AMES FACILITY FOR SIMULATING PLANETARY PROBE HEATING ENVIRONMENTS

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MR. STINE: I wish to bring you up to date on what has been done at Ames Research Center in recent years in development of arc-jet entry simulation apparatus, what we are now doing, and what we are planning to do. Along the way, I will attempt to make you aware of the rationale for our activities and try to acquaint you with our schedule for accomplishing this work.

The first illustration, (Figure 6-51) is a sketch of the only piece of arc-jet apparatus ever built at Ames that came anywhere near generating an environment corresponding to a giant planet entry. Its performance is described in Reference 1.* Essentially, it is a long, skinny, tube chopped up into segments. Each segment is made of a good heat conducting material, namely copper. It is water cooled. The segments are spaced with electrical insulation so that the whole device can support the voltage gradient of an electric arc which is established within the tube. At the ends of the tube, are arrays of electrodes, the number being picked to limit the amount of current that each element has to handle to a value that will permit the machine to survive. Remember that this apparatus in itself, is exposed to the same environment that we are trying to simulate, within a factor of two or so. It is a real challenge to assemble such an apparatus so that it will remain intact long enough to accomplish its purpose. Unfortunately, this device is unsuitable for heat shield materials testing because its run duration is only 1/2 sec at most.

The next figure, (Figure 6-52) is a table that shows, historically, Ames arc-jet facility development activity during the last few years. The top two entries in the table list Ames facilities

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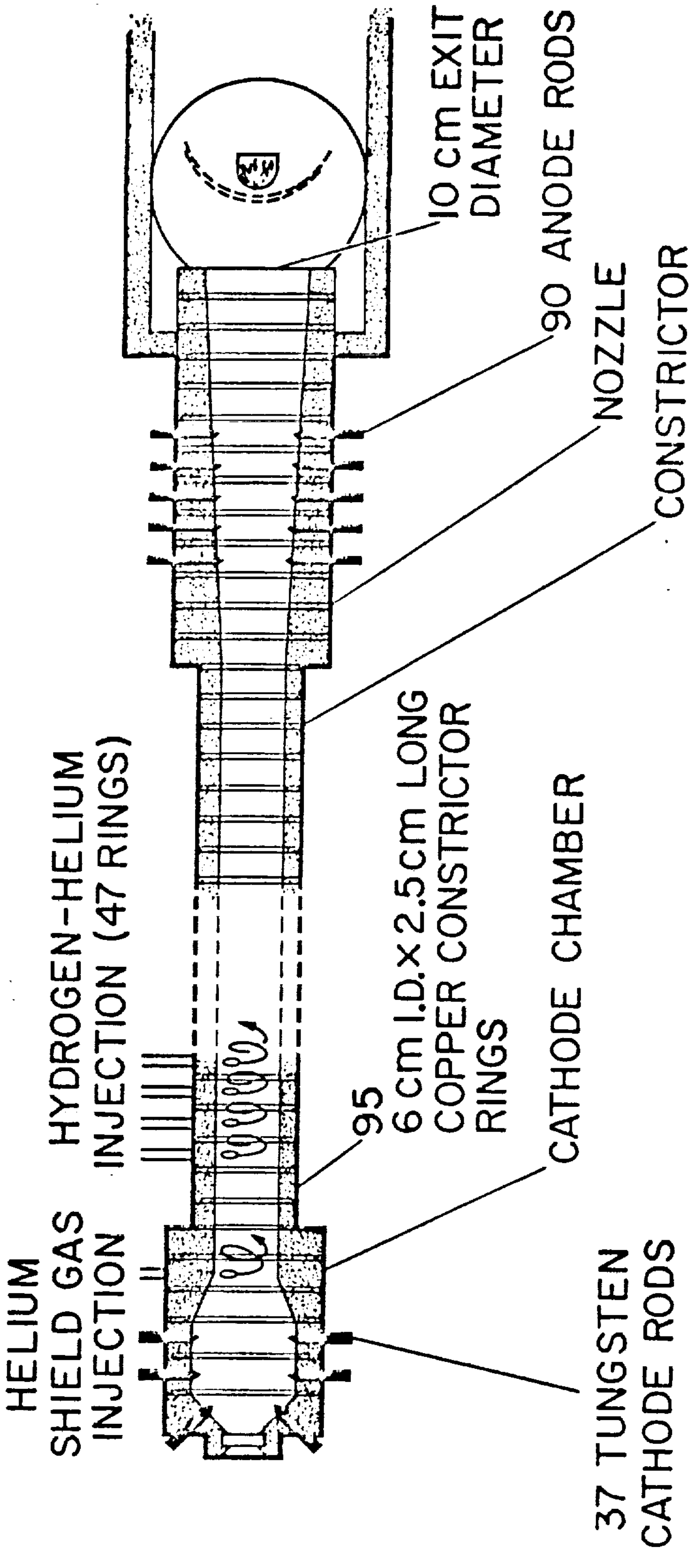
*Shepard, Charles E.: "Advanced High-Power Arc Heaters for Simulating Entries into the Atmospheres of the Outer Planets" AIAA Paper No. 71-263. AIAA 6th Aerodynamic Testing Conference; Albuquerque, New Mexico/March 10-12, 1971.



