ION PROPULSION AND COMET HALLEY RENDEZVOUS

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I couldn't help thinking, as Professor Delsemme was talking, of an analogy with Professor Delsemme as Captain Ahab and this great white ghost in the sky as some "Moby Comet." And the mission I propose uses an instrumented probe as your harpoon.

Ion drive, an advanced propulsion system, will provide the ship, taking us out to the comet and allowing our "harpoon" to sample the comet. Some day perhaps we'll bring the sample back and put it into a museum, or a zoo, whichever may be appropriate.

In speaking about a mission to a comet, specifically a Comet Rendezvous, we are talking about a significant energy problem in terms of what it takes to get there. The basic problem follows from an understanding of the cometary orbits that were shown by Professor Whipple earlier in the day. They were generally quite elliptic, or "egg-shaped", and most of them are highly inclined to the ecliptic plane. Thus to intercept and match the cometary paths we must change both the shape and the spatial orientation from a flat circular orbit to an inclined elliptical one. This maneuver requires more energy than is generally available from our conventional rockets. You see in Figure 1. an estimate of the launch mass capabilities of several Shuttle and Inertial Upper Stage combinations. The launch energy parameter C_3 is on the abscissa. This is a measure of how much energy is put into the transplanetary trajectory.

If we overlay this capability with the requirements of a number of space missions (Figure 2) -- and I apologize that the chart gets a bit busy -- we can see that missions lying below the curves are within our general capability.

I have encircled general mission regions indicating the energy classes. Basically, this shows that conventional chemical systems are unable to capture comet rendezvous missions even if we projected four stage versions of the IUS. Obviously we need some advanced propulsion capability to brighten the bleak prospects for comet rendezvous.

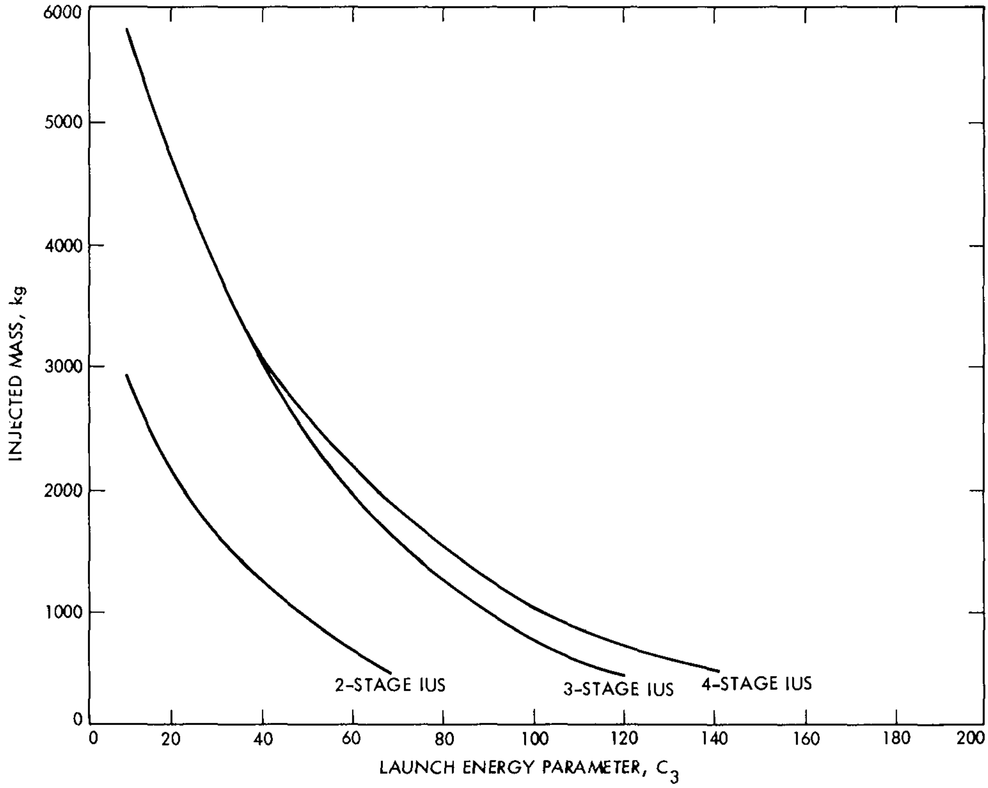


Fig. 1. Shuttle/IUS capabilities.

