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PROJECT LONGSHOT

AN UNMANNED PROBE TO ALPHA CENTAURI

U.S. NAVAL ACADEMY

NASA/USRA University Advanced Design
Program Project Report for 1987-1988

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PROJECT LONGSHOT

This report presents a preliminary design for an unmanned probe to Alpha Centauri with a planned launch early in the 21st century. This mission was based upon a requirement stated in the report by the National Commission on Space, Pioneering the Space Frontier. The probe would be assembled at the space station and take approximately 100 years to reach the nearest star. Several technologies must be developed in order for this mission to be possible. A pulsed fusion microexplosion drive with 1,000,000 seconds of specific impulse is the primary enabling technology. A large, long-life fission reactor with 300 kilowatts power output is also required. Communications lasers would use a 0.532 micron wavelength since there is minimal power output by the stars in that frequency band. A laser with an input power of 250 kilowatts would allow for a data rate of 1000 bits per second at maximum range. There are three types of information to be gathered by the probe: properties of the interstellar medium, characteristics of the three-star Alpha Centauri system, and astrometry (finding distances to stars using parallax measurements).

ACKNOWLEDGEMENTS

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The faculty advisors were Assistant Professor Walter K. Daniel and Professor George F. Pieper. The NASA representative from Goddard Space Flight Center was Dr. Stephen Paddack, who is also a Naval Academy Visiting Professor. Visiting Professor Fred Mobley from the John Hopkins Applied Physics Laboratory participated in the design courses.

1.0 MISSION MODEL

1.1 General Mission

The subject of this report is the design of an unmanned probe to Alpha Centauri. This mission is called for in the report by the National Commission on Space, Pioneering the Space Frontier. On pages 38 through 40 the commission outlines a program for solar and space physics which is planned for the period "beyond the initial operation of the space station," and includes "a long life high-velocity spacecraft to be sent out of the Solar System on a trajectory to the nearest star." Our probe will be a completely autonomous design based upon a combination of current technology and technological advances which can be reasonably expected to be developed over the next 20 to 30 years. The expected launch date is in the beginning of the next century with a transit time of 100 years.

The mission profile will be as follows:

1. Assembly of modular components on the ground.
2. Launch of components to LEO.
3. Assembly of components at Space Station.
4. Boost assembled and fueled spacecraft to injection point for interstellar trajectory using chemical upper stage.
5. Start main fusion drive and begin interstellar flight which will last approximately 100 years.
6. During this period data will be returned on the interstellar medium and magnetic fields.
7. Enter elliptical orbit around Beta Centauri and begin transmission of data.

1.2 Technology

Using purely current technologies, a mission to another star system would be impossible to complete. There are basically three main areas where advances are needed: propulsion, data processing for command and control functions, and reliability.

In order to reduce transit time to an acceptable length, specific impulses on the order of 10E6 seconds are required. This represents an increase of several orders of magnitude over chemical rockets and nuclear rocket models which can be implemented using only present technology. To achieve the required levels of impulse, a pulsed fusion reactor based rocket engine is proposed. Based on the current level of technology in the field of microbomb fusion it is reasonable to assume that in 20 to 30 years such a system will be possible.

Due to the great distance at which the probe will operate, positive control from earth will be impossible due to the great time delays involved. This fact necessitates that the probe be able to think for itself. In order to accomplish this, advances will be required in two related but separate fields, artificial intelligence and computer hardware. AI research is advancing at a tremendous rate. Progress during the last decade has been phenomenal and there is no reason to expect it to slow any time soon. Therefore, it should possible to design a system with the required intelligence by the time that this mission is expected to be launched. The problem with basing the design on current hardware is one of weight and speed. Producing a system with the required intelligence and speed, while including the needed redundancy using current technology, would result in a huge unit requiring a cooling system as large as a nuclear power plant's. Current advances have shrunk a Cray 2 from a room sized system needing a huge cooling plant to two chips, and with the advent of high temperature super-conductor technology there is every reason to assume that many more such quantum leaps in computer technology may be expected in the next 20 to 30 years.

Since no one has ever designed a dynamic system to last for more than a century, it is impossible to guess just how much the reliability of current systems will have to be improved. However, many satellites which were designed with mission lives of only a few years have operated for much longer periods of time, often failing merely because they ran out of expendables. The Transit family is a good example: they were designed to last for only 18 months and there are some still operating after 18 years or more. Other examples include Pioneer, Mariner, Voyager, and Viking. With successes in reliability such as these, and the improvements in simulation technology which will come with the improvements in computer technology (discussed in the previous paragraph), there should be no difficulty in designing in the required reliability.

1.3 Infrastructure

A very strong effort towards space exploration will be required to complete this mission and this commitment will have to begin in order to ensure that those systems essential for the production of the probe and its initial boost phase will be in place when the enabling technologies are realized. These systems include a heavy-lift launch vehicle, a large space station and an advanced, high energy upper stage. These requirements represent merely the technological infrastructure; also required is a very large initial human infrastructure, as well as a long term human commitment.

The heavy-lift launcher is needed since current weight estimates for the spacecraft are in excess of 350 metric tons. Even after taking into account the assumption that the ship will be launched to LEO as a series of modular components, the size of many of the modules precludes their launch on the Shuttle. Additionally, some units will be too massive and complex to be launched by available launch vehicles.

Since a basic assumption in this analysis is that the probe will be launched in a modular form and assembled in orbit, it is necessary to provide an orbiting base of operations for the personnel assembling the components of the spacecraft. This base will be Space Station. Requirements for the station will include:

Capability to house a large work force to include assembly technicians and test engineers.
A number of large manipulator arms and sufficient mechanical support structure to allow attachment of all required assembly jigs.
Adequate data processing capability to perform systems checks during assembly and the final system check-out following assembly.

Due to the nature of the main drive, it is both inadvisable and impossible to complete the mission by igniting the fusion drive in LEO. This fact leads to the requirement for the advanced upper stage. The planned in-solar system mission profile calls for a series of three burns using these upper stages to escape the solar system from which the interstellar injection may be made. This report will assume that the upper stage will have twice the impulse and similar weight characteristics to a Space Shuttle SRB.

The human side of the infrastructure will be a much greater challenge than the technical side because the required commitment spans such a long period of time. The time between the initial authorization for the mission until the return of the first data from the Alpha Centauri system will be well in excess of one century. In fact it will probably be on the order of two centuries when the time needed for hardware design, procurement, in-orbit assembly, and transit are considered. The effort required to design, build and launch the probe would be on the order of the Apollo project or much larger. The commitment at the other end of the mission should be an easy one to fulfill since scientists will be eager to analyze the incoming data. Thus, the greatest challenge comes with the caretaker portion of the mission - the century of travel time when very little data will be transmitted. The problem here is not the number of people required, since it will be small, but rather the time involved. There has never been a similar project in modern history carried out over such a long time scale. However, there have been organizations which have lasted for such a time. In fact, some have lasted longer! Some examples include: the militaries of nations such as the U.S. and U.K., various research institutions like the National Geographic Society and the Smithsonian Institution, and private organizations such as the Red Cross and the Explorer's Club. The precedent exists for organizations continuing for the required time frame. Therefore it can be assumed that the required support structure can be established.

2.0 MISSION PROFILE

2.1 Objective Star System

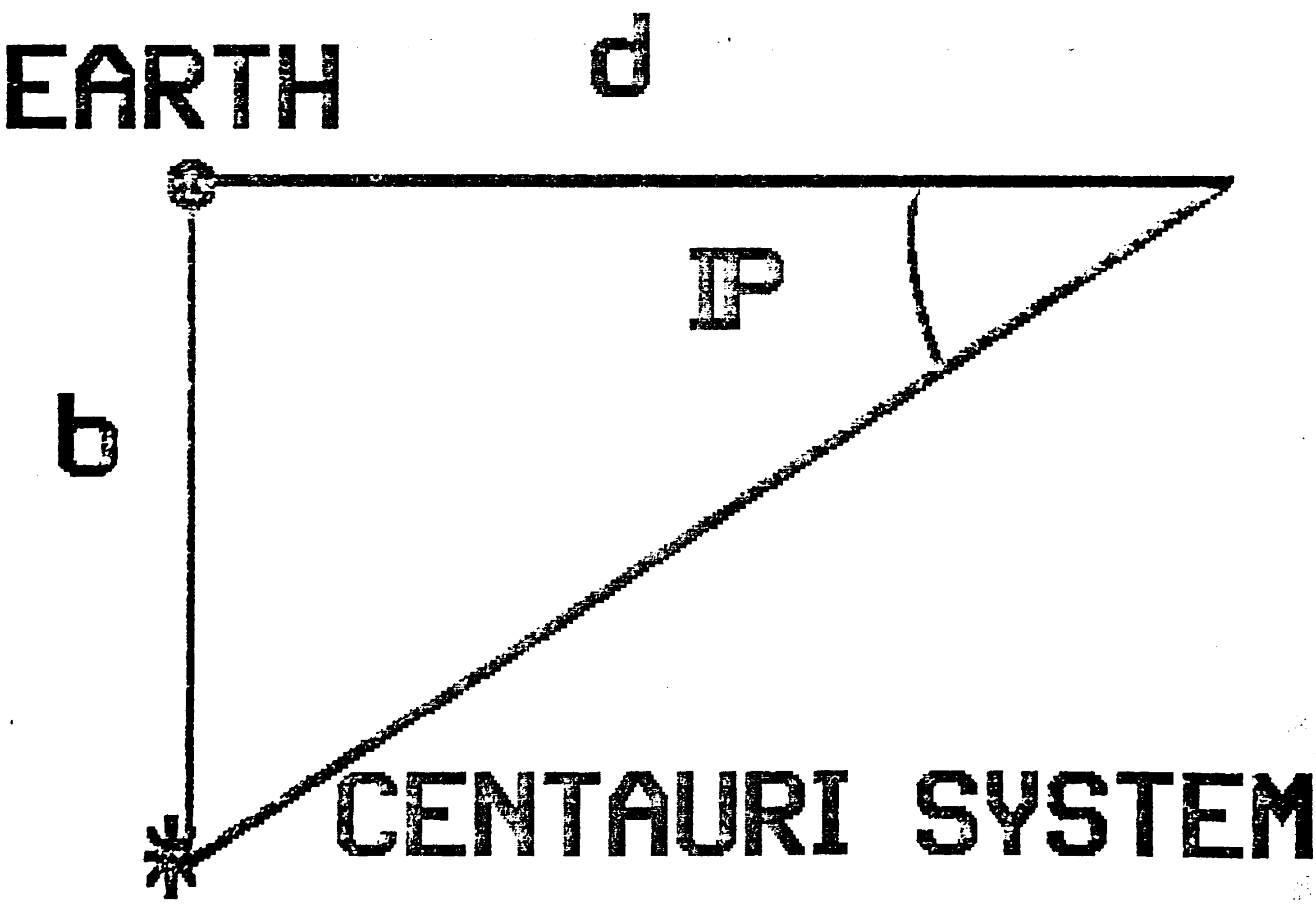
The star system chosen as our objective system for this mission is the Alpha Centauri trinary star system. There are three main reasons for choosing this system as the destination of the probe: (1) the system's proximity to our solar system; (2) the scientific interest of a trinary system; (3) sending a probe to this star system provides an opportunity to make great advances in the field of astrometry.

One of the main concerns regarding the success of the mission is the ability of the probe to be in good working order when it reaches the objective system. While any interstellar mission will require transit time in excess of a century, the Alpha Centauri system is the closest to our own, and thus provides the best opportunity to deliver a functional probe to another star system.

While it would be a great achievement to do a close-up study of any other star system, the Alpha Centauri system promises to be a particularly interesting objective. Alpha and Beta Centauri, which are type G2V and dK1 stars, respectively, orbit each other with a separation of 11 to 35 AU. The third star of the system, Proxima Centauri, orbits the other pair at a distance of about 1/6 of a light year. Proxima Centauri is a type dM5e red dwarf, which exhibits sudden changes in magnitude. It is also one of the smallest known stellar masses. Proxima's position should provide an opportunity for the probe to pass relatively close by on its way to its final destination, a close orbit about Beta Centauri. There is also the possibility that this star system contains planets. Advances in astronomy before the probe is launched should provide much more information about the system to help plan the probe's exploration.

Perhaps the greatest contribution that the mission will make to the scientific community will be in the field of astrometry. Sending a spacecraft to the Alpha Centauri system provides an opportunity to make parallax measurements with a baseline of 4.34 light years (see Fig 2.1a). This is over 63,000 times longer than the present method, which uses the semi-major axis of the Earth's orbit as a baseline (see Fig 2.1b). At this time, parallax measurements are only accurate to about 20 parsecs from the Sun. The longer baseline would allow accurate measurements of stellar distances of more than 1.2 million parsecs. If the probe lasts long enough, it has the potential to accurately determine the distance to hundreds of trillions of stars. Knowing the distance to a star is vital in determining its properties. Such an accomplishment would keep astronomers busy for quite some time.

PARALLAX DETERMINATION

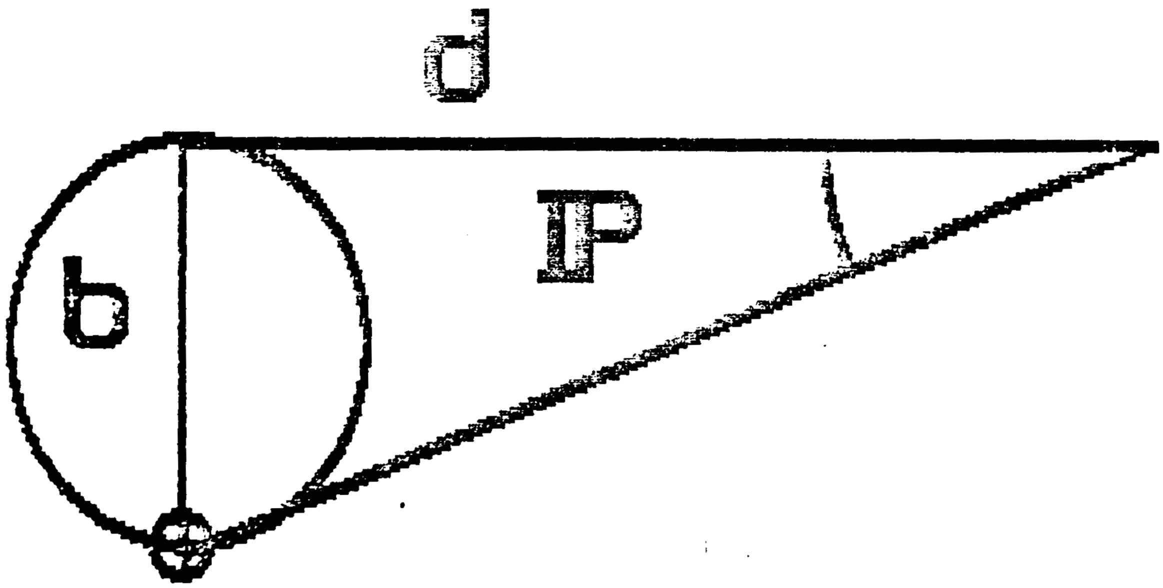


THE BASELINE FROM CENTAURI SYSTEM IS LONG.

