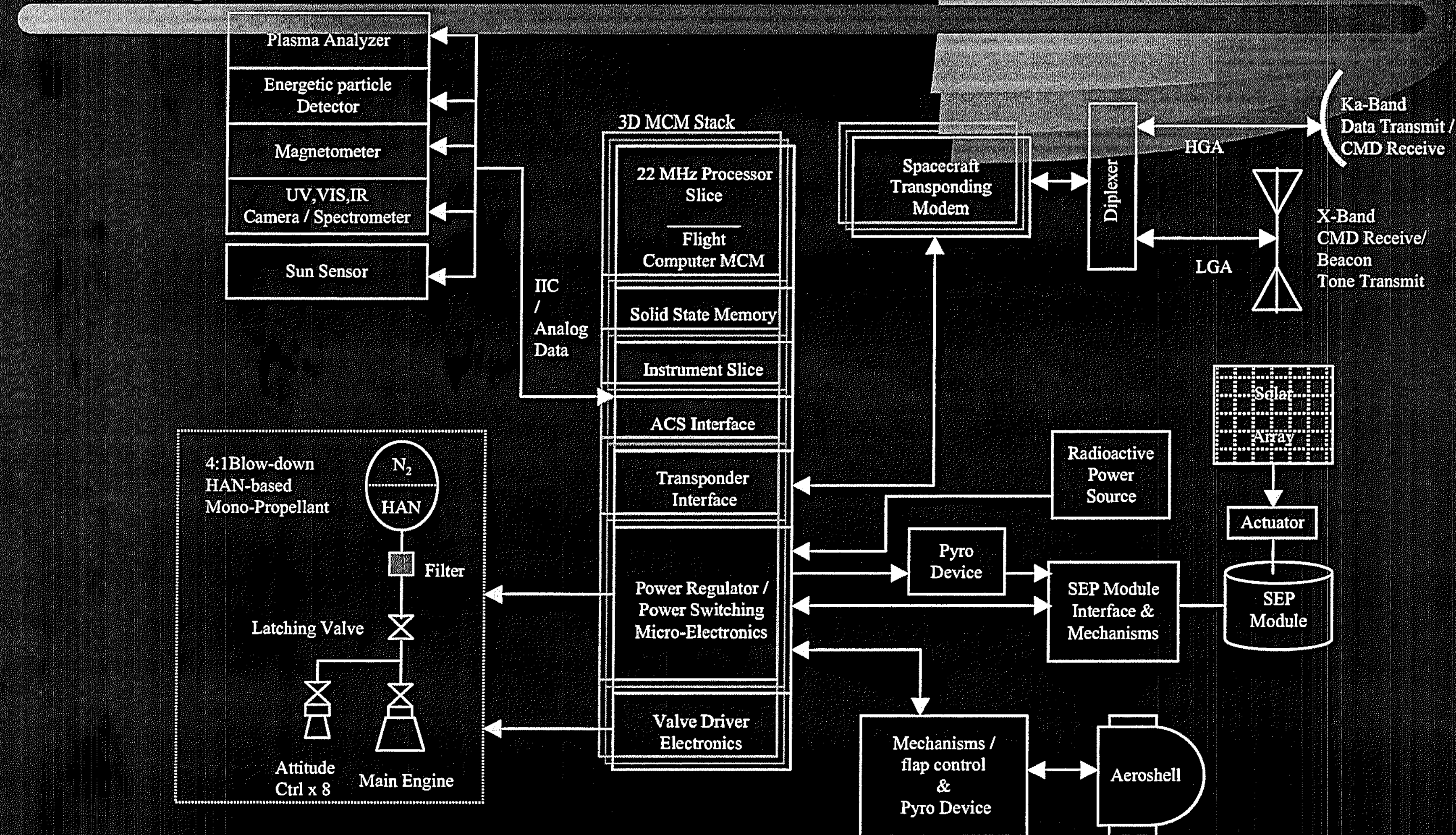
- Simple radiation balance computation

- Heat input from the Sun and Neptune is negligible

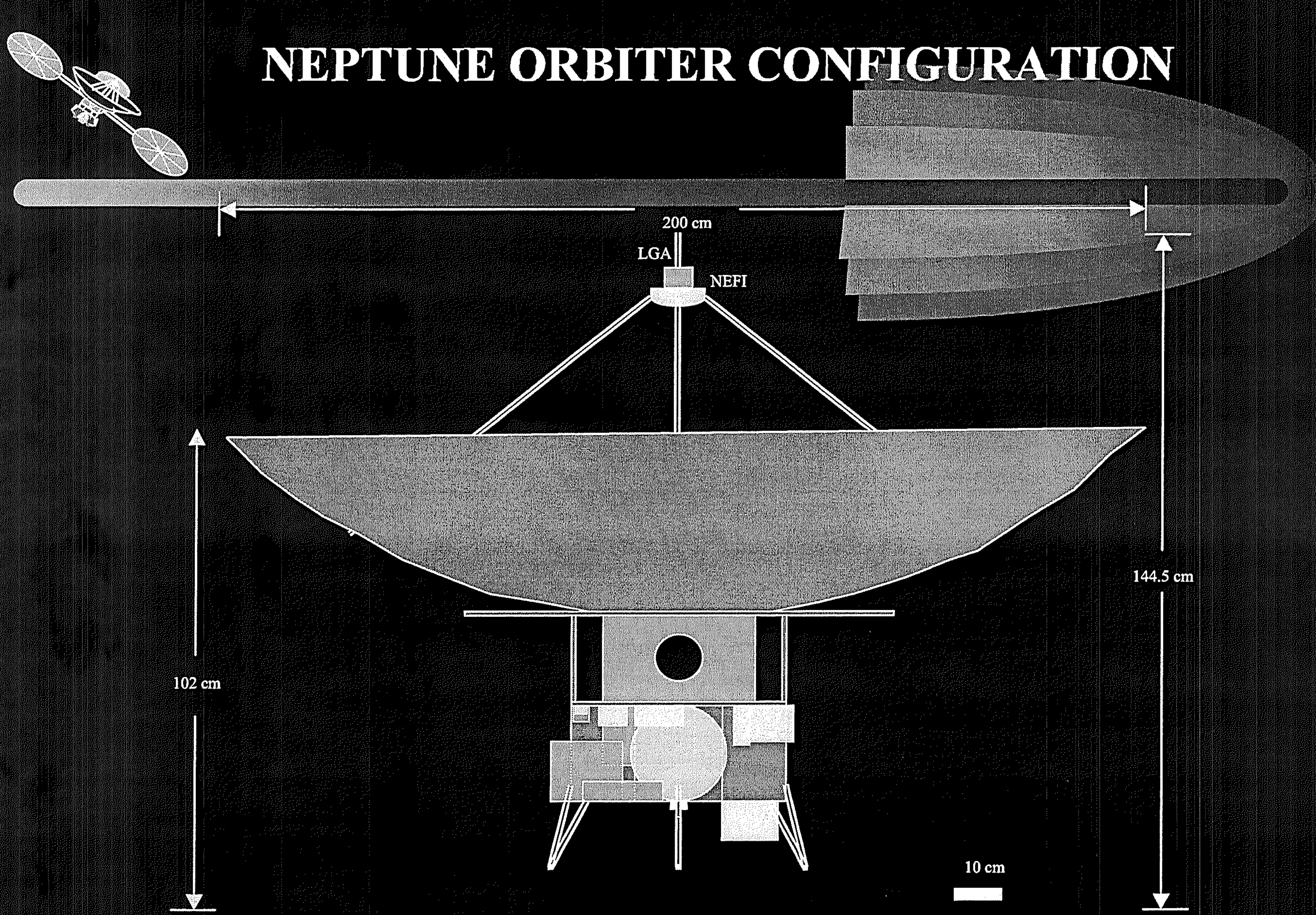
- Heat balance determined by emissivity and internal heat source

- Variable emissivity allows dramatic control of equilibrium temperature, varying from +23 to -41 °C for emissivities of 0.3 to 0.8, respectively (peak operating power).