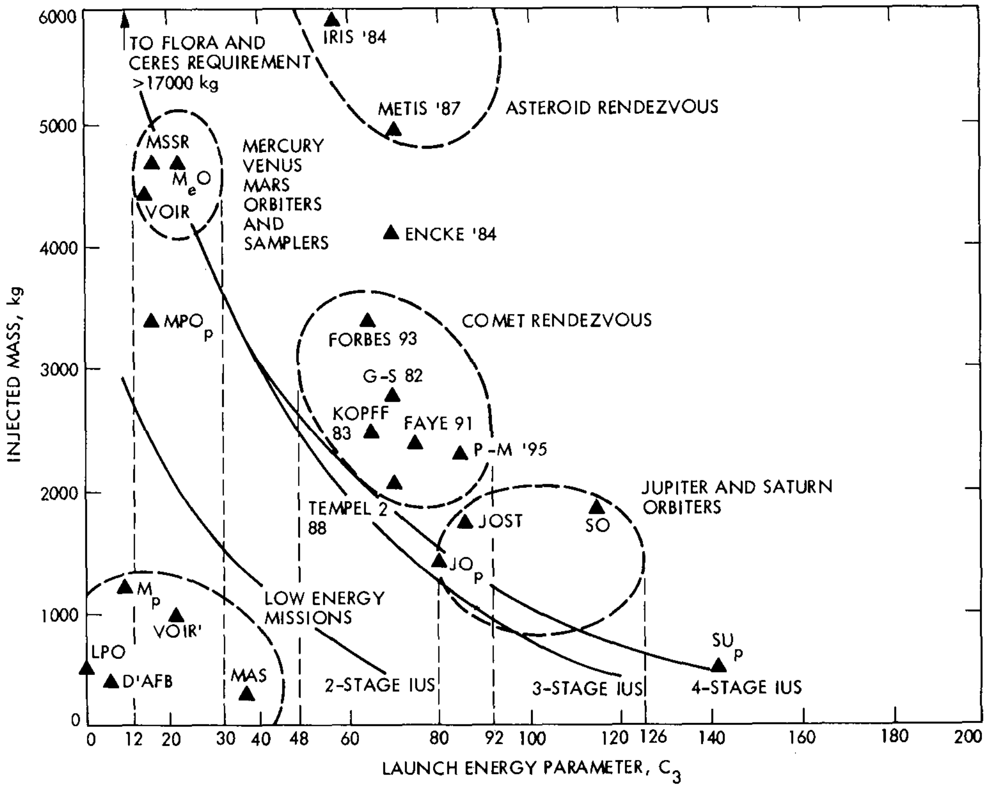


Fig. 2. General requirements for selected ballistic missions.

In the last several years NASA has funded the development of ion propulsion. This system uses ion rocket engines that have a fuel efficiency, or a "miles-per-gallon" improvement on the order of 10 times better than chemical rockets. This says that you can deliver over four times the amount of total impulse than you can with a chemical system while using less than half the fuel.

This allows us to talk about making impulse changes equivalent to that required to achieve a rendezvous with Comet Halley.

Cometary rendezvous missions are not the only customers for ion propulsion. This flight system has a number of applications in the planetary regime. Missions such as Mercury orbiters, Mars sample returns, and Saturn orbiters are included along with bringing back the museum piece for Professor Delsemme. It also has some applications in Earth orbit. I will not dwell on those today, but I would like to have you recognize that this system is something that carries a broader interest than applications in comet missions.

Let's talk about some of the characteristics of this system. I have already alluded to the high fuel efficiency; a factor of 10 improvement. Ion propulsion uses an inert fuel, liquid mercury. Liquid mercury looks nothing like a comet so you do not mistake things you might see from your engine for things you might see in a comet.

The acceleration is very low. You get only about 0.002 pound of thrust per engine; but the system will be operated for significantly long periods of time. Two or three years of continuous propulsion is something that appears to be well within the capabilities of the technology. The integral will provide very respectable vehicle velocities.

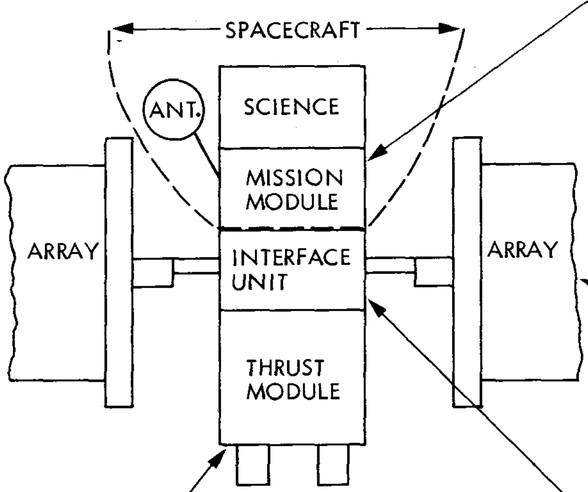
One of the reasons the engine can last so long is that it has no moving parts. The only real wear-out mechanism that we worry about is the erosion of the accelerator grid caused by the particles as they pass through and are exhausted from the engine.

Ion engines provide a modular approach to spacecraft design. Several engines can be clustered, each with its individual support equipment. Each engine unit may be considered as a module. This allows a lot of flexibility to vary the number of thrust units to match the mission requirements. Fewer engines are required for some applications while more are necessary for others.

Further examining its operational characteristics, we recognize that an electric system like this generates electric and magnetic fields. We have to deal with electric and magnetic interaction with the rest of the spacecraft. The charged exhaust particles lead us to concerns about deposition on surfaces and attenuations if we communicate through the exhaust plume. I'll come back to this later.

Now, I would like to describe the physical characteristics of an ion propelled spacecraft. Figure 3 identifies the basic parts of the vehicle. It is comprised of the thrust module, an interface unit and the large solar arrays that collect sunlight and turn it into electricity for actually operating the engines. Above the dotted line is the scientific spacecraft or the payload. It consists of a mission module that carries all the command and control equipment and a science package.