Fig. 2.1a

PARALLAX DETERMINATION

$$d(\text{parsecs}) = \frac{b(\text{AU})}{\mathbb{P}(\text{arcsecs})}$$



From Earth the baseline, b, is short.

Fig. 2.1b

2.2 Operations

Assembly of the probe will occur in two phases; major components and subsystems will be assembled and tested on the ground, and then sent to LEO for final assembly and integration into the spacecraft. Transfer to orbit will require multiple launches with initial estimates indicating that launches will be carried out in the following manner, (based on current projections):

Fusion engine - one launch on an ALS-class vehicle.
Main structure - one launch on a Shuttle-class vehicle.
Fuel tanks - one launch on an ALS-class vehicle.
Fuel - one launch on a Growth ALS-class vehicle.
Payload - one launch on an ALS-class vehicle.
Upper stages for the initial phase of the mission will be launched as required based upon advances in upper stage technology.

The fusion drive will be launched as a finished unit due to its complexity. It will be equipped with a plug-in type interface for integration with the remainder of the ship. The main structure will be a collapsible space frame, which will be erected from its stored configuration by personnel at the space station. Additional structure will also be orbited in collapsed form for erection at Space Station. The fuel tanks will be built of sheet aluminum with formed end caps. The end caps will be launched in a completed and stacked configuration and the sheeting for the bodies will be rolled into a solid cylinder for launch. Assembly will occur in orbit using advanced adhesives technology. The fuel for the fusion engine will consist of He3 and deuteruim. The He3 will probably be manufactured on earth using particle accelerators, and then both components of the fuel will be launched in liquid form to orbit for processing into pelletized reactor fuel. The payload, like the fusion drive, will be launched fully-assembled, and have a simple plug-in interface to the rest of the system.

By the time that this mission will be flown, the experience gained through the assembly of Space Station, and the ongoing orbital operations which it is expected to support, will provide an adequate base of technology for personnel to assemble the probe. During assembly, systems checks will be run as each component is integrated into the spacecraft, to prevent failures which could necessitate disassembly of components assembled in orbit. Following assembly, a comprehensive system check-out will be made prior to ignition of the upper stages.

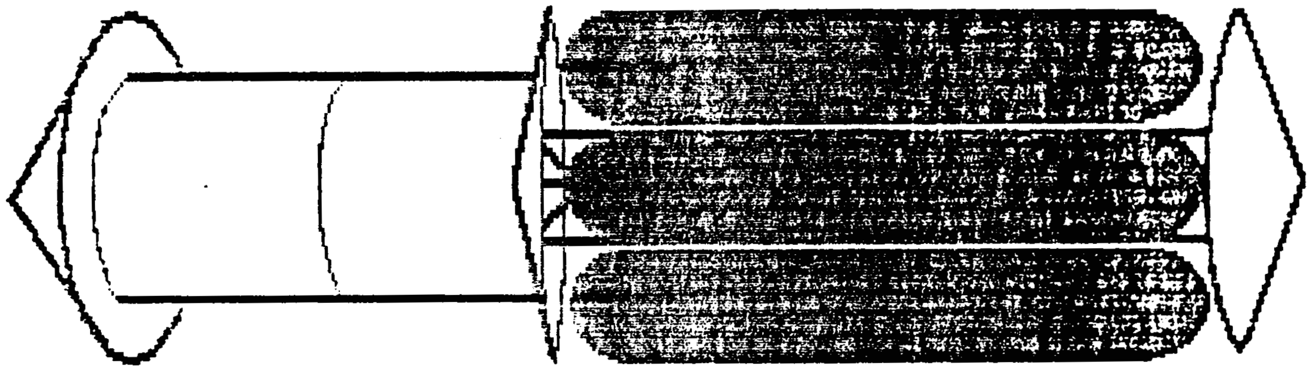
The fission reactor will be used to provide the initial power required to start the fusion reactor. Once the drive is ignited it will become self-sustaining and provide enough excess power to operate the systems in use during the transit. During this phase, fuel will be drawn from symmetrically located pairs of fuel tanks to avoid instability caused by non-homogeneous mass distribution. As each pair of tanks is emptied, they will be discarded. Tank volume has been calculated so that four of the ship's six tanks will have been jettisoned by the time it reaches the turn-around point (see Figs 2.2a and 2.2b). This point has been chosen so that reversal of the spacecraft and reignition of the main drive will result in arrival at the target at proper insertion speed. When the turn around point is reached, the drive will be shut down, and the probe rotated 180 degrees with respect to its velocity vector using the attitude control system. Following the turn around maneuver, the fission reactor will again be used to provide power to restart the drive. These activities will occur at the 71.27 year point in the mission (see Figs. 2.2c and 2.2d for graphs and appendix for calculations).

Throughout this phase of the flight, data from experiments on interstellar space will be returned to earth at low data rates. This will serve two purposes, providing scientific data, and ensuring that contact will be maintained with the probe. Since the probe will be fully autonomous, any problems with the communications system, due to degradation of the transmitting equipment or faulty link analysis will have to be corrected by making improvements to the receiving equipment. Maintaining constant contact will allow the required lead time to implement any necessary corrective measures in the receiving equipment.

After deceleration is completed, the two remaining fuel tanks and the fusion drive will be discarded and the instruments deployed. The attitude control system which was used to rotate the entire spacecraft will be used as necessary to place the

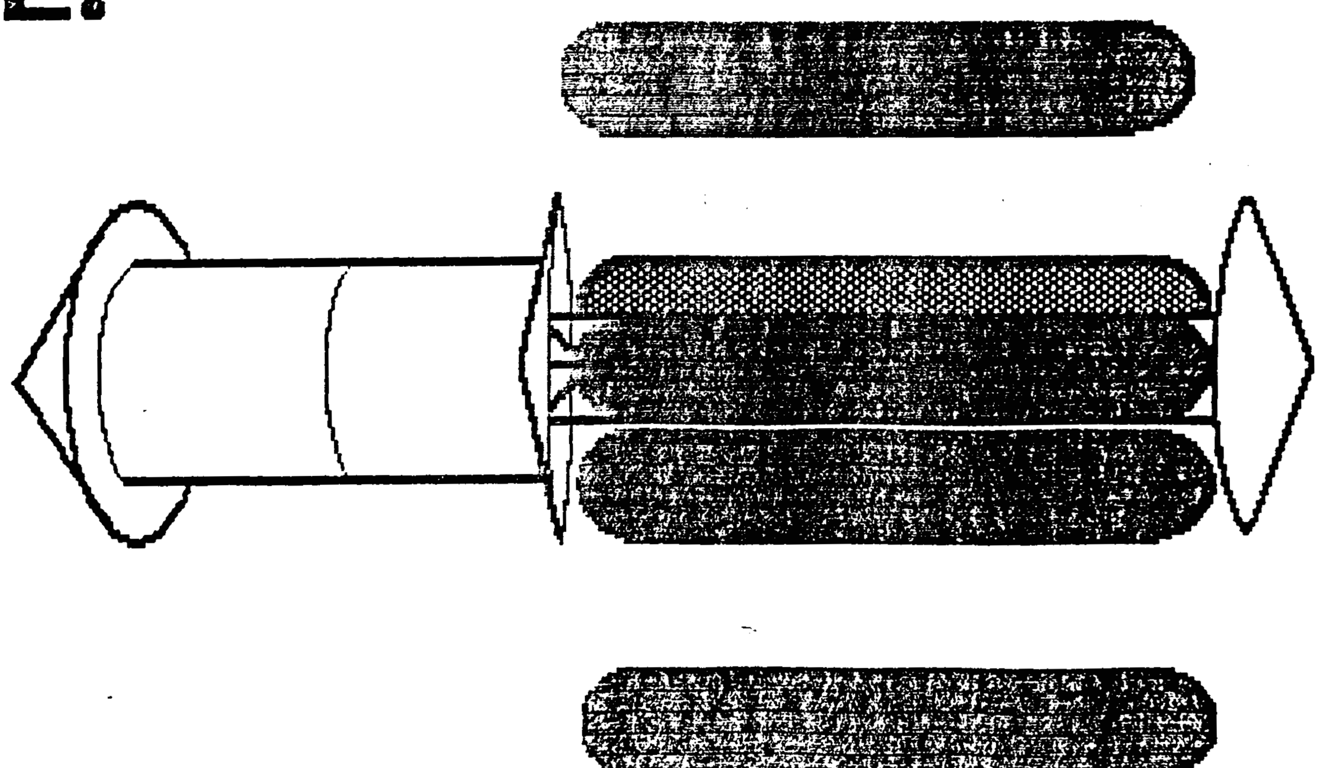
INTERSTELLAR FLIGHT PHASE

1.



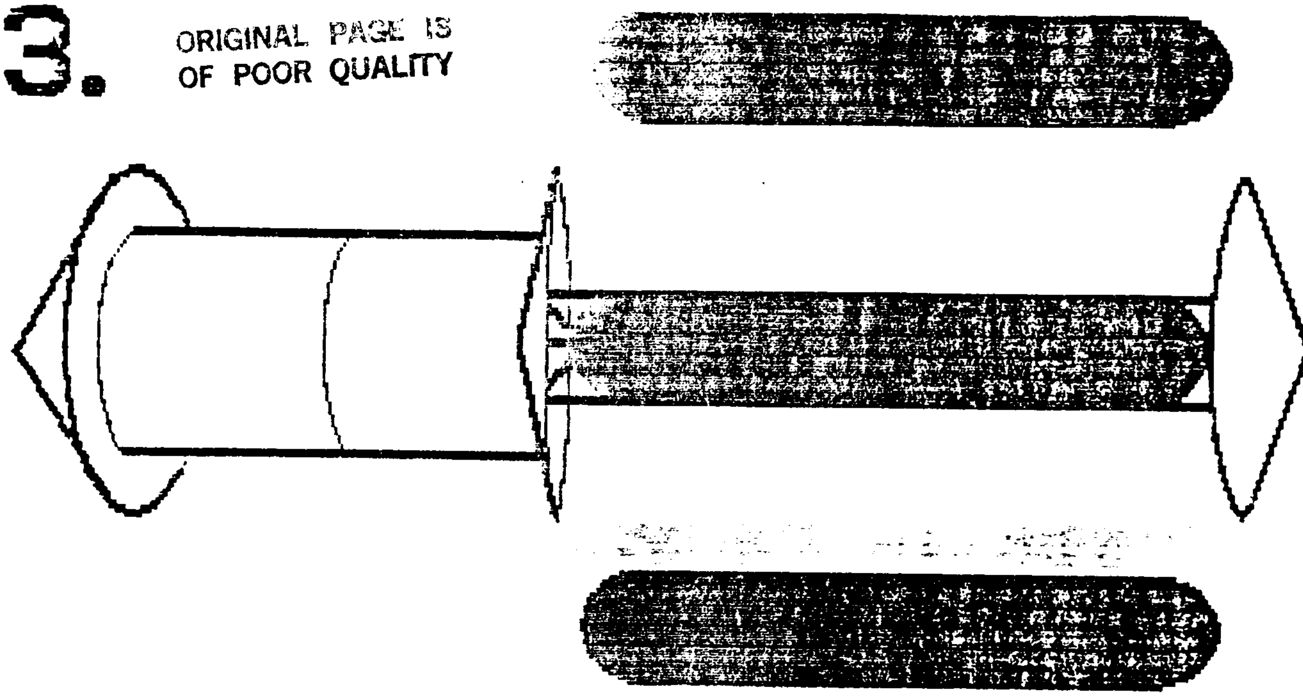
INITIAL CONFIGURATION

2.



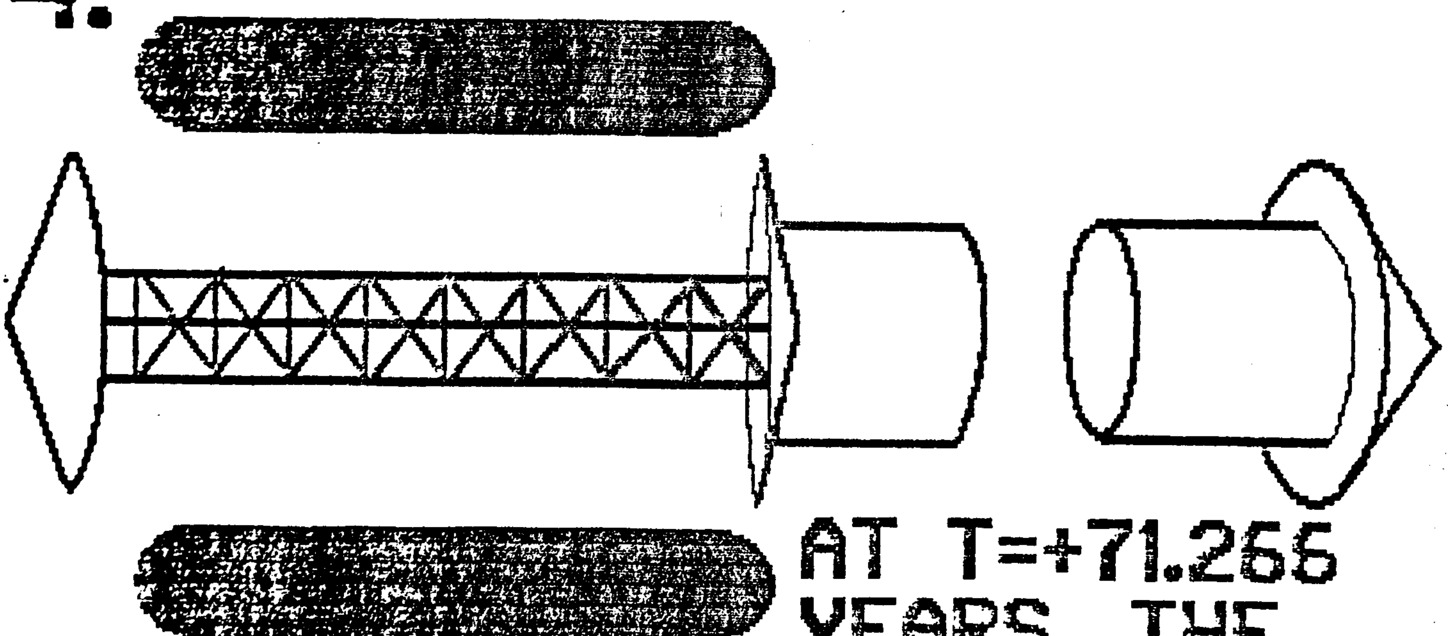
TANKS ONE AND TWO JETTISONED
AT TIME T=+33.35 YEARS

3.