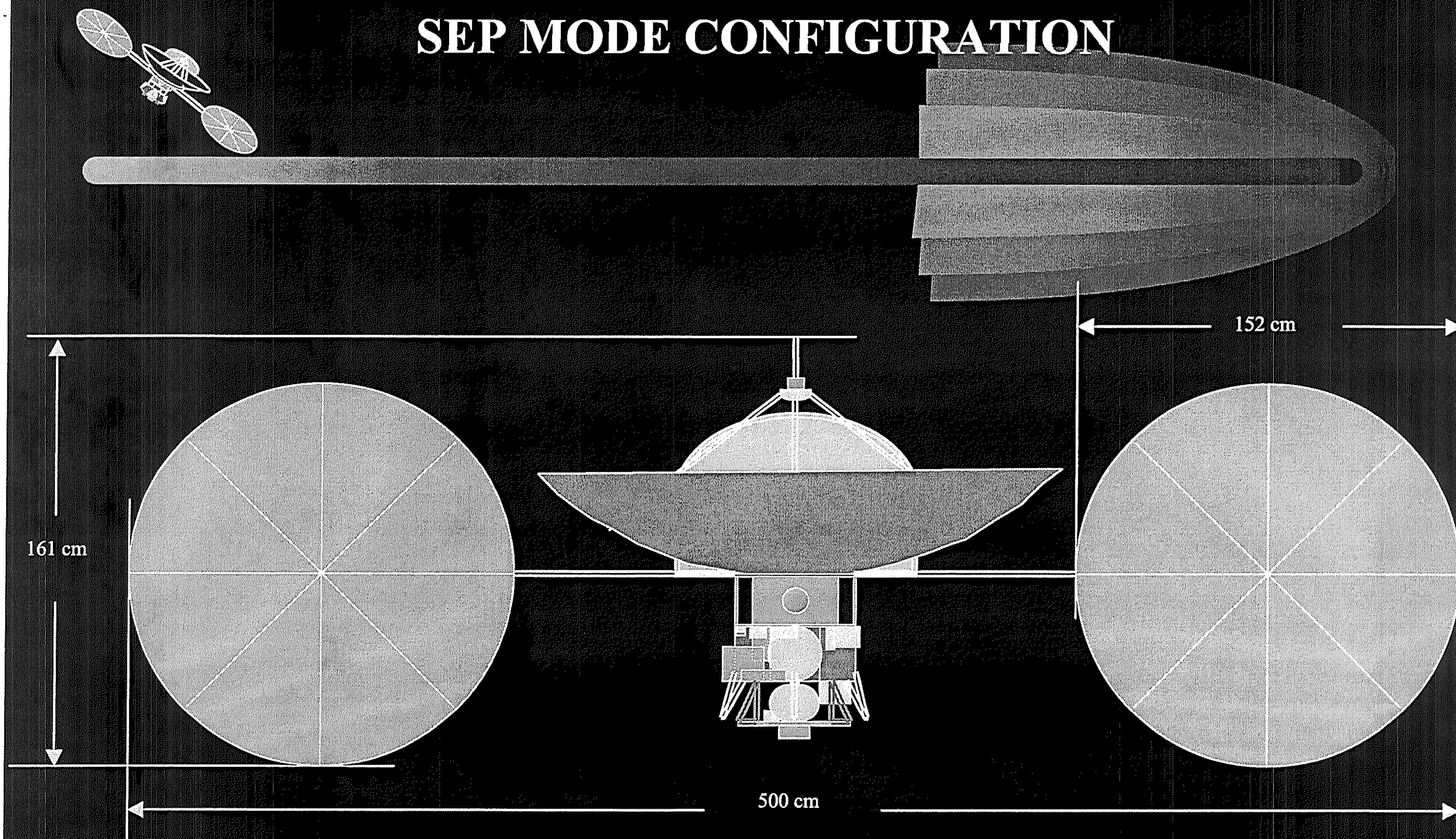
PHYSICAL BLOCK DIAGRAM



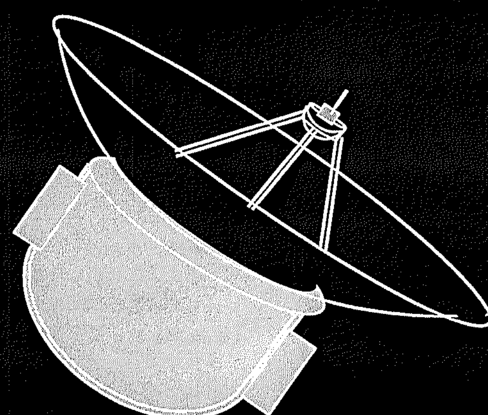
NEPTUNE ORBITER CONFIGURATION



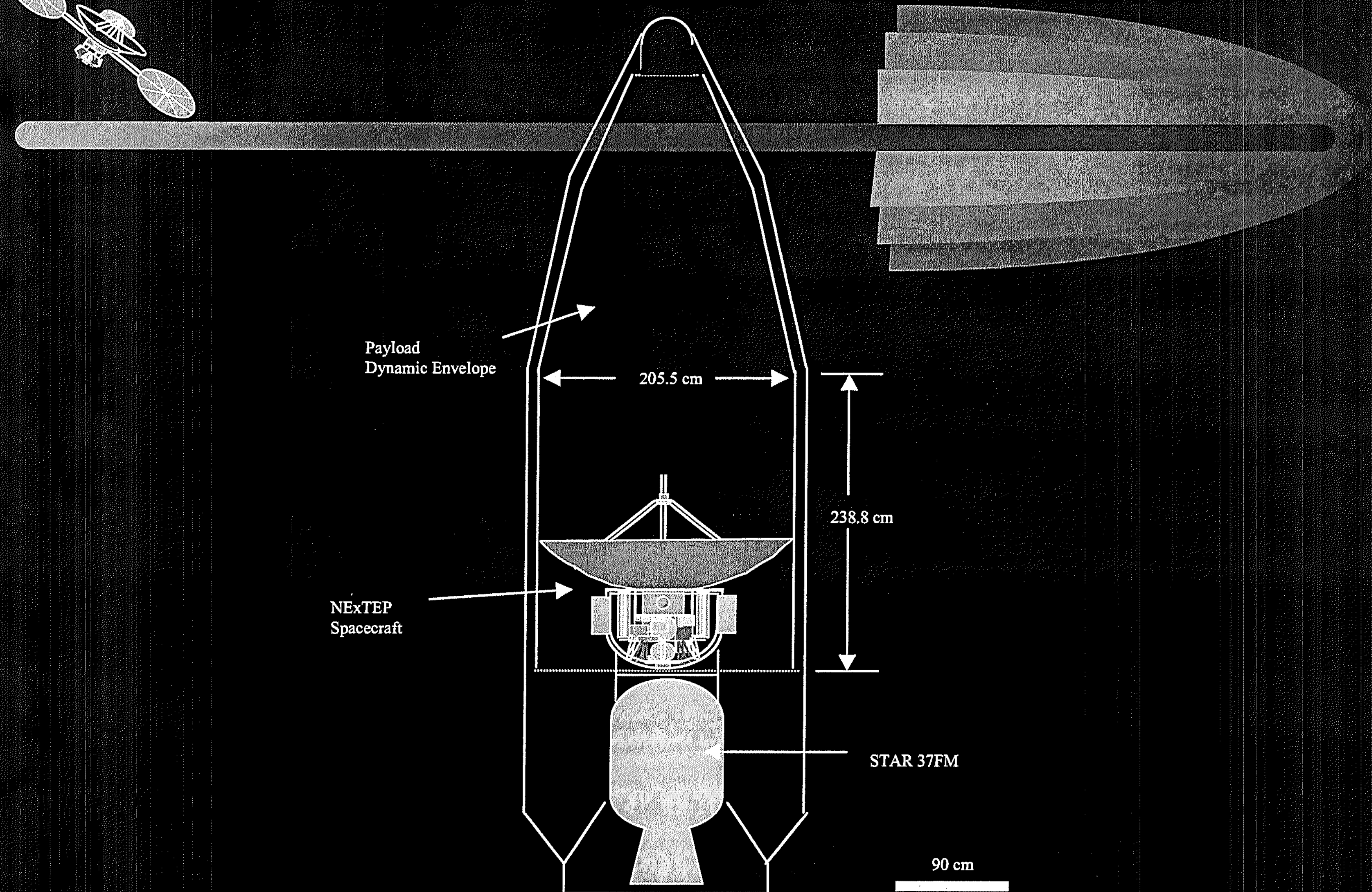
SEP MODE CONFIGURATION

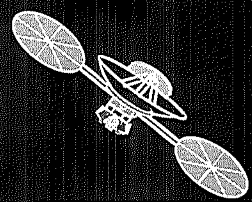


AEROCAPTURE MODE CONFIGURATION

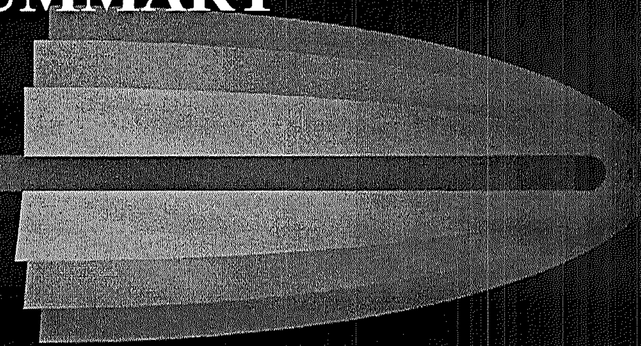


LAUNCH VEHICLE CONFIGURATION





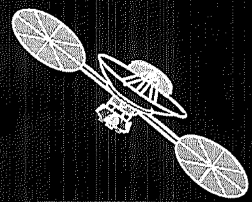