Figure 4 shows the design developed for a Halley rendezvous mission. This artist's rendition displays the thrust subsystem with the ion engines to the right. On the sides are the large, solar arrays with reflectors to collect the sunlight and focus it on the solar cells at the bottom of the trough. The technique of light concentration through use of the reflectors essentially fools the solar cells into thinking they are closer to the sun than they really are, and this mitigates the magnitude of the power loss experienced as we go away from the sun. Thus, thrust performance stays at a relatively high level. Higher thrust leads to larger payloads and shorter flight times.



MISSION MODULE*

- TELECOMMUNICATIONS
- ATTITUDE AND ARTICULATION CONTROL
- ANTENNA
- CHEMICAL PROPULSION
- POWER
- STRUCTURE
- DATA HANDLING AND CONTROL

*VARIES WITH APPLICATION

ARRAY SUBSYSTEM

- ARRAY MODULES
- DEPLOY/RETRACT MECHANISM

INTERFACE UNIT

- PROPELLANT STORAGE
- ARRAY ARTICULATION
- STRUCTURE
- POWER TRANSFER

THRUST MODULE

- POWER HANDLING
- ION ENGINES
- HEAT REJECTION
- GIMBALS
- CABLING
- STRUCTURE
- DCIU
- PROPELLANT DIST

ION PROPULSION MODULE

- THRUST MODULE + INTERFACE UNIT + ARRAY SUBSYSTEM

THRUST SUBSYSTEM

- THRUST MODULE + INTERFACE UNIT

Fig. 3. Ion drive vehicle definitions.

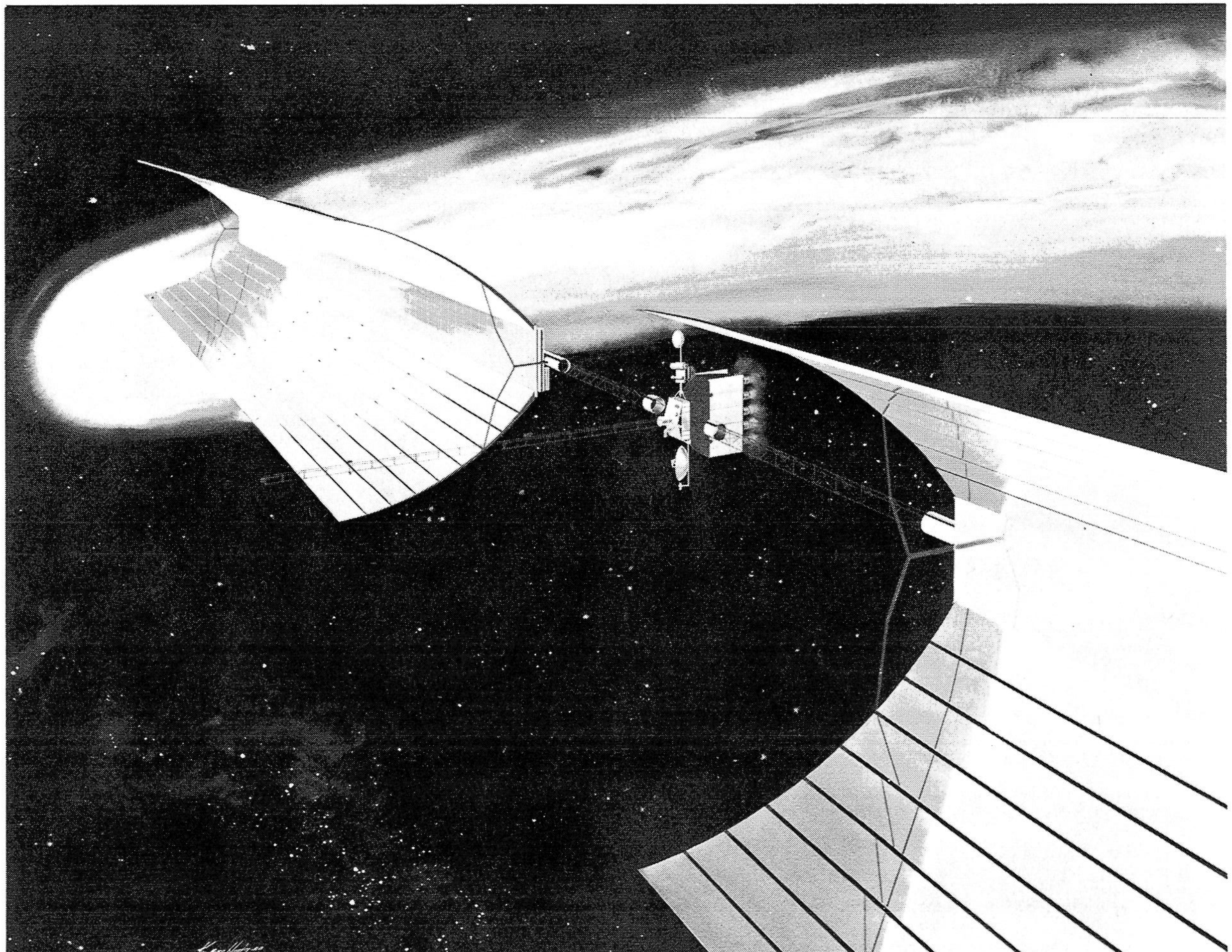


Fig. 4. Artist's conception of ion drive vehicle required for a rendezvous with Halley's comet.