TANKS THREE AND FOUR JETTISONED AT TIME T=+66.7 YEARS

4.



AT T=+71.266 YEARS, THE SPACECRAFT ROTATES. AT T=+100 YEARS (ARRIVAL AT TARGET STAR), TANKS FIVE AND SIX JETTISONED, ENGINE AND SHIELDS SEPARATE.

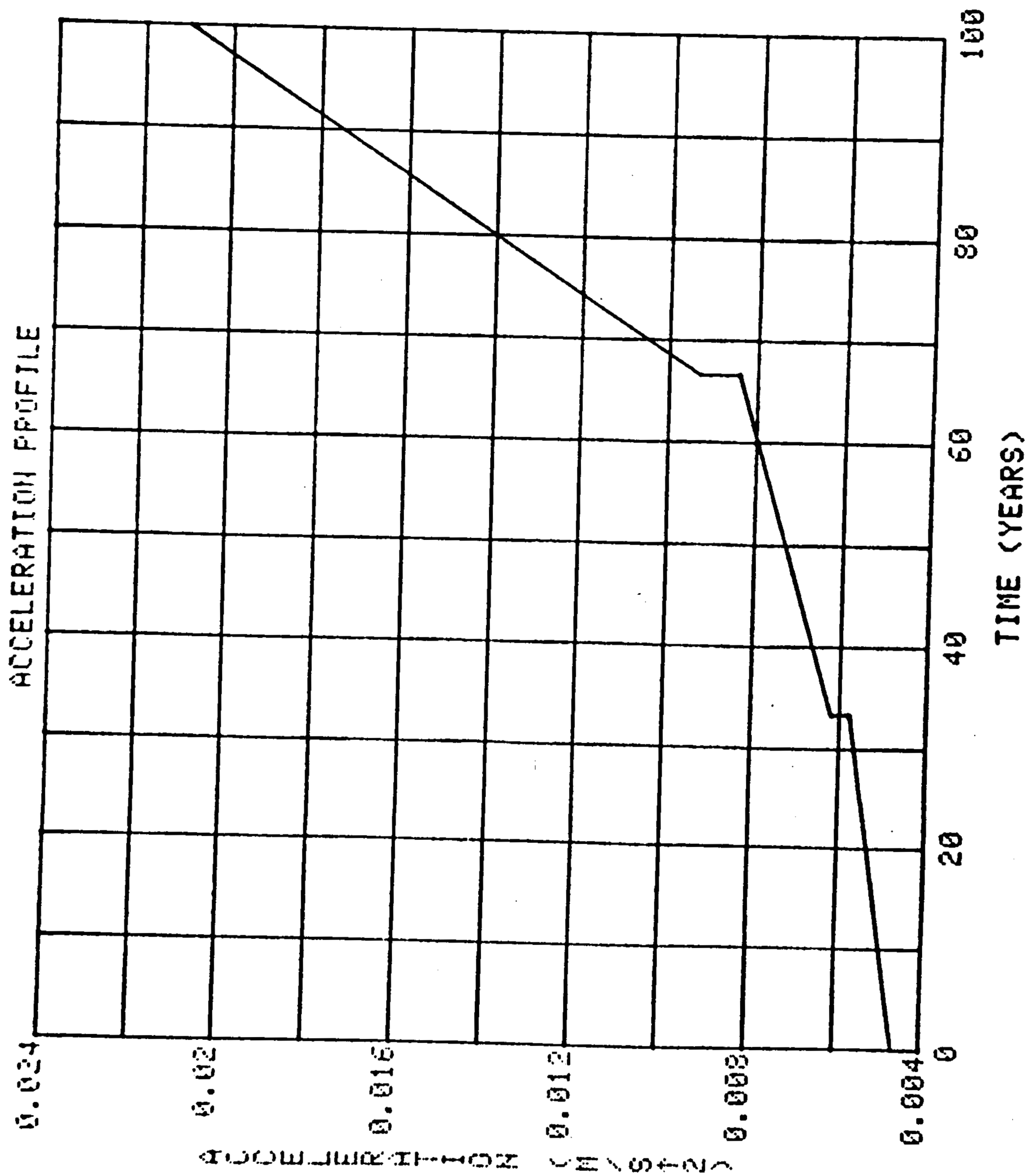

ACCELERATION PROFILE
TIME (YEARS)
0
20
40
60
80
100
0.024
0.02
0.016
0.012
0.008
0.004

Fig. 2.2c

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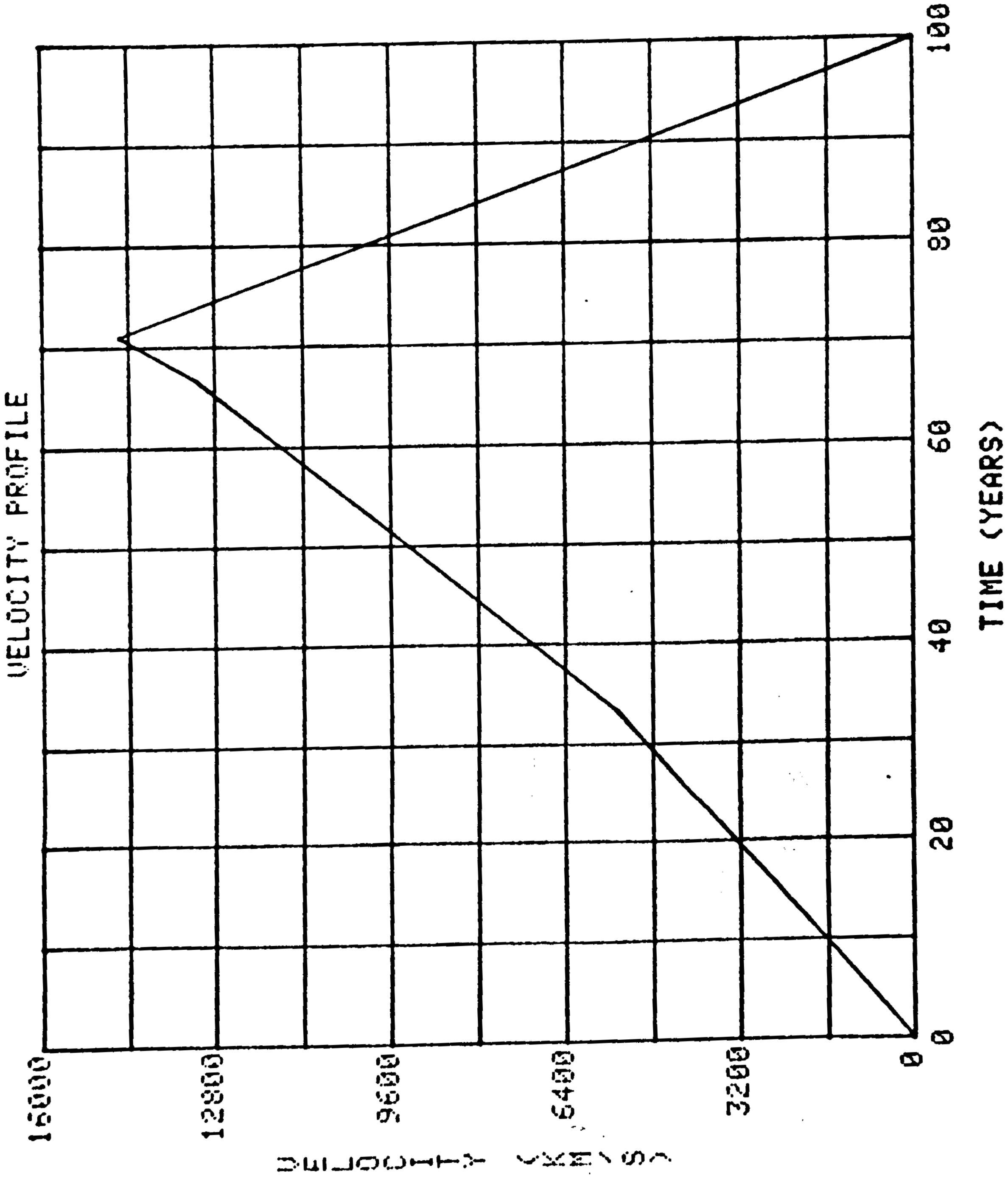