MASS AND POWER SUMMARY



	Mass (kg)	Power (W)
Science	14	14
Str. & Mech	6	
C&DH	0.1	0.5
RF Comm	1	10
Power	4	
Thermal	0.7	1
Harness	1	
Rad Shield	3	
ACS	1	2
CHEM	7	3
Aeroshell	10	
SEP	17	198

Total Mass ~ 77 kg
(incl. 20% contingency)

Total Spacecraft Power ~ 37 W
(Peak, incl. 20% contingency)



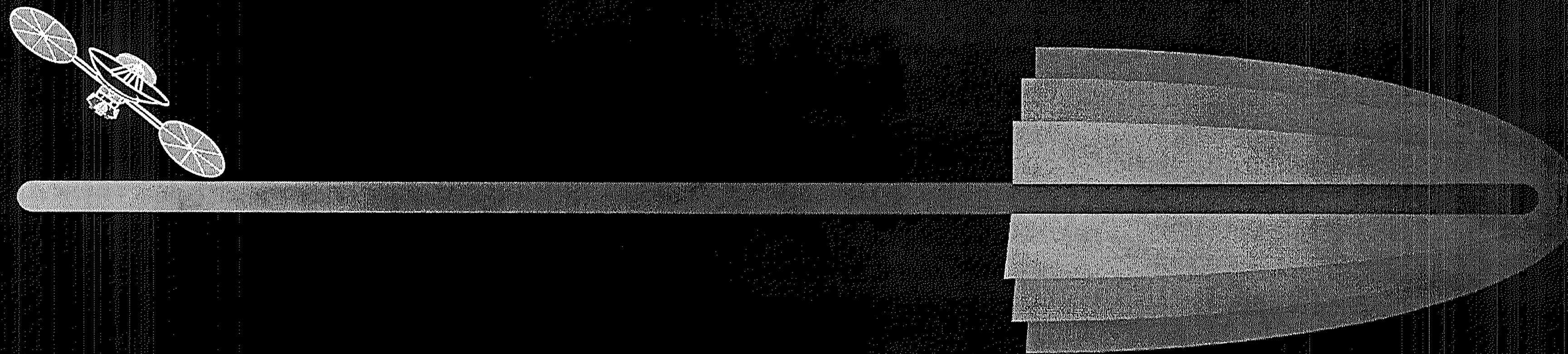
CONCLUSIONS

- The use of advanced technologies enables a class interplanetary spacecraft unlike anyone before, with an injected mass at about 77 kg.

- Both SEEGA and Aerocapture are essential to the accomplishment of this mission.

- Ka-band allows the return of a generous amount of science data, given the vast distances involved.

- NExTEP demonstrates the feasibility of a low-cost mission to Neptune, using a Taurus-class launch vehicle.



BACKUP CHARTS

NEPTUNE ORBITER CONFIGURATION