The dimensions of the vehicle from "wing tip to wing tip" are something on the order of 450 to 490 feet. The array wings are about 12 feet wide, so you can see this is not a small machine. Each engine is 15 inches in diameter. You may think that 450 feet is fairly long (it is about a football field and a half from one wing tip to the other). However, on the scale of some systems that have been considered for the Halley rendezvous, the ion drive vehicle is relatively small. The solar sail, which was considered as an alternative technique for accomplishing a Halley Rendezvous mission, was nearly nine miles from wing tip to wing tip.

A better understanding of the ion propulsion technique is gained from looking at the engine cutaway shown in Figure 5. The ion engine is deceptively simple in its operation. It looks much like a coffee can about 15 inches in diameter and about 10 inches deep. The fuel, in liquid form, is brought in through a couple of heaters or vaporizers that transform the liquid mercury fuel to a vapor and distribute it through this manifold. At the base of the engine is an electron emitter or cathode. Electrons flow from the cathode to the anode out around the circumference. The electrons pass through the mercury vapor and cause ionizing collisions. Once charged, the mercury ions are forced by magnetic and electric fields toward the two accelerating screens over the exhaust end of the engine. A high electric field is placed between these two separated screens so that as the ions drift into it they are accelerated to a very high velocity and exhausted at speeds ranging from 50,000 to 75,000 miles per hour. The achievement of very high exhaust speeds at relatively small expenditures of energy leads to the benefit of high fuel efficiency. The engines thus offer a tremendous advantage in doing missions that we ordinarily refer to as "high energy requirers". They allow achievement of these missions for relatively small amounts of "fuel". Figure 6 shows a photograph of one

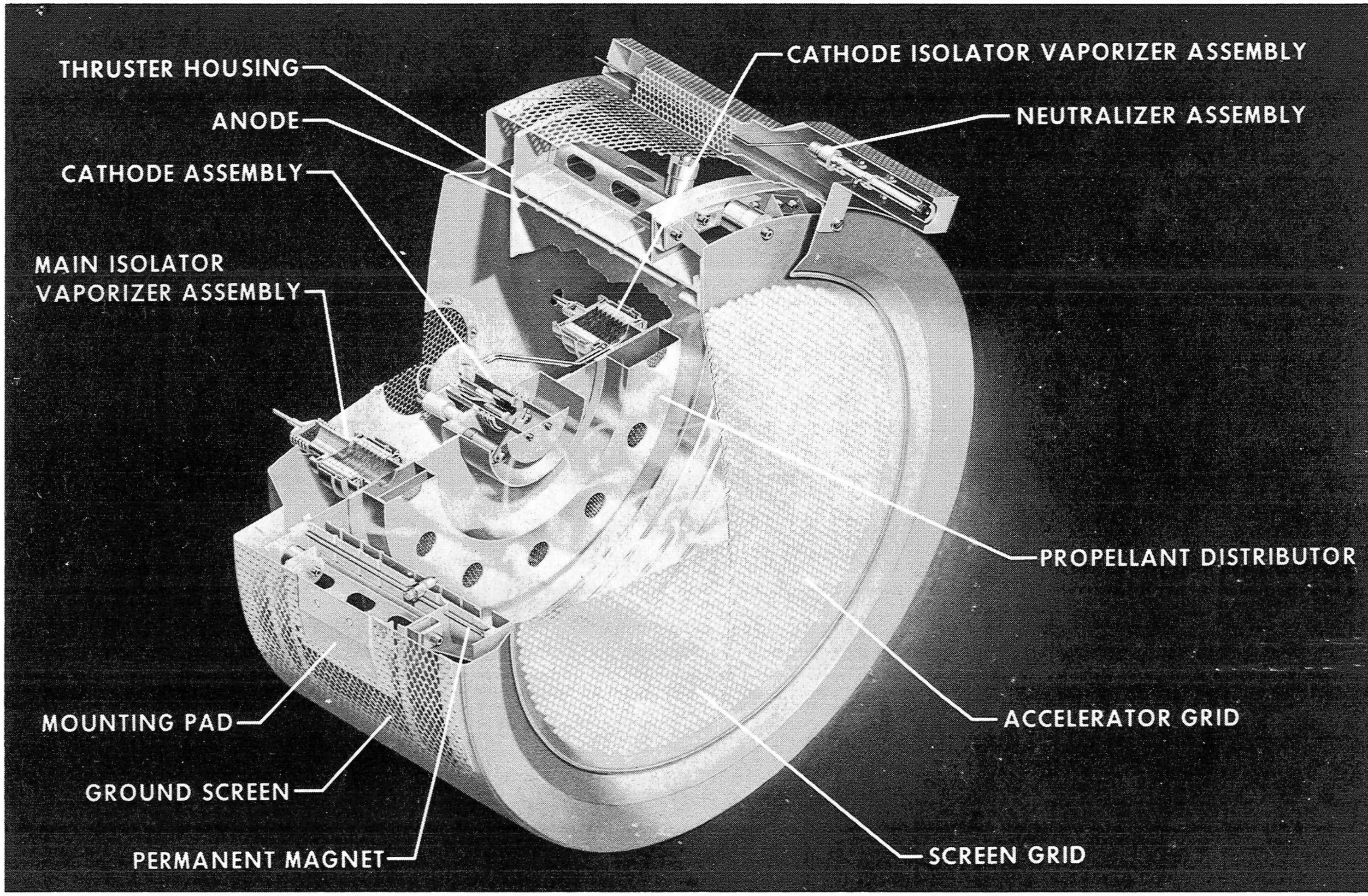


Fig. 5. Model of ion engine.