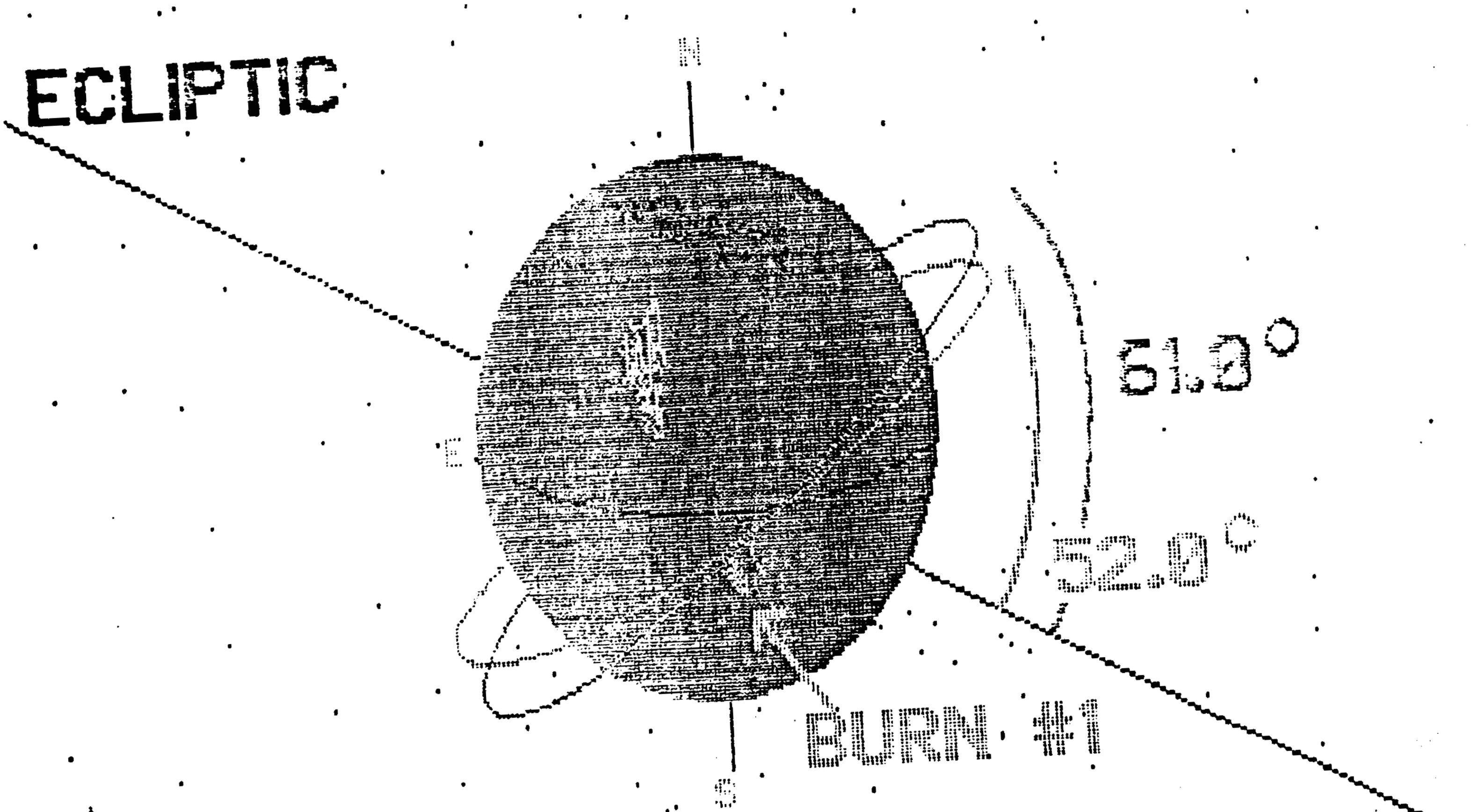
Fig. 2.2d

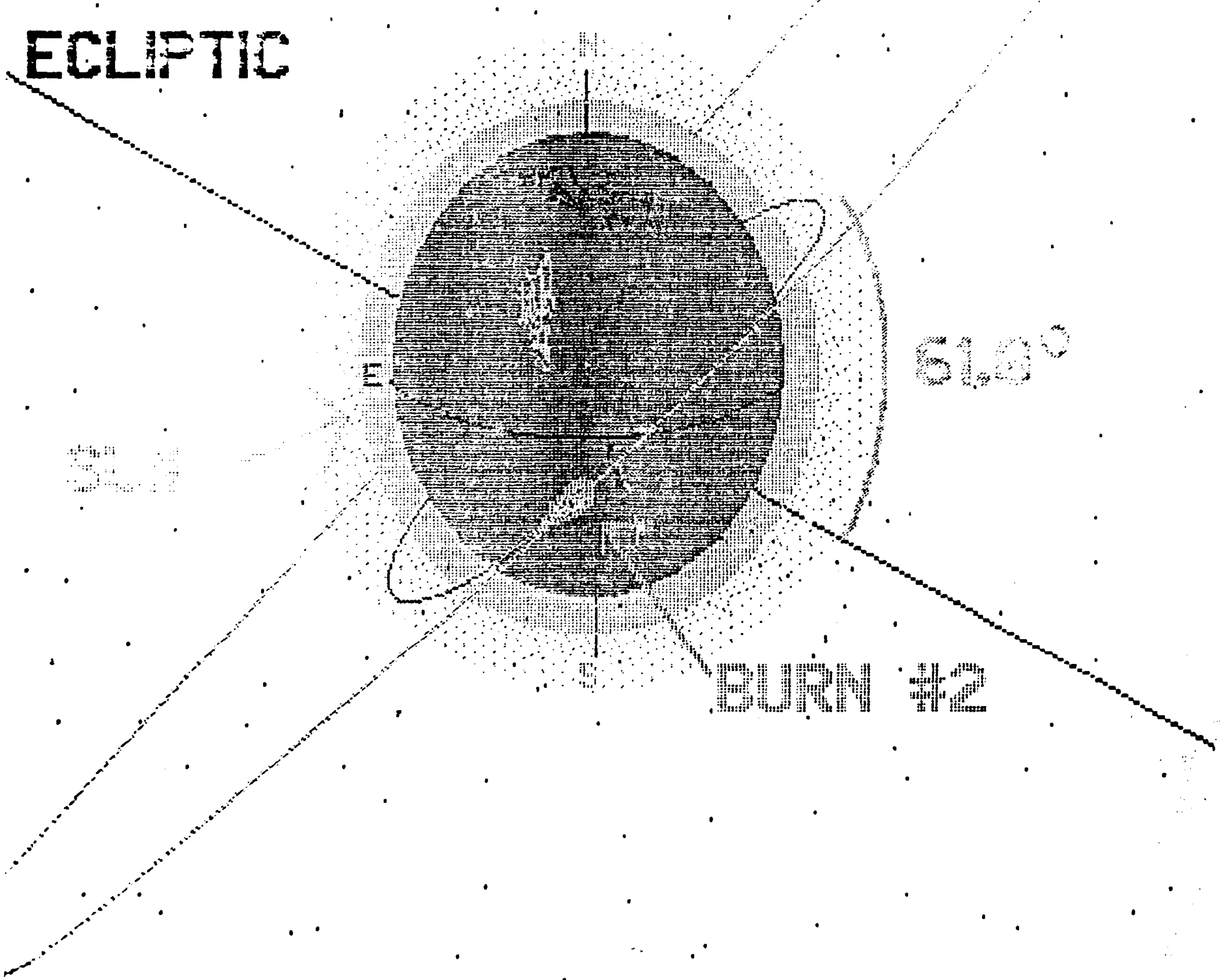
probe into an elliptical orbit around Beta Centauri and to maintain this orbit. Once in orbit, high data rate collection and transfer will begin based on both a preprogrammed series of studies and a set of prioritized experiments (determined by what is found in the system). This will continue until the spacecraft's nuclear plant ceases to produce enough power to operate the communications lasers, which will constitute the end of the mission.

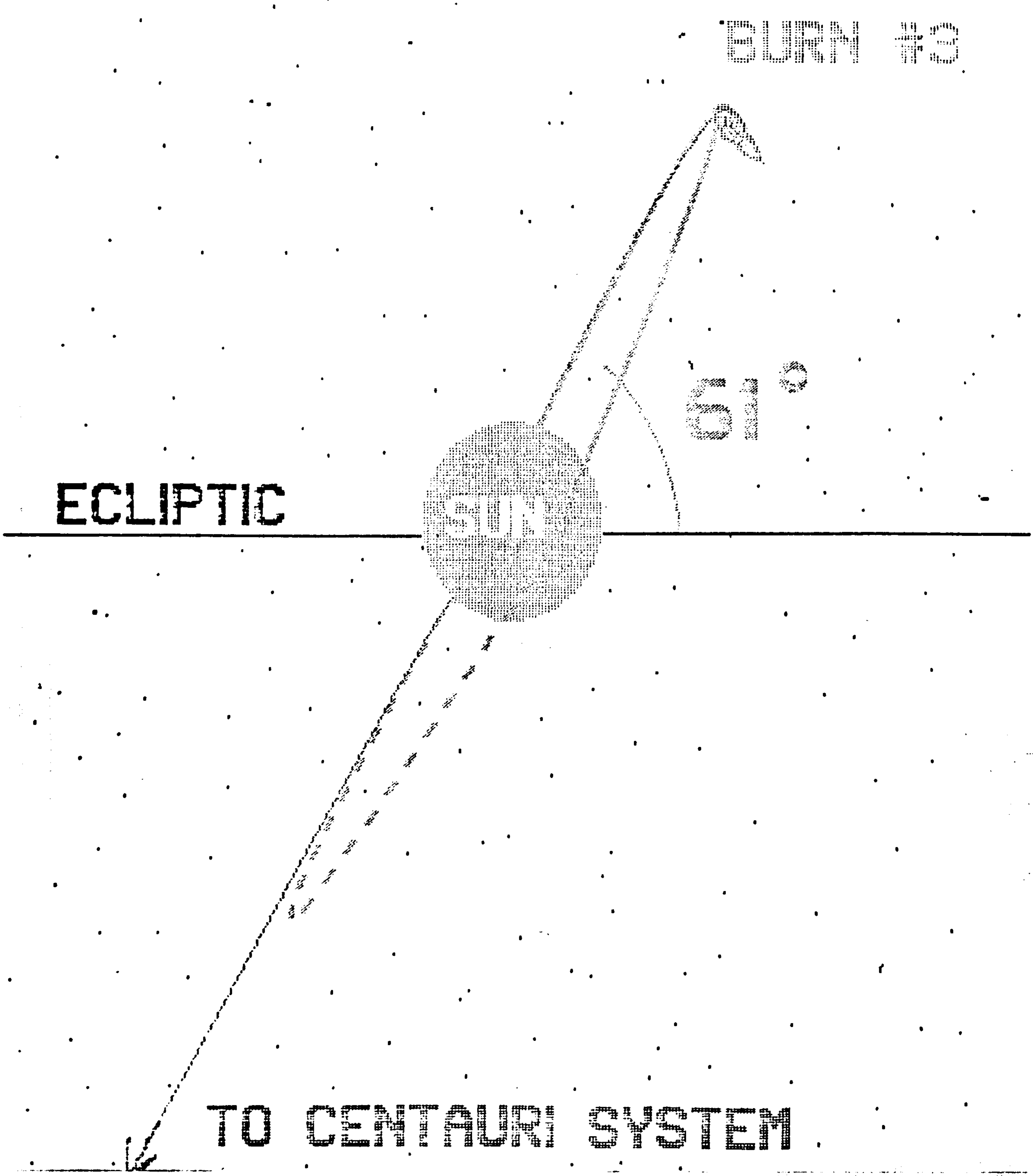
2.3 Orbits

Once the probe is assembled in orbit at the space station, it will be nudged into an independent butsimilar orbit to prevent damage to the station due to the exhaust from the first upper-stage burn (see Fig. 2.3a). This burn will be made to increase the inclination of the probe orbit from 28.5 degrees to 37.5 degrees so that it will sum with the obliquity and result in an orbit inclined 61 degrees relative to the ecliptic. This stage will be jettisoned, and the spacecraft will then escape Earth with a second burn which occurs at the ascending node of the probe's orbit about the earth (see Fig. 2.3b). This point then becomes the ascending node of the probe's heliocentric orbit, which is a circular orbit at 1 AU and at an inclination of 61 degrees. The second stage will then separate, and three months (i.e. one-fourth of an orbit) later, the third and final upper-stage will burn. This will send the spacecraft on an escape trajectory toward the Centauri system (see Fig. 2.3c), which is located at a declination of -61 degrees to the ecliptic. Upon completion of the interstellar phase of the mission the probe will be inserted into an eccentric orbit about Beta (see Figs. 2.3d and 2.3e).

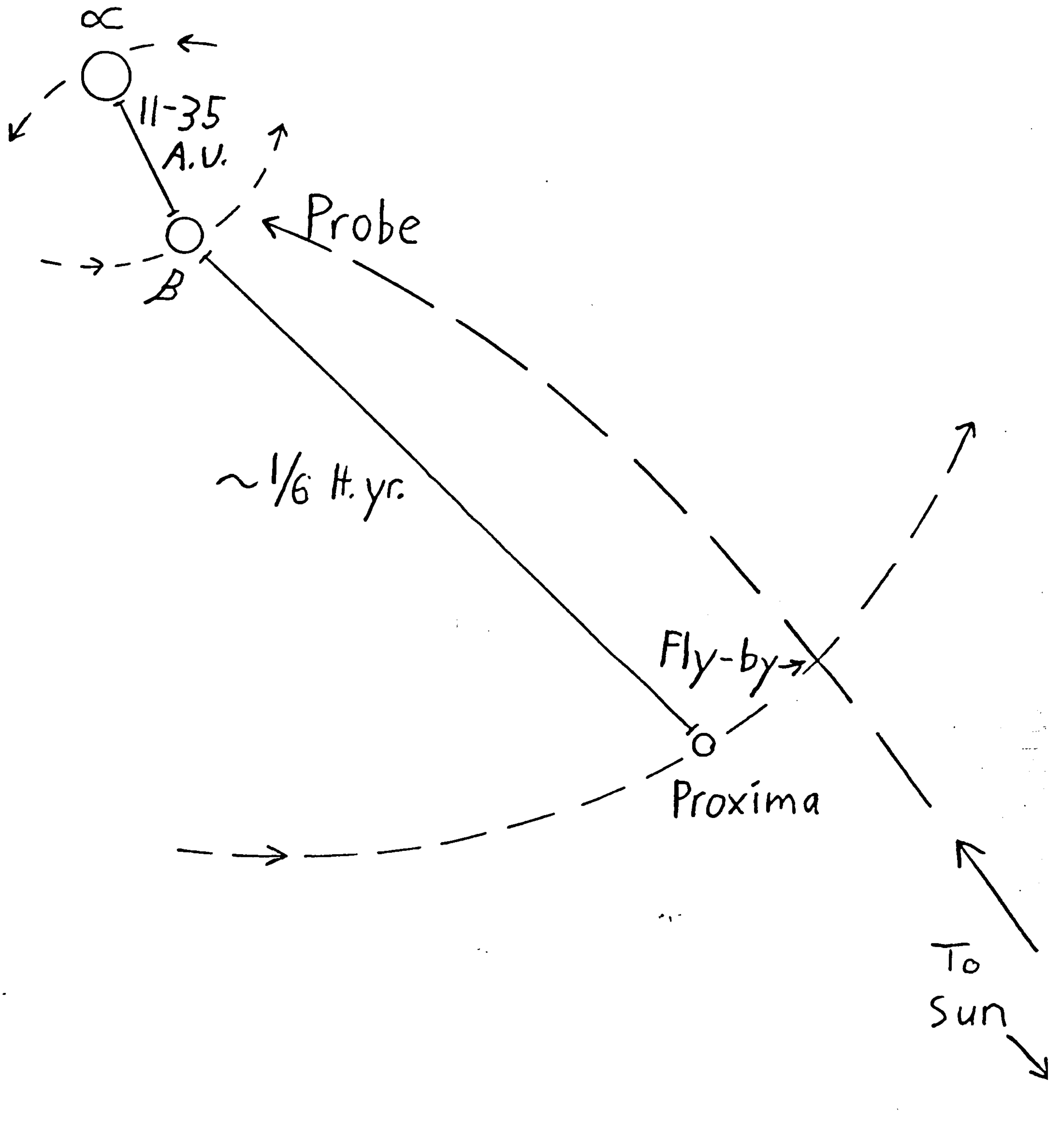
Assuming a space station orbit of 300 kilometers at an inclination of 28.5 degrees, the following values were determined for required velocity changes for the probe. The Alpha Centauri star system is at a


ECLIPTIC
N
E
S
51.0°
52.0°
BURN #1

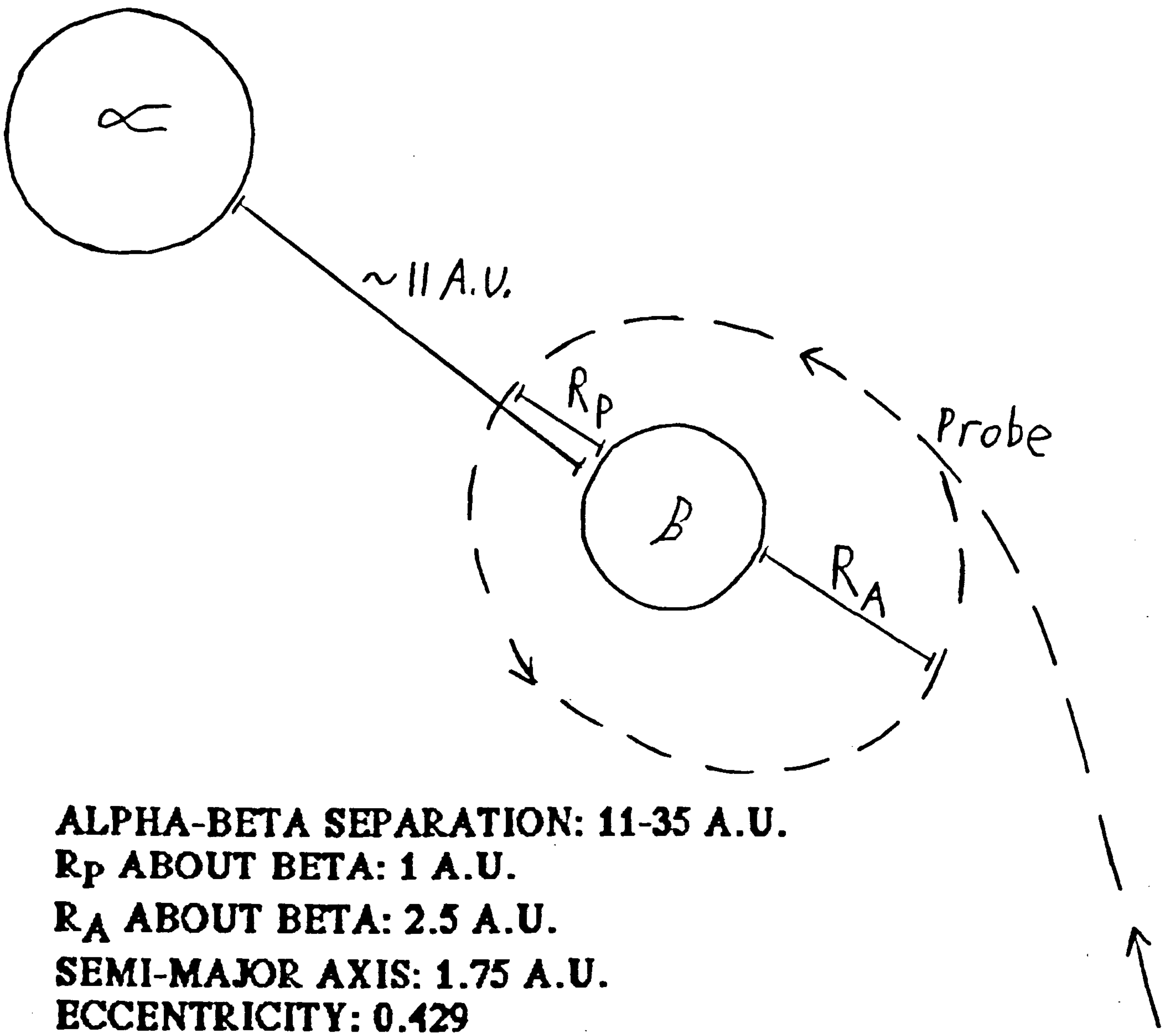

ECLIPTIC
N
E
S
61.8°
BURN #2


BURN #3
61°
ECLIPTIC
SUN
TO CENTAURI SYSTEM

SYSTEM INJECTION



FINAL ORBIT
ABOUT BETA CENTAURI



ALPHA-BETA SEPARATION: 11-35 A.U.
R_P ABOUT BETA: 1 A.U.
R_A ABOUT BETA: 2.5 A.U.
SEMI-MAJOR AXIS: 1.75 A.U.
ECCENTRICITY: 0.429
PERIOD: 2.5 EARTH YEARS
VELOCITY AT APOGEE: 13.1 km/sec
VELOCITY AT PERIGEE: 32.9 km/sec

declination of -61 degrees relative to the ecliptic of our solar system. At the optimum launch position, the obliquity (23.5 degrees from the ecliptic) will sum with the inclination angle of the spacecraft's orbit (28.5 degrees from the equator). This will make the probe's orbit 52 degrees from the ecliptic. Thus, a 9 degree plane change is required to put the probe into a 61 degree orbit around the earth (relative to the ecliptic). From this orbit, another velocity change is necessary to escape the earth's gravity and inject the probe into a circular orbit about the sun at 1 AU and a 61 degree inclination. At this point, there are two options to be considered, depending on the fuel source, Earth or Jupiter. For the first option, the probe will leave from this orbit directly for Alpha Centauri, in which case it will change velocity at the perihelion of the transfer orbit between our solar system and Alpha Centauri. For the second option the spacecraft will transfer to a Jupiter-distanced heliocentric orbit, using a velocity change at the perihelion of the Earth to Jupiter transfer orbit, and inject into an orbit around Jupiter at a 61 degree inclination (to take on fuel). The probe will then escape back into a Jupiter-distanced heliocentric orbit at 61 degrees relative to the ecliptic. Finally, it will escape the solar system and head for Alpha Centauri, with a burn at perihelion of the Sol-Centauri transfer orbit.

(see appendix for actual number calculations)

1. Delta-V for plane change of 9 degrees	1.2123 km/s
2. Delta-V to escape earth	3.2002 km/s
3. Delta-V to escape solar system	12.4273 km/s
4. Total Delta-V for Option #1	16.8398 km/s

For Option #2, the first two numbers are the same.

5.	Delta-V to enter Earth-Jupiter transfer	8.8223 km/s
6.	Delta-V to orbit around Jupiter	7.4814 km/s
7.	Delta-V to escape Jupiter	6.1705 km/s
8.	Delta-V to escape solar system	5.4087 km/s
9.	Total Delta-V for Option #2	32.2954 km/s

Obviously, the option of picking up fuel mined from the atmosphere of Jupiter would be impractical because of high cost and complication.

For the objective orbit within the Centauri system, Beta was chosen as the target star because it is a dK-Type star, about which we have very little data, while Alpha is a G2 type star like our own, which we have studied extensively. The orbit chosen is based on an assumption that Alpha and Beta (which vary in distance between 11 and 35 AU) will be at the lesser of the two distances. The orbit chosen is an elliptical orbit around Beta for which the aphelion lies on the line between Alpha and Beta. The perihelion radius was set at 1 AU. The aphelion was determined based on a requirement that the gravitational effect of Alpha would not exceed 5% of the gravitational effect of Beta. Accordingly, an aphelion of 2.5 AU was chosen. At this aphelion the gravitational force on the probe due to

Alpha will be equal to 3.3% of the gravitational force due to Beta. Based on the chosen perihelion and aphelion radii, the orbital parameters were determined:

a = 1.75 AU
e = 0.428572
E = -216.95 kmE2/secE2
T = 2.4977 Earth years
Va = 13.1 km/s
Vp = 32.935 km/s

The perihelion velocity will be the velocity to which the probe must be slowed for proper insertion into this orbit.

3.0 SPACECRAFT SYSTEMS

3.1 Power

Power for the instruments, computer, communication lasers, and star trackers will be supplied by a 300 kilowatt nuclear reactor. This reactor will be compact-sized, have a low specific mass, long life, high reliability, and a variable power output. Different systems were compared, and a design published by Jones, MacPherson, and Nichols, of the Oak Ridge National Laboratory was chosen and scaled down to suit the needs of the Centauri mission.

This power system concept defines a nuclear reactor with ceramic fuel, clad with refractory metal, and cooled by liquid potassium (1365 K). Also described is a direct, closed Rankine power conversion cycle, and a large tetraxial flywheel energy storage system featuring graphite composite materials and magnetic bearings. The fuel is is enriched uranium nitride pellets. The reactor and flywheel systems will be constructed as separate modules designed to fit in the shuttle cargo bay.

The reactor will boil potassium which will then be piped through a turbine that will convert the thermal energy to mechanical energy. The potassium is further cooled by flowing through the heat radiators and is then recycled back into the reactor.

The electrical current produced by the spinning turbine is directed to the two (for redundancy) energy storage systems located at either end of the main structural truss. The modules contain flywheels which store the energy in their spin rate, and also provide attitude control by absorbing external torques.

	Mass
reactor	500 kg
shielding	830 kg
turbine	230 kg
piping and miscellaneous	680 kg
8 flywheels	3400 kg
flywheel motors, structure	760 kg
Total mass	6400 kg

Power output is variable but will need to be a minimum of 250 kW during the in-system phase of the mission to power the communication lasers and computer.

3.2 Propulsion

3.2.1 In Solar System

Since it will not be practical (or safe!) to ignite the fusion drive while in earth orbit, another propulsion system will need to be used for the plane change and to escape the Earth and the solar system (see Orbits). Advanced solid rockets will be employed to accomplish these velocity changes. It is assumed that they will be similar in size and fuel to the Space Shuttle's SRB's with twice the specific impulse (near 600 seconds). Based on this assumption, the following parameters for the various upper stages were calculated:

(see appendix for calculations)

Booster	Mass (kg) Fuel/Total	Length (m)	Diameter (m)
Plane change	352/417	16	3.7
Escape Earth	605/715	25	3.7
Escape Sun	252/298	11	3.7
Total mass:	1209/1430		

3.2.2 Interstellar Transit

Developing a Propulsion system capable of meeting the 100-year interstellar travel time is the most difficult part of the mission design. 4.3 light years is an easily misinterpreted distance. It is equivalent to 41,000 terra meters (41E15 km) which would take the space shuttle just over 190,000 years (assuming it had escaped the solar system at the speed of Low Earth Orbit). Although 100 years is a long time, this requirement expects a three-order-of-magnitude leap over current propulsion technology.

3.2.2.1 Choosing the System

After the initial inspection of potential Interstellar Drive candidates, it was decided that chemical fuels would not be able to produce a three order of magnitude leap over current systems in the near future. Five alternate technologies were compared for their potential as Interstellar Drive candidates: Pulsed Fusion Microexplosions, Laser-pumped Light Sails, Ion Drive, High Temperature Thermal Expansion of Gas, and Matter Anti-matter Annihilation (see Fig. 3.2a for a summary table). After a thorough inspection of each of the five candidates it was decided that only the Pulsed Fusion Microexplosion was adequately capable of carrying out the mission requirements.

INTERSTELLAR DRIVE TRADE-OFF STUDY

SYSTEM	Isp (1000s)	FEASIBILITY
FUSION MICRO-EXPLOSION	1020	MEDIUM
LASER-PUMPED LIGHT SAIL	N/A*	LOW
ION DRIVE	3.5-10	HIGH
THERMAL EXPANSION OF GAS	39	HIGH-V. LOW
MATTER/ANTI-MATTER DRIVE	100	EXTREMELY LOW

* EXTERNAL DRIVE SOURCE--3.75 TERRAWATT LASER

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The Matter Anti-matter Annihilation could potentially be capable of producing the necessary specific impulse of a million seconds, but it was not considered to be feasible to create a system adequate for storing the anti-matter for 100 years under the limited power constraints of a spacecraft.

The ideal rocket equation was used to determine the potential specific impulse of an extremely high temperature expansion of gas through a nozzle. (See calculations and assumptions in appendix.) Using the critical temperature for sustained Deuterium fusion (3.9E8 degrees Kelvin) a specific impulse of 39000 seconds was calculated (1/300th the specific impulse desired). Since this specific impulse is insufficient for the mission requirements (using an extremely optimistic temperature under ideal conditions), this candidate was dropped.

Advances in technology for an accelerated ion drive (using a magnetic/electric field to fire charged particles out a nozzle) have brought the specific impulse to 3500 seconds. Although this is a current technology that could be implemented now at relatively low cost, it is felt that the two remaining orders of magnitude will remain out of reach in the near future. Therefore, this candidate was also discarded.

In determining the feasibility of a Laser-pumped Light Sail, another method besides comparing specific impulse becomes necessary, since the drive is external. The single impulse required to reach the designated system in 100 years was determined to be 13,500 km/sec.

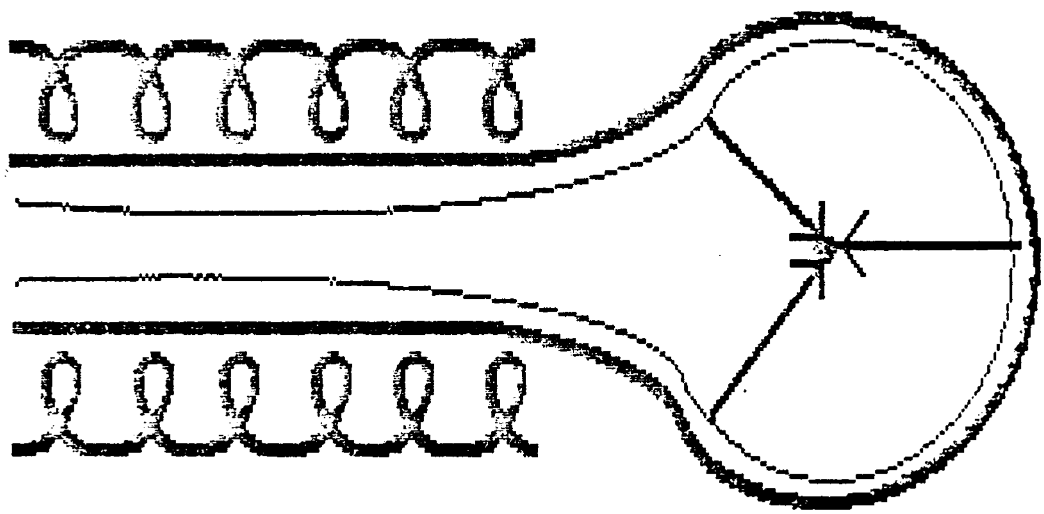
The size of a laser with continuous output, to accelerate the payload to 13,500 km/sec in a year, is 3.75 Terra Watts. Since a micropulsed 1 Terra Watt laser has been developed, it is conceivable (although extremely unlikely) that the necessary laser could be invented within the next 20 years. The low feasability, coupled with the lack of a system for decceleration into the Centauri System, led to the cancellation of this system's candidacy (see appendix for calculations).

3.2.2.2 Pulsed Fusion Microexplosion Drive

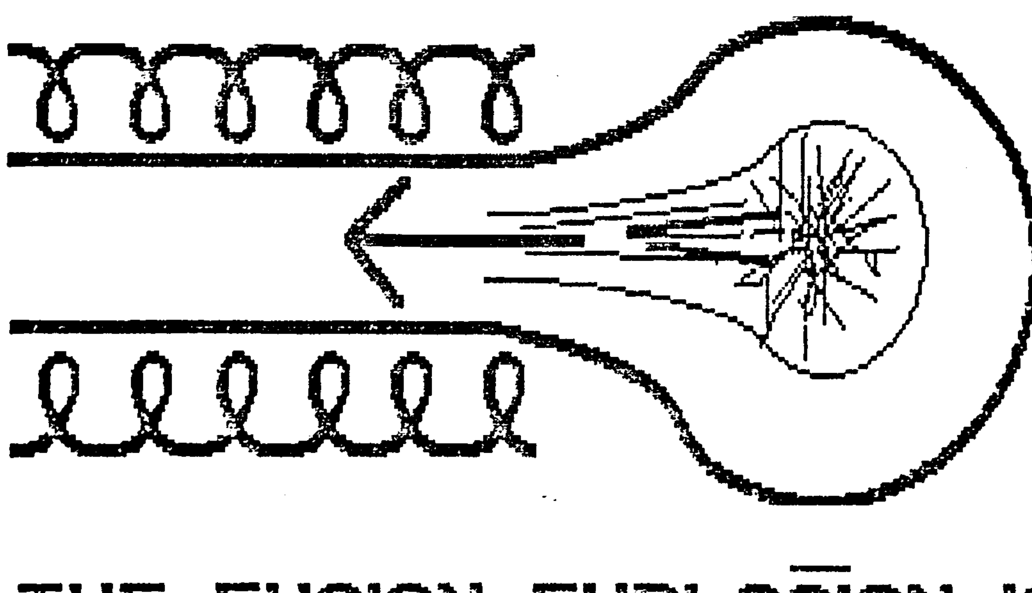
The Pulsed Fusion Microexplosion Drive is not a current, but rather an enabling technology. The system concept, modeled after the British Interplanetary Society's project DEADALUS, is to fire high energy particle beams at small fusionable pellets that will implode and be magnetically channeled out the nozzle (see Figs. 3.2b and 3.2c). The expected specific impulse is 1.02E6 seconds. The specific mass breakdown for separate sections (including fusion chamber, particle beam igniter system, and magnetic nozzle/inductor system) is included in the structures section (2.3.2). Finally, the entire system is expected to gimble a full degree in two axes to enable navigational corrections in three dimensions.