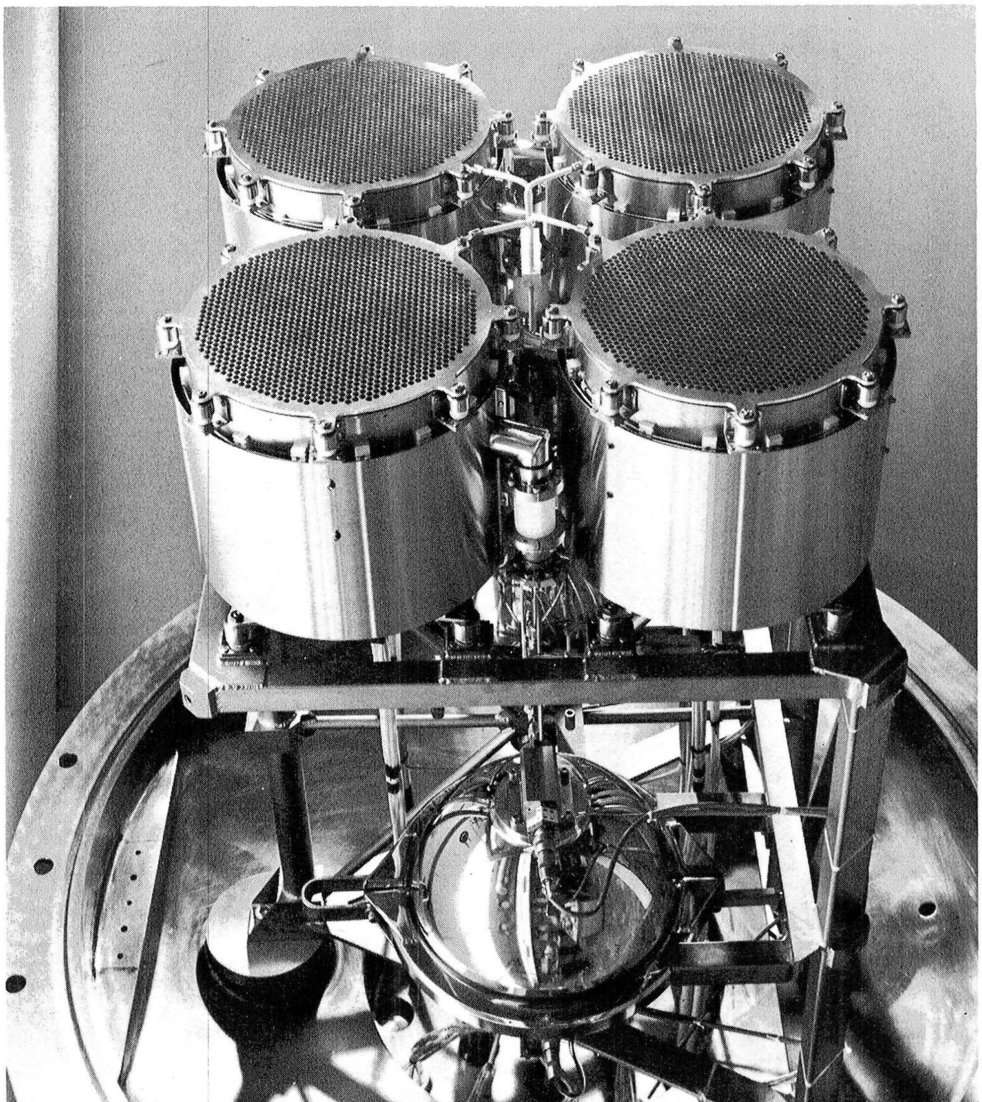


Fig. 6. Photograph of an ion engine.

of the engines. These engines have been tested both on Earth and in space and are still undergoing tests at Lewis Research Center and its contractors.

The modular nature of the thrust subsystem is shown by the scale model in Figure 7. This model has thrust units that combine two of these engines in each module with the electric power processing equipment in two racks at the end opposite the engines. The plates on the side are radiators which take away the excess heat that can't be used in the power conversion process. The components, put together in this fashion, become bimodular thrust units that can be standardized and stacked tinker-toy fashion to form a thrust subsystem for the ion drive rendezvous.

In the interface unit, just forward of the thrust modules, a propellant tank and two roots for the connection of the solar arrays are housed. The interface unit also provides the hard points for mounting the spacecraft.

Figure 8 depicts, in a series of scenes showing six different events, the ion drive deployment from the shuttle. Basically, we start at the bottom left with the ion drive stowed in the shuttle atop its twin-stage, solid, rocket booster. This stack is then erected in the shuttle bay and separated. The shuttle backs away to a safe distance and as the 3rd scene shows, the solid rocket booster is ignited and drives the ion rocket to a positive escape energy relative to Earth.