The type of fuel used in the pellets is of critical importance. Due to the extremes of temperature and duress inherent in fusion reactions, a magnetic field is required to supplant the casing around the fusion

PULSED FUSION CONCEPT

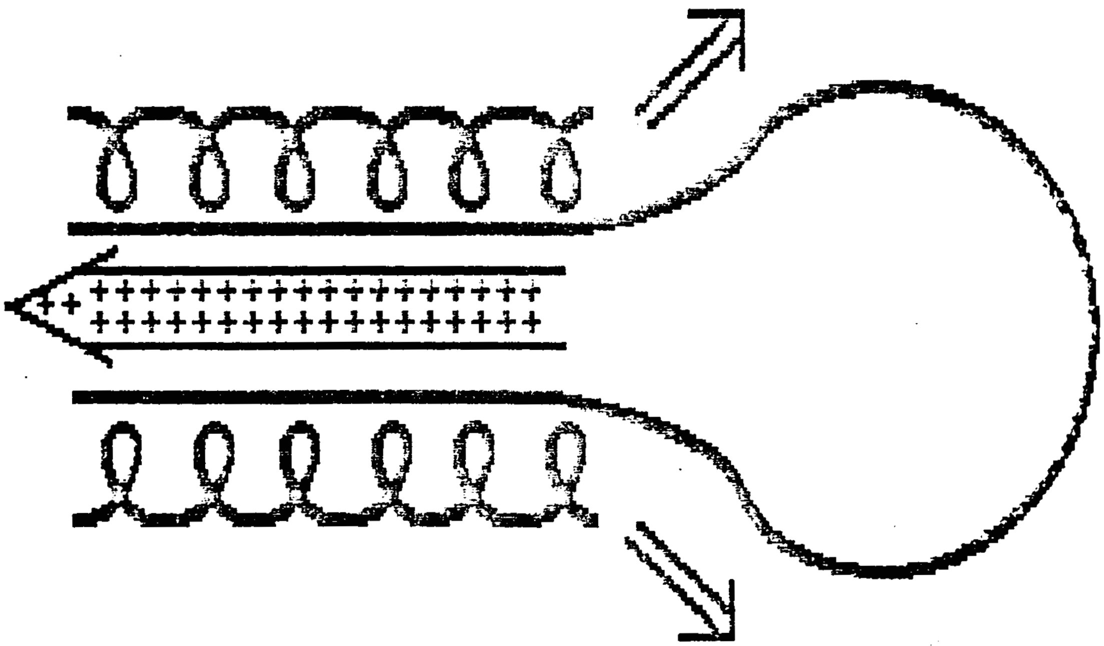


1. THE PELLET IS LOADED AND FIRED UPON BY SEVERAL HIGH POWER PARTICLE/LASER BEAMS.



2. THE FUSION EXPLOSION IS DIRECTED OUT OF THE EXIT VIA THE MAGNETIC "NOZZLE".

PULSED FUSION CONCEPT



3. THE HIGH VELOCITY PULSE (~10000 KM/S) INDUCES A CURRENT IN THE COILS THAT SURROUND THE EXIT PORT. THIS ENERGY IS USED TO RE-CHARGE THE PARTICLE/ LASER BEAMS AND THE MAGNETIC FIELD.

chamber. The problem involved with using such a field (besides the obvious requirement for immense quantities of energy) is that only charged particles will be channeled out the nozzle. Although the extreme temperatures will instantly ionize all of the atoms and molecules, any neutrons produced in the fusion reaction will not be affected by the magnetic field. Instead, they will irradiate the drive and the entire spacecraft over the 100 year transit, and reduce the drive efficiency. Since this is a highly undesirable result, a reaction which produces few to no neutrons is required (see appendix). He3 + H2 yields no neutrons (although realistically some of the deuterium will react with itself producing a limited number of neutrons in each implosion). The problem is not solved, however, since there is not enough He3 on our planet to fuel the spacecraft! Three methods of gaining the necessary He3 have been compared: mining the planet Jupiter; creating He3 through the bombardment of Lithium in nuclear accelerators; and capturing He3 from the Solar Wind. Another possibility is for a further technological breakthrough to enable using higher threshold-energy fusion reactions (higher than H,He) which use more abundant elements in a no-neutron reaction. None of the options seem very reasonable, and each should be explored and further developed to determine the best method for collecting the necessary fusionable material.

The pellet size, in order to obtain the proper mass flow through the nozzle, depends upon the pulse frequency. Smaller pellet size could potentially lower the coil mass as well as the igniter mass, although the higher frequency would complicate fuel injection in a system that must run for 100 years continuously, without repair. The appendix shows the spectrum available between the DAEDALUS pellet size and frequency (since DAEDALUS required a higher mass flow).

After the final upper stage separation, the nuclear reactor will be increased to full power in order to charge the interstellar drive capacitors for initial ignition. The Interstellar drive will then be used for both acceleration and deceleration. The system is to be turned off at the appropriate time (determined through an internal navigational calculation), rotated 180 degrees, and restarted, all while staying on course. The payload contains a 300 kw nuclear power reactor which must be also capable of starting and restarting. The nuclear reactor will have to be ignited, and rechanneled to repower the slowly draining capacitors of the Interstellar Drive igniter system, after the spacecraft has fully rotated and stabilized in the proper alignment.

3.2.2.3 Feasibility

The entire Interstellar Drive is highly dependent upon enabling technology. Building an actual scale model that is capable of running continuously for 100 years will be a challenge by itself! Barring further significant technological breakthroughs, the collection of fuel will be the most difficult and time consuming portion of the building. Never the less, within 20 years, these projects should be possible with the proper funding. Current technology is already capable of creating singular microexplosions in the laboratory.

3.3 Instrumentation

3.3.1 Instruments

The instruments to be carried on board the probe head are as follows:

- IR Imagers
- Visual Imagers
- UV Telescopes
- High-Energy Particle Detectors
- Astrometrical Telescopes
- Wide-Band Spectrophotometers
- Magnetometers
- Solar Wind Plasma Analyzers
- Communications Lasers

Three of each item will be carried on the spacecraft for triple redundancy.

The total weight of the instrumentation package (including everything listed, except the communications lasers) is estimated at not more than 3 metric tons. The estimated weight of the communications lasers is 2 metric tons. The peak power requirement of the instruments is estimated at 300 kW.

The justification for the visual imagers is obvious. Everyone will want to "see" what another star system looks like. In addition to providing important scientific information, a picture will be worth a thousand words or a thousand pages of numbers when it comes to obtaining funding for follow-up missions to other star systems.

IR Imagers and UV Telescopes will provide the first exact data on the characteristics of stars other than our own. Also, one must not forget the possibility that the Alpha Centauri system contains planets. These instruments could also provide data on the radiation and thermal environment of any planets in the system.

The High-Energy Particle Detectors are one of the few types of instruments which will be active during the transit to the objective system. Hard data on the energy level and density of such particles could provide insight into the origin and eventual fate of the universe.

The Astrometrical Telescopes will be the backbone of the mission. By providing the data to accurately determine the distance to the further stars, these instruments will advance the study of stellar characteristics immeasurably. The only limit to this aspect of the mission will be the endurance of the spacecraft. (The section on the objective system contains an explanation of how this will be accomplished.)

The Wide-Band Spectro-photometers will determine the composition of the stars and any planet sized bodies which the system may contain.

The Magnetometers will also be in use during the entire life of the probe. These instruments will provide extensive data on what should prove to be the very interesting magnetic field of a trinary star system. Also, they will provide the first hard data on the galactic magnetic field and how it interacts with the magnetic fields of our own solar system and the

Alpha Centauri system.

The Solar Wind Plasma Analyzers will also provide some scientific "firsts". While the composition of the Sun's solar wind is already known, these instruments will accurately determine how far the wind extends into inter-stellar space. This will also be done for the Centauri wind, as well as determining its composition. Also, the close binary pair of Alpha and Beta Centauri should exhibit a very interesting pattern where their solar winds interact.

The communications lasers, in addition to performing their obvious function, will at the same time provide data on extremely long-range laser communication and the extent of spreading losses caused by the interstellar medium.

3.3.2 Instrumentation Configuration

Two possible configurations for the mounting of the instruments were considered. Both consisted of three booms attached to the probe body spaced at 120 degree intervals with each boom supporting a complete instrument package, but one was dynamic and the other static.

The dynamic boom configuration was designed with the intent of retaining the forward particle shield as a structural and operational part of the probe body after orbit is achieved in the target system. The particle shield was to be infused with pipes to provide additional radiating area for waste heat. The shield could also be used to house elements of the probe's central processing units. The major advantages of the dynamic boom configuration are its additional cooling capability and the additional shielding which would be provided in-system for the body of the probe. The major disadvantage is that the mobility of the booms would have to be maintained for the length of the mission. This configuration would require movable mounts at the base of each boom capable of handling the large torques caused by moving the boom. These torques would also pose an additional problem for the probe's attitude control system. Furthermore, the advantage of a larger cooling surface would be offset by the added thermal control complications.

The static boom configuration, (see Fig. 3.3a) was designed to discard the front particle shield upon approach to the target system. The instrument booms will be firmly attached to the probe body and the only movable parts will be the individual instrument mountings. The major advantages of the static boom configuration are the lower number of parts expected to move after the long interstellar transit, and the lower final mass of the probe in-system. The major disadvantage of this design is the need for pyrotechnics to eject the shield after transit. All things considered, the static boom design was adopted, mostly its the greater reliability.

STATIC BOOM
PROBE CONFIGURATION

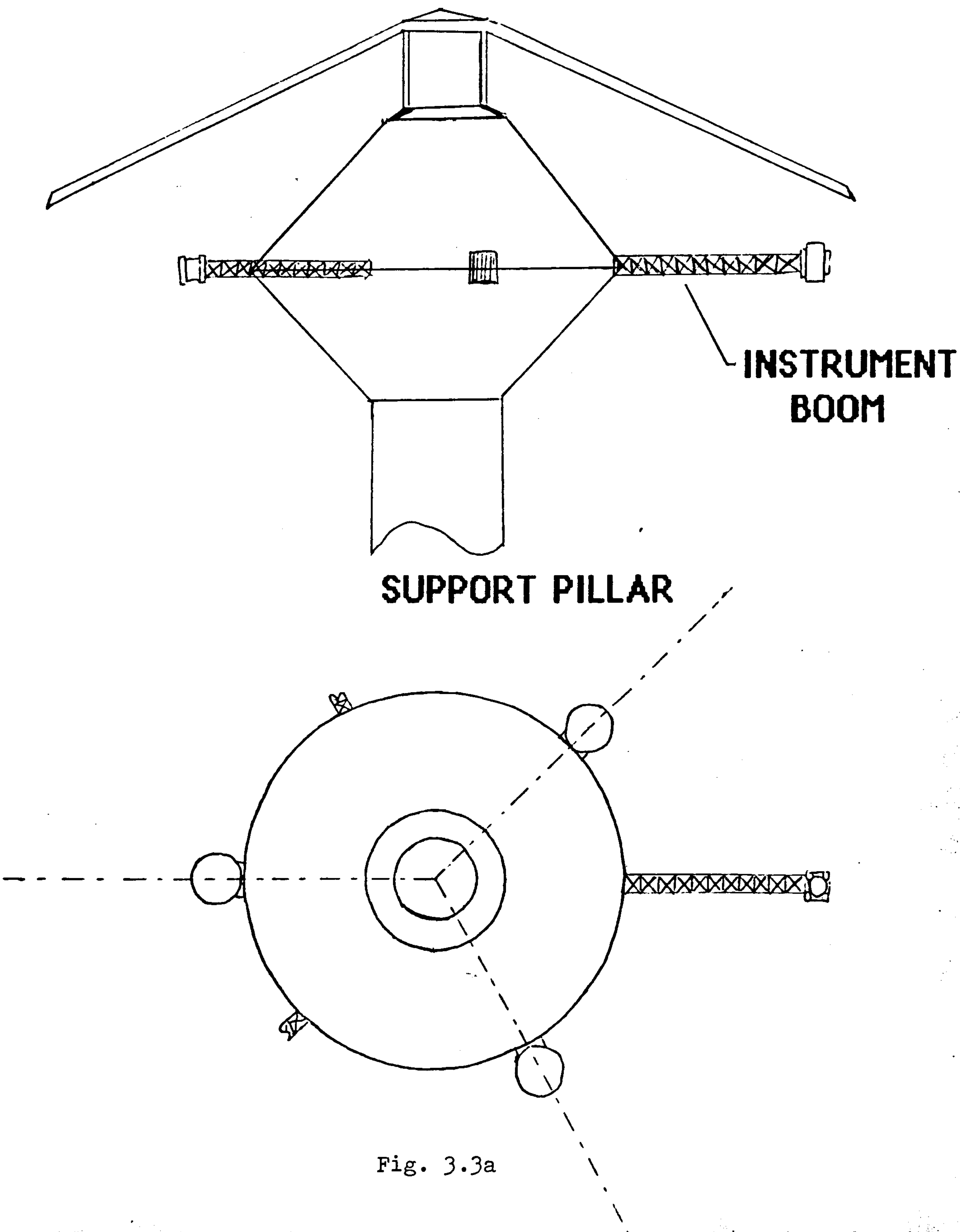


Fig. 3.3a

3.4 Communications System Design

The major challenges for the communications system of the interstellar probe both occur when the probe enters the target system at a range of 4.3 light-years, or 4.109 x 10^16 meters. This is the maximum transmission range; a fairly high data rate must be maintained, since all probe instrumentation is returning data. The only type of communications system capable of the necessary directivity and data rate is a high-power laser using pulse code modulation (PCM).

Low background noise from the target system is necessary for a low power level, so a laser wavelength of 0.532 microns was chosen. Radiation of this wavelength is almost totally absorbed by the outer atmospheres of K and G type stars, leaving a hole in the absorption spectrum (no transmitted radiation). Laser radiation of this wavelength can be produced by a frequency-doubled diode-pumped YAg laser with an optical attachment to provide a large initial aperture.

The transmitter aperture is 2 meters in diameter with receiving mirrors of 24 meters diameter. The spreading angle is 1.22*lambda divided by the aperture diameter, or 3.25 x 10^-7 radians (0.067 arcseconds). At 4.34 light-years, the spreading results in a footprint radius of 13.4 million kilometers, 8.9% of an Astronomical Unit (AU). Both the pointing accuracy of the laser mount and the attitude determination capability of the probe must be within 0.067 arcseconds, so very low error laser mounts and star trackers will be used.

A total input power of 250 kilowatts is needed for each laser that is transmitting. With an assumption of a 20% lasing efficiency, the transmitted power is 50 kilowatts. If the power is distributed isotropically over an area of 5.64 x 10^20 square meters (the area subtended by the laser beam when it reaches Earth), the power density is 8.87 x 10^-17 watts per square meter, or 222 photons per square meter per second. For a 12 meter radius receiving mirror (area of 452.4 square meters), the received power level is 4.01 x 10^-14 watts, or 100,000 photons per second. Using the assumption that a digital pulse "on" level is 100 photons, the receiver sees 1000 pulses per second. A data rate of 1000 bits per second is low. Note that this rate is the minimum because the transmitter would be at maximum range. If extremely reliable lasers are used, each transmitter can operate at a slightly different wavelength, so the data rate would be up to six times greater depending upon the number of lasers used.

The communications system would use six 250 kilowatt lasers. Three would be placed on the outside of the fuel tanks with the star trackers for communications during the acceleration phase. Three more lasers would be attached to the probe head for communications during the deceleration and in-system phases of the mission. The receiving mirrors would be in geosynchronous orbit about the earth in a constellation of several mirrors with a central node serving as a relay station to TDRSS and the ground.

3.5 Data Processing

One of the significant "enabling technologies" required to perform the interstellar probe mission is that of advanced processing. When the spacecraft reaches its target, the probe will be 4.3 light-years away from command and control facilities on Earth, and will thus have to be completely autonomous and self-repairing. The processing system will ideally have low power consumption to reduce heat dissipation requirements. It will be multiply redundant with advanced shielding and survivability features, and also be able to control all facets of probe operations, including high level decision-making. As shown in the sectional appendix, the probe must evaluate given mission objectives to control the scientific instruments in order to explore the Alpha Centauri system most effectively. If the system can integrate high-accuracy attitude determination and scientific data instantaneously, the attitude control requirement can be relaxed to a level easily maintained by such a large structure. Finally, the data must be taken out of processor's memory and sent to earth via laser. The communications lasers must be pointed with an accuracy of .067 arc-seconds, and a hard file of the position of the earth relative to Sol must be retained in memory to govern the pointing of the laser. Once the target system is reached, the processing unit must be able to achieve and maintain an acceptable orbit, and maneuver to investigate high priority phenomena, such as evidence of intelligent life. For a block diagram of the data processing system, see appendix.

3.6 Guidance

A system of star trackers will be used for both navigation and attitude determination. This system has been chosen for its high accuracy (4 arc sec) and adaptability, and for its low weight (7 kg) and power requirements (18 watts). Star scanners were not chosen since the spacecraft is not rotating, and they are less accurate. The trackers will be coupled to a computer system which will have a star catalogue of 200-300 stars' locations. "Adaptability" refers to this catalogue, because a "best guess" of star locations that the probe will "see" on the trip and in orbit in the Centauri system can be programmed into the computer before launch, thus increasing the accuracy of position/attitude determination. This best guess could even be updated enroute or in Centauri-orbit by the astrometry calculations that the computer will make.

Initially, during the transit between Earth and the point where the probe-head separates from the propulsion system, trackers located on the last fuel tanks will be used. These trackers will be oriented in different directions in order to gain a nearly complete field of view. 18 trackers will be used, 3 in each of the 6 axis directions to get the greatest field of view and triple redundancy. The power for these trackers will come from generators drawing energy from the propulsion system waste heat. In the final mission phase, 9 trackers located on the instrument booms will be used, 3 on each boom instrument head. (This will require a very accurate position determination of the boom rotation angles.)

Three 3-axis rate-gyro assemblies will determine the rate of change of any two pointing angles and the spacecraft roll rate. This data will supplement the trackers' information and increase the attitude determination accuracy.

Star tracker parameters:

Solid state (vice photomultiplier tube)
4 arcsecond accuracy (future improvement is expected)
Magnitude range -1 to +6
Field of view 6 x 6 degrees
6 seconds to search field of view
1.2 seconds to search field in 1 x 1 degree search mode
Has a track mode during which it follows a specific star
Total weight - 189 kg
Total power in transit - 324 watts
Total power after probe separation - 162 watts

A summary of the attitude control systems available to choose from are listed in Fig. 3.6a. The probe's attitude control will be accomplished using two sets of flywheels arranged on 4 axes (described in section 3.3 Power System), and an auxiliary system of hydrazine thrusters. These flywheels will serve as momentum wheels, controlled by the computer using the attitude/rate information, providing torque to maintain spacecraft stability. The 4-axis configuration will enable the reaction wheels to absorb external torques from any direction. The magnitude of this reaction torque is easily modulated by electronic control of the reaction wheel motor current. One disadvantage of this system is the need to control wheel speeds in order to limit vibrational effects. "Unloading" the energy of

ATTITUDE CONTROL TECHNIQUE COMPARISON

TYPE	COST	ACCURACY	MISSIONS	COMMENTS
3-AXIS ACTIVE CONTROL (1) REACTION WHEELS	VERY HIGH	.007 ARC-SECONDS-1.0 DEG.	ASTRONOMICAL, WEATHER	VIBRATIONS AT HIGH RPM'S MAY REDUCE ACCURACY
(2) HYDRAZINE THRUSTERS	VERY HIGH	.1-1.0 DEG	DEEP SPACE	FUEL LIMITED
SPIN STABILIZATION	LOW TO MODERATE	.1-2.0 DEG.	EARTH ORB. INTERPLANETARY	SPIN RATE AND DIRECTION REQUIRE CONTROL
DUAL-SPIN STABILIZATION (1) HALF SPIN, HALF STABILIZED	HIGH	.01-.1 DEG.	GEOSYNCH. COMMS. SATELLITES	REQUIRES COMPLEX TECHNOLOGY FOR ELEC. AND MECH. CONNECTIONS
(2) INTERNAL MOMENTUM WHEELS	HIGH	.01-.1 DEG.	GEOSYNCH. COMMS. SATELLITES	HIGH TECHNOLOGY REQUIREMENTS
MAGNETIC STABILIZATION	VERY LOW	10-20 DEG.	LOW ALT., SCIENTIFIC	REQUIRES A MAGNETIC FIELD
GRAVITY-GRADIENT STABILIZATION	LOW	1.0-10 DEG.	CIRCULAR, LOW ALT.	REQUIRES A GRAVITY FIELD & LARGE MOMENT OF INERTIA FOR SATELLITE

the wheels is done by transferring momentum to the second set of wheels, discharging energy through the power system, and using the hydrazine thrusters. The hydrazine tanks are located within the main truss between the flywheels, encircled by the main fuel tanks (so they may be cooled by the same refrigeration units). The nozzles are located on the circumference of the spacecraft pointed in each axis direction. The flywheels will be used for attitude control in the solar system phase of the mission, and in the Centauri system. The hydrazine system is primarily used as a backup.

3.7 Thermal Control

There are two significant problems to consider in the thermal design:

There is a huge amount of waste heat from the propulsion system and the nuclear reactor (both fission and fusion reactions);

The fuel will be stored in large tanks at near-absolute temperatures, and must be shielded from the waste heat of the nuclear reactions.

The spacecraft will require highly efficient radiators to dissipate the thermal energy released by the interstellar drive, namely the inductors, particle beams, and fusion reaction. The radiation from this dissipation process will be reflected away from the rest of the spacecraft by a mirror specifically engineered to reflect infra-red energy. Additionally, conduction will be buffered by special ceramic materials between the power and propulsion units.

The nuclear reactor will dump its waste heat to the same radiators used by the propulsion unit. Ceramic buffers will also be located between the power unit and the fuel tanks.

The fuel tanks will contain pelletized helium and deuterium which must be shielded from conductive and radiative heat energy. During the initial phase of the mission the tanks will be shielded from the sun by a shroud which will be blown off at a sufficient distance from the sun where the solar radiation becomes negligible. The mirrors and ceramic buffers will keep the spacecraft's waste heat away from the tanks, while refrigeration units will keep the fuel vapor pressure low enough to remain in pelletized form for the duration of the mission. The tanks will be painted black to emit as much radiation as possible in deep space.

The probe head will be protected from the radiation from Beta in the Centauri system by a thermal blanket. Heat from the computer, instruments, and lasers will be convected through heat pipes to the radiators at the rear of the spacecraft.

4.0 SPACECRAFT DESIGN

The general structure of the probe consists of five main components. The probe head, fuel tanks, central truss, fission power reactor and fusion drive system.

The actual probe will house all of the necessary instruments and data processing equipment. There will also be a particle shield in front to protect the spacecraft during the interstellar flight phase. The particles may not be all that large, but the spacecraft will be traveling at velocities near 5 percent of the speed of light; therefore, they will have a tremendous amount of energy.

The fuel tanks were designed to be cylinders. This shape was picked for its ease in construction. The calculations on the sizing of the fuel tanks are in the appendix. The tanks are connected to a central framework using explosive bolts which will permit their jetisioning when empty. A detailed structural analysis on the sizing of the tanks may be found in the Appendix.

The central truss will be a collapsable space frame and fulfill several functions. Its primary role is to connect the probe head with its power source while providing adequate separation for thermal and radiation protection. Additionally, it will house the attitude determination and control systems and support the fuel tanks during the interstellar transit phase of the mission.

The fission power reactor will be attached to the aft end of the main truss behind a thermal reflector. This sheild will protect the cryogenic fuel from the heat generated by the drive as well as the reactor. The rear end of the reactor will incorperate a flange for mounting fusion drive. This connector will contain pyrotechnic elements to separate the drive system once the spacecraft reaches Alpha Centauri.

The fusion drive system was described in the Propusion section. It will serve the additional function of providing attach points for the after particle shield and the chemical upper stages. The rear shield is needed during the decceleration phase of the flight when the spacecraft is flying backwards.

A weight table is included in the appendix as well a diagram of the structure.

APPENDIX

Delta-V Calculations

Assumptions:

space station orbit altitude	= 300 km
" " " inclination	= 28.5 deg
obliquity	= 23.5 deg
1 AU	= 149.6×10^6 km
Earth radius	= 6378 km
f_{earth} = GMe	= 398,601.2 km^2/sec^3
f_{sun}	= 1.3271544×10^{11} km^2/sec^3
$f_{Jupiter}$	= 1.268×10^8 km^2/sec^3

(1) Velocity of probe about the earth:

$V_p = (GMe/Rcircular)^{.5} = (398,601.2/6678)^{.5} =$
7.7258 km/sec

(2) Amount of plane change:
$i = 61x - (28.5x + 23.5x) = 9x$

(3) Delta-V for $9x$ plane change:
$\text{Delta-}V_{pc} = 2 \times Vp \times \sin(i/2) =$ **1.2123 km/sec**

(4) Earth escape velocity:
$V_{e-escape} = (2GMe/R)^{.5} = 10.9260$ km/sec

(5) Delta-V to escape earth:
$\text{Delta-}V_{e-esc} = V_{e-esc} - V_p =$ **3.2002 km/sec**

(6) Velocity of probe around sun:
$V_{p-sun} = (f_{sun}/1\ AU)^{.5} = 29.7849$ km/sec

(7) Solar system escape velocity:
$V_{sun-escape} = (2f_{sun}/1\ AU)^{.5} = 42.1221$ km/sec

(8) Delta-V to escape the solar system:
$\text{Delta-}V_{sun-esc} = V_{sun-esc} - V_{p-sun} =$ **12.4273 km/sec**

(9) Total Delta-V required to escape solar system:
$\text{Delta-}V_{total} = 16.8398$ km/sec

Rough calculations for Delta-V's for orbit changes to take the probe out to Jupiter (to take on fuel) are made using Hohmann transfer equations as an approximation (actual orbits would be patched-conics). The first six calculations are the same for this analysis:

(1) Energy of Hohmann transfer orbit:
$E_t \square -\mu_{sun}/6.2\ AU = -143.0894\ km^2/sec^2$

(2) Perigee velocity of transfer orbit:
$V_1 = [2(\mu_{sun}/1\ AU + E_t)]^{.5} = 38.6171\ km/sec$

(3) Delta-V to enter transfer orbit:
Delta-$V_1 = V_1 - V_{p-sun} =$ **8.8223 km/sec**

(4) Apogee velocity of transfer orbit:
$V_2 = [2(\mu_{sun}/5.2\ AU + E_t)] = 7.4157\ km/sec$

(5) Velocity required to orbit Jupiter at an altitude of 500,000 km:

$V_J = (\mu_{Jupiter}/571370)^{.5} = 14.8971\ km/sec$

(6) Delta-V to inject into orbit about Jupiter:
$V_J - V_2 =$ **7.4814 km/sec**

(7) Jupiter escape velocity:
$V_{J-escape} = (2\mu_{Jupiter}/571370)^{.5} = 21.0676\ km/sec$

(8) Delta-V to escape Jupiter:
Delta-$V_{J-esc} = V_{J-esc} - V_J =$ **6.1705 km/sec**

(9) Velocity of probe about sun at Jupiter distance:

$V_{p-sun-J} = (\mu_{sun}/5.2\ AU)^{.5} = 13.0601\ km/sec$

(10) Velocity to escape sun at Jupiter distance:
$V_{sun-esc-J} = (2\Gamma_{sun}/5.2\ AU)^{.5} = 18.4697$ km/sec

(11) Delta-V to escape sun at Jupiter distance:
$V_{sun-esc-J} - V_{p-sun-J} = 5.4087$ km/sec

(12) Total Delta-V for Jupiter analysis Delta-
$V_{total} = 32.2954$ km/sec

This is nearly twice the Delta-V required for the first case. This fact, along with the difficulties involved in mining the atomosphere of Jupiter, getting the fuel to a million kilometer orbit around the planet, etc., has made it obvious that obtaining fuel from Jupiter is not feasible.