The fourth event shows burnout of the solid and separation of the ion system. Event 5 shows the beginning of the deployment of the solar arrays while the final scene at the lower right shows the partially deployed arrays that signal the beginning of the ion thrust phase.

Let's now discuss science acquisition options. We understand your concerns about operating with a system that has large electric and magnetic fields. There are several modes for science acquisition in such an environment. First, we have no difficulty in shutting the thrusters off, and in fact, the design

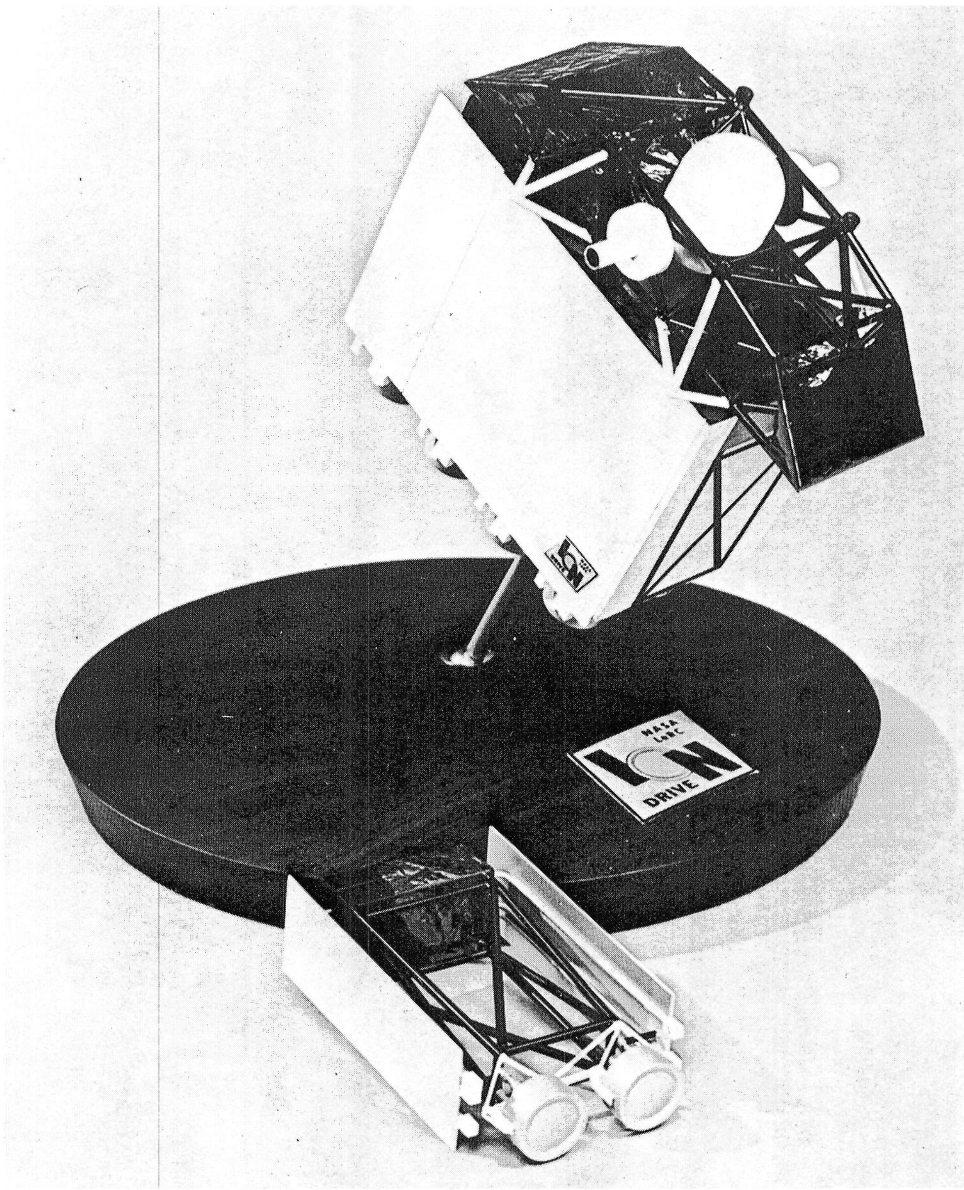


Fig. 7. Model showing possible modular construction of an ion propulsion system.