Acceleration and Velocity Profiles

1. Accelerations The accelerations for the mission were found using the equation F=ma. Since it is a constant thrust, the acceleration will increase at a constant rate. The acceleration was found by dividing the thrust by the mass left at the time. This gives the acceleration chart on page.

2. Velocity Since the acceleration changed at such a small rate, it was assumed that an average value for the acceleration could be used for computing the velocity. The acceleration at the beginning of a phase and at the end of a phase were averaged. This acceleration was then multiplied by the time interval for which it pertained. This delta V was then added to the previous velocity. The turning point for the mission was found with the computer program on the next page. Different turning points were tried until one was found that gave a final velocity of about 32.935 km/s.

```
DESII     07 Apr 88  17:23

100 REM *** THIS PROGRAM ASSUMES THAT THE ACCELERATIONS ***
110 REM *** CAN BE AVERAGED SINCE THEIR VALUE IS SMALL  ***
120 REM *** AND THEY DO NOT CHANGE MUCH.***
130 REM
140 PRINT "ENTER THE TURNING POINT."
150 INPUT TP
160 LET A1A=(.00464+.00577)/2
170 LET V=A1A*33.35*3.147E7
180 REM
190 REM **** VELOCITY AT RELEASE OF TANKS 1 AND 2 ****
200 REM
210 LET A2A=(.00619+.0084)/2
220 LET V=V+A2A*33.35*3.147E7
230 REM
240 REM **** VELOCITY AT RELEASE OF TANKS 3 AND 4 ****
250 REM
260 LET A3A=(.00931+ATP)/2
270 LET V=V+A3A*(TP-66.7)*3.147E7
280 REM
290 REM **** VELOCITY AT TURNING POINT ****
300 REM
310 LET A4A=(.021+ATP)/2
320 LET V=V-A4A*(100.05-TP)*3.147E7
330 REM
340 REM **** FINAL VELOCITY ****
350 REM
360 PRINT V/1000,ATP
370 PRINT "GO AGAIN?"
380 INPUT ZZ$
390 IF ZZ$="Y" THEN 150
400 END

Ready
```

Probe Wt. mt	NO. SRB's Shuttle Size	Delta V km/s	S/C TOTAL Wt. mt
1409.695	.1	.205	1469.3
1409.695	.2	.401	1528.905
1409.695	.3	.589	1588.51
1409.695	.4	.768	1648.115
1409.695	.5	.94	1707.72
1409.695	.6	1.104	1767.325
1409.695	.7	1.263	1826.93
1409.695	.8	1.415	1886.535
1409.695	.9	1.562	1946.14
1409.695	1	1.703	2005.745

Plane change of 9 degrees
Delta V required is 1.2123 km/s

Probe Wt. mt	NO. SRB's Shuttle Size	Delta V km/s	S/C TOTAL Wt. mt
694.435	1	2.914	1290.485
694.435	1.1	3.112	1350.09
694.435	1.2	3.298	1409.695
694.435	1.3	3.475	1469.3
694.435	1.4	3.643	1528.905
691.435	1.5	3.802	1588.51

Escaping Earth
Delta V required is 3.2002 km/s

Probe Wt. mt	NO. SRB's Shuttle Size	Delta V km/s	S/C TOTAL Wt. mt
396.41	.1	.689	456.015
396.41	.2	1.28	515.62
396.41	.3	1.795	575.225
396.41	.4	2.249	634.83
396.41	.5	2.653	694.435

Aiding in escaping solar system
Delta V required is at least 2.5 km/s

Laser-Pumped Light Sail

Assumptions:

1) 100% of laser is focused onto the sail continuously for one year.

2) the solar energy to pressure ratio holds true for the specific laser used.

At 1 A.U.:

1353 watts/square meter from the sun
and
4.6E-6 N/square meter from the sun

therefore,

2.94E8 watts/N.

Payload Mass = 30,000 kg
Delta V required = 13500 km/sec
Time interval = 31,472,262 sec (1 year)

Therefore,

Required acceleration = .429 m/sec squared
and
The force required = 1286.8 N

So that with a laser operating at 100% efficiency

Required power = 3.78E12 watts

EXTREME HIGH TEMPERATURE EXPANSION OF GAS

"Ideal" Rocket Nozzle: Perfect Gas
Steady Flow- no shock, friction, or heat losses
One Dimensional Flow
Frozen Chemical Equilibrium

V_e $(exit\ \ velocity) = L\ \ E$

L = Limiting Gas Velocity

E = Pressure Expansion Ratio

$$E = \sqrt{1 - \frac{P_e}{P_t}^{\frac{\gamma-1}{\gamma}}} = 1 \qquad (P_e = 0)$$

$$L = \sqrt{\frac{2\gamma \tilde{R} T_t}{(gamma - 1)\, M}}$$

$\gamma_{(monoatomic)} = 1.67$
$\tilde{R} = 8.31441$
$M_{H_1} = 1.00794$
$T_{t_{critical\ deuterium\ fusion}} = 3.5x\,10^8$ K
$L_{\max} = 379\ \frac{km}{sec}$
$I_{sp} = \frac{V_e}{g} = 39000$ sec

Fusion Reaction

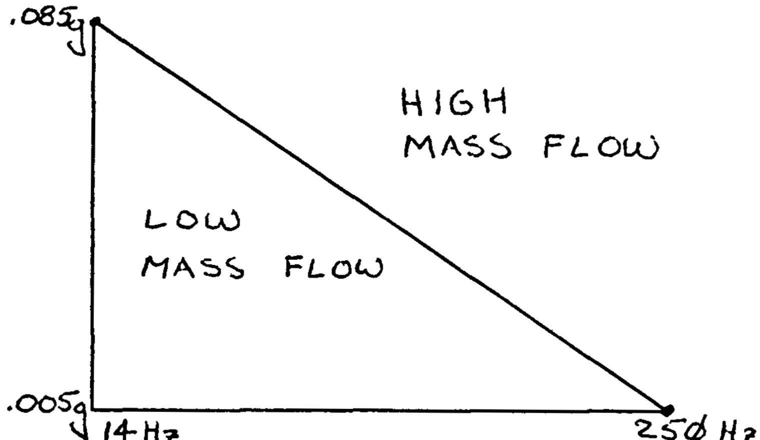
$$He_3 + H_2 \longrightarrow He_4 + H_1$$

at reaction temperature:

$$He_4 = \alpha_4^{2+} + 2e^-$$
$$H_1 = p_1^+ + e^-$$

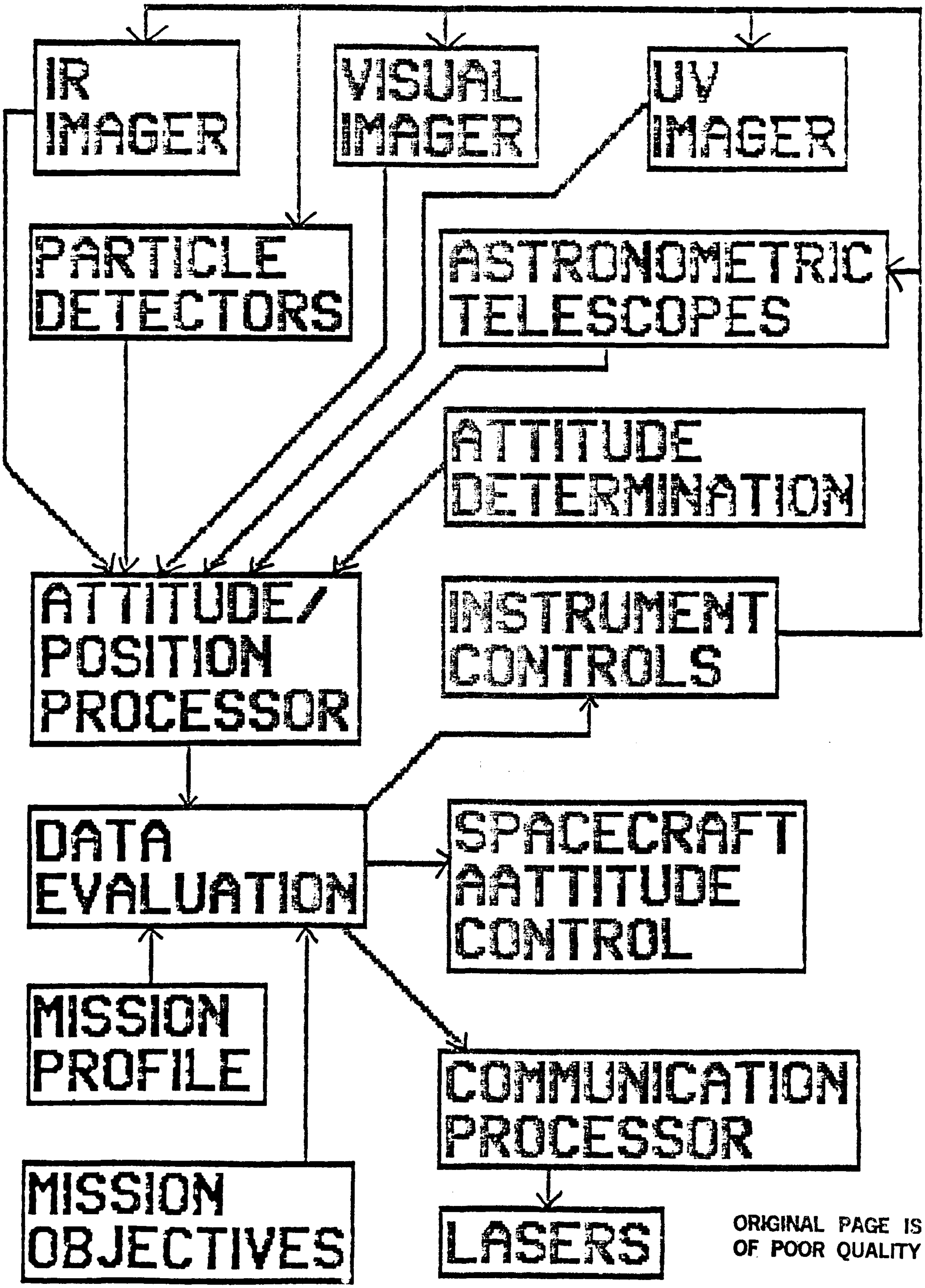
the resulting charged particles can be magnetically funneled and used to charge induction coils upon exiting.

Pellet Size vs. Frequency



an engineering analysis must be done on the proposed engine to determine pellet size and pulse frequency.

PROCESSING BLOCK DIAGRAM



Sizing of the Fuel Tanks

1. Tank Volume

The storage density for the fuel is .0708 metric tons per cubic meter. Therefore, the total volume needed is:

$$Vol = (264.276\ mt)*(1/.0708\ mt/m^3) = 3732.71\ m^3$$

The radius of the fuel tanks is set at 2.5 meters and the length is then computed.

$$length = (Vol/6)/(pi*r^2) = (3732.71\ m^3/6)/(pi*(2.5)^2) = 31.68\ meters$$

The total volume is divided by six, because six fuel tanks are used.

2. Tank Thickness

A. Interstellar cruise phase

Newton's equation, F=ma, is used to find the forces on the fuel tanks during flight. The maximum force will occurr when the acceleration is a maximum. This is when the mass is a minimum for a constant thrust problem. In our case, the minimum mass is:

$$Mmin = 2\ fuel\ tanks + 6\ straps + center\ section + engine + payload = 89.345\ metric\ tons$$

Therefore,

$$Amax = Thrust/m = 1.838e3\ N\ /\ 89.345e3\ kg = .021\ m/s^2$$

The maximum force possible on the tanks could then be:

$$Fmax = (mass\ of\ fuel\ in\ tanks) * a = 44.05e3\ kg * .021\ m/s^2 = 924.97\ N$$

A safety factor of 5 is now applied to find the design load.

$$Fdes = 5 * F = 4.62\ kN$$

Next, the tank area that the force is acting on is found.

ORIGINAL PAGE IS
OF POOR QUALITY

Area = pi * r^2
= pi * 2.5^2
= 19.635 m^2

So, the pressure will be:

p = F/A
= 4.62 kN / 19.635 m^2
= 235.54 N/m^2

The thickness of the tanks is now determined.

t = (P * r)/(2 * yield stress)

If we assume that we will use Al 1100-0, the yield stress is 3.45e7 N/m^2. This gives a thickness of:

t = (235.54 N/m^2*2.5 m)/(2*3.45e7 N/m^2)
= 8.53e-6 m or .00853 mm

Therefore, the fuel tanks can be made from 2 mm Al 1100-0 sheets.

B. Orbital Manuvers

Since the upper stages will require advanced upper stages, the forces on the spacecraft are not known. Through the use of staging, multiple burns per manuver, and the use of a stronger aluminum alloy, the thickness of the fuel tanks can be kept at 2 mm.

WEIGHT TABLE

Item	Components		Weight Metric Tons
Engine			
	Chamber		4.35
	Igniter		17.543
	Field Coil		10.245
		Total	32.138
Fuel		Total	264.276
Structure			
	Fuel Tanks		55.038
	Straps		9.151
	Center Section		1.737
	Other Structure		4.074
		Total	70.00
Payload			
	Reactor		10.00
	Instruments		3.00
	Lasers		2.00
	Misc. (shielding, etc...)		15.00
		Total	30.00
		Overall Total	396.414