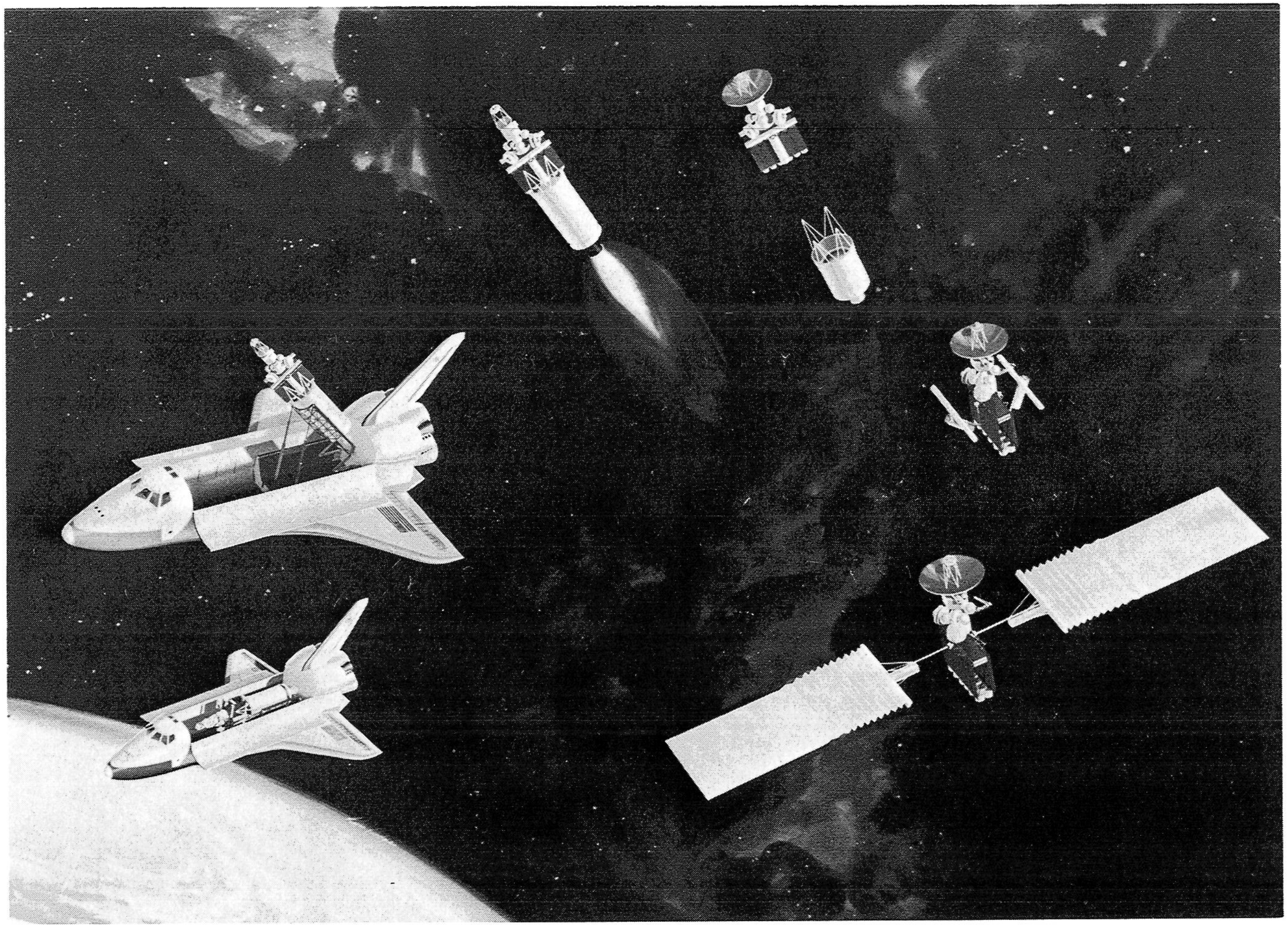


Fig. 8. Ion propulsion system deployment from the Shuttle/IUS.

of the Halley comet mission calls for exploration strategies where during most of our time in the vicinity of the comet, the engines are shut down and in a very quiet "coast" mode for taking the science data. Another option is to keep one of the engine neutralizers operating. This achieves active control of the spacecraft potential by providing a controlled source of electrons to balance charge build-up.

In a third option, we could continue to operate the engines and take data while both thrusters and neutralizers are operating. There are several ways to handle the problems caused in that mode. We can use clever positioning of the instruments, such as on booms, or we can shield the instruments.

We have also looked at the difficulties or concerns that might be seen in handling a mercury propellant, both in loading it and launching. A number of "worst-case" situations such as reentry of the entire mercury tank after an explosion during launch have been studied. These studies found that the effect on the Earth's environment is equivalent to a temperature change resulting from a trip of 300 miles; you deplete the ozone layer in a very, very limited vicinity for a short period of time.

In talking about missions to comets with ion drive there are several but a limited number of options for targets. I will discuss two today - the Halley Rendezvous and the Encke Rendezvous. Both have received considerable interest from the Science Working Group.

Figure 9 is a picture of the trajectory to achieve rendezvous with Halley's comet. The orbit of Earth is a dark circle. The launch would occur somewhere around June, 1982. The spacecraft goes out, away from the Earth, and begins to slow down much like a rock thrown up in the gravitational field. Then it "hangs a left", or makes a big "U turn" and begins to thrust back toward the sun. The orbit of Halley's comet is the dashed curve. The rendezvous occurs

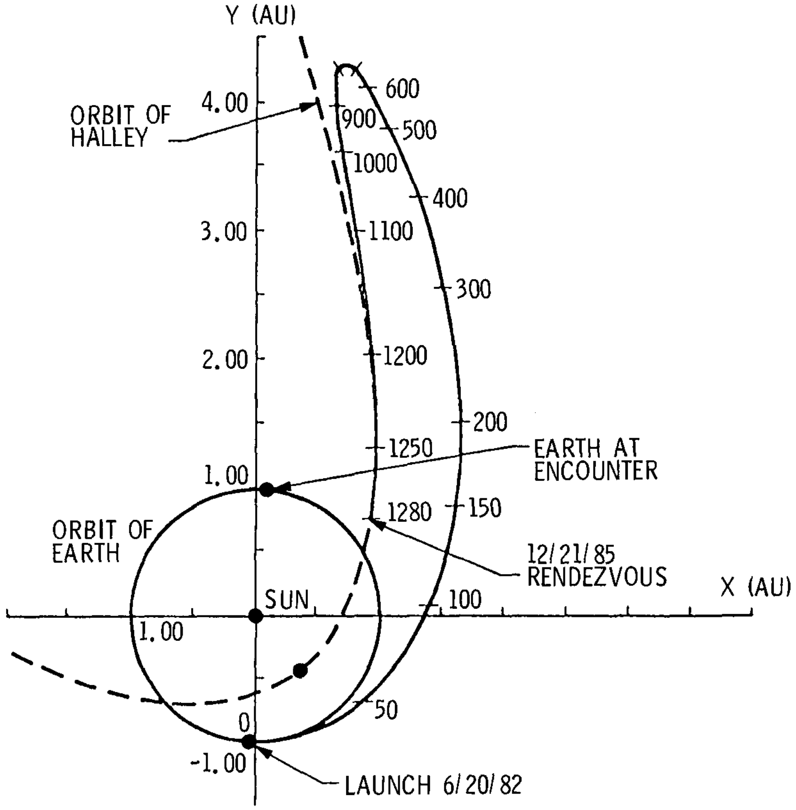


Fig. 9. Ion drive trajectory to attain a rendezvous with Halley's comet.

when the comet overtakes the spacecraft, just before Christmas, 1985. It will make an interesting Christmas star as seen from the spacecraft.

The other alternative target is comet Encke. Figure 10 shows the trajectory for Encke's 1987 apparition. The launch would occur in March, 1985. The spacecraft would arrive 700 or 800 days later in May, 1987, some 50 to 60 days before perihelion. During this particular apparition of Encke, the Earth is across the solar system from the comet. This situation is not particularly attractive for ground based optical observations of comet Encke, but we see no real difficulties in communication with the spacecraft during the rendezvous.

One thing about the Encke mission that I think is significant is how close it passes the sun during its perihelion, about 0.34 astronomical units. That is going to be a very hot thermal environment, and it is going to take some clever approaches on the part of engineers in order to solve the thermal problem if this mission receives serious consideration.

In summary, I've introduced ion drive, discussed its characteristics and operation, and briefly overviewed its potentially wide spectrum of applications. Its modular nature and high fuel efficiency while operating from electricity generated by collecting sunlight make it an ideal adjunct to the Shuttle Transportation System. I specifically addressed its unique potential for achieving comet rendezvous and used the examples of Halley's comet and Encke as prime mission candidates. I hope from this brief introduction I've been able to transmit something of the excitement I think is inherent in the combination of an exotic new propulsion technique, ion drive, with a mission to investigate Halley's and other comets.

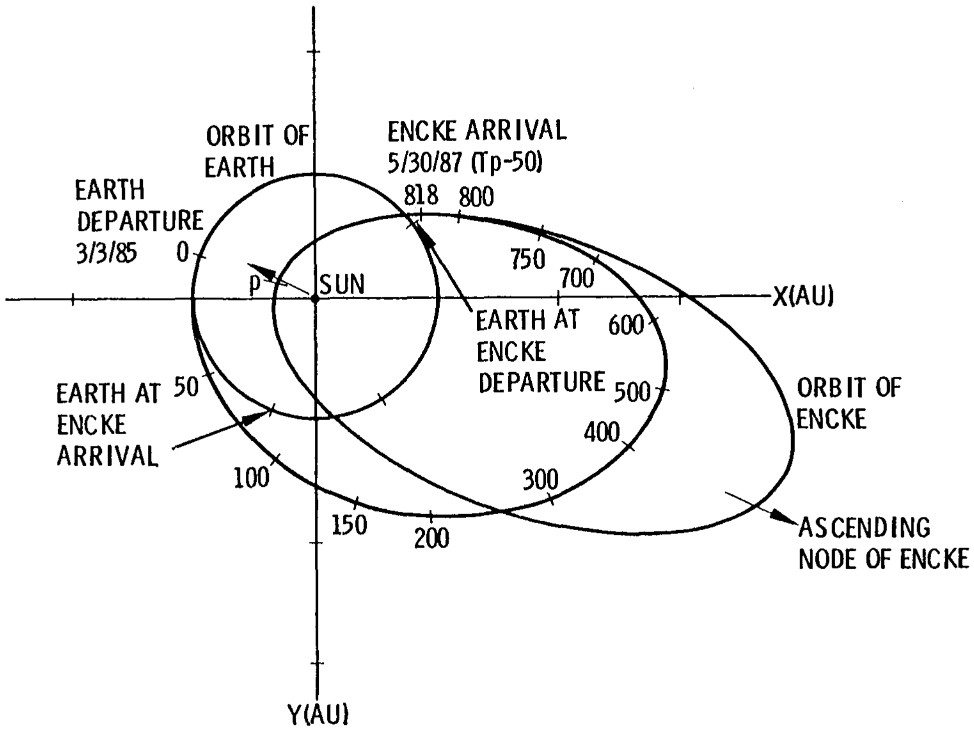


Fig. 10. Encke rendezvous (1987) trajectory.