6 cm PULSED CONSTRICTED ARC JET

Figure 6-51

TPS FACILITY DEVELOPMENT

AMES RESEARCH CENTER

Name	Power (MW)	Impact Press (Atm)	Enthalpy (MJ/KG)	Stream Area (CM^2)	Gas	Gas Flow Rate (KG/Sec.)	Purpose	Status
TPS Pilot Facility	20	.12 .36	32 32	1135 710	air air	1.25 1.25	RCC Char. & Devt. HRSI Char. & Devt.*	Operational Shakedown
Interaction Heating Facility (CofF '72)	60	.12 .36	32 32	8500 2550	air air	2.5 2.5	RCC Dev. & Qual. HRSI Devt. & Qual.*	Under Const. Under Const.
Giant Planet Pilot Facility (CofF '74)	110	6	600	95	H_2+He	0.1	Arc Technology Devt. Giant Planet Entry Simulation	Design
Trans. & Turb. Flow Test Apparatus (CofF '75)	110	20	4.6	314	air CO_2+N_2	14	Turbulent Flow with Massive Ablation	In Budget
GiantPlanet Facility (CofF '77)	160	10	600	113	H_2+He	0.15	Jupiter Entry Simulation	Proposed

*Semi-elliptic-duct nozzle
(all other conical)

5/74 - NASA-Ames

Figure 6-52

dedicated to space shuttle TPS testing. The first is a twenty megawatt machine now in operation, for cyclic testing of high temperature reusable surface insulation. The second, called "interaction heating facility," is in shakedown status. Construction began in 1972 with C of F funding. It consists of a sixty megawatt arc heater and associated D.C. power conversion equipment, and it is nothing more than a scaled-up version of the 20 mw pilot facility.

Finally, of more interest to the people here are the remaining entries in Figure 6-52. For a number of years a need has been recognized for a facility to simulate entry into giant planet atmospheres. Just two months ago authority was received to construct what is called a giant-planet pilot facility. It is expected to operate at a power level of 110 megawatts delivered to the arc heater, to generate impact pressures of six atmospheres at an enthalpy of up to 600 megajoules per kilogram. These conditions are close to those expected at the peak heating point for a shallow entry into the atmosphere of Jupiter. The stream will not be large; only an area of ninety-five square centimeters would be possible without additional electric power. Mixtures of hydrogen and helium will be used as the working gas, at very low flow rates. Two purposes will be met by building this pilot facility. One is to advance the technology of arc heater development to permit operation in the giant-planet entry regime; the second is to at least come close to being able to simulate, if not Jupiter entries per se, then those of Saturn or Uranus probe missions. As I said, we have been authorized to go ahead with the giant planet pilot facility. It is at present under design.

In the fiscal year 1975 budget is an item (Figure 6-52) to produce another arc heater in the 100 MW class. This device, called "Transitional and Turbulent Flow Test Apparatus," is nothing more than an upgraded Linde arc heater that will be used to produce very large flow rates of moderate enthalpy gas.

It can be operated with air, or CO_2 but it could for that matter accept mixtures of hydrogen and helium. It's purpose is to produce flows in which transition to turbulence will occur simultaneously with massive ablation from heat shield materials. It will not produce appreciable radiative heating, but will rather produce very high convective heat transfer rates.

Finally, it is in our plan, which is based on a 1984 Jupiter probe mission, to build a more powerful giant planet facility that would achieve the full Jupiter entry simulation assuming the nominal Jupiter atmosphere. It would produce impact pressures up to ten atmospheres, the same enthalpy as the pilot facility, be somewhat larger, but not very much. I will try to point out why it is the large increases (from 110 to 160 MW) don't permit much increase in size.

Figure 6-53 shows domains of enthalpy, or energy content per unit mass as a function of impact pressure for probes that enter giant planet atmospheres. On it one can conveniently also plot the corresponding performance domains of such simulation facilities as exist today. Notice that their operating domains lie very close either to the ordinate or the abscissa. Close to the abscissa and continuing out to even much higher impact pressures than those shown (of the order of two hundred atmospheres) the RENT and the HIP facilities, by nature very low enthalpy devices, can operate. The crosshatch band adjacent to the ordinate corresponds to the performance domain for the six-centimeter pulsed device shown on Figure 6-51. It has, indeed, generated enthalpies that correspond to Jupiter atmosphere entry, close to 10^9 joules per kilogram, but only at impact pressures of less than one atmosphere.

As I said, peak heating for Jupiter entry lies at enthalpy and pressure values of 600 MJ/kg and 10 atm., respectively for a fifteen degree initial entry angle. Saturn and Uranus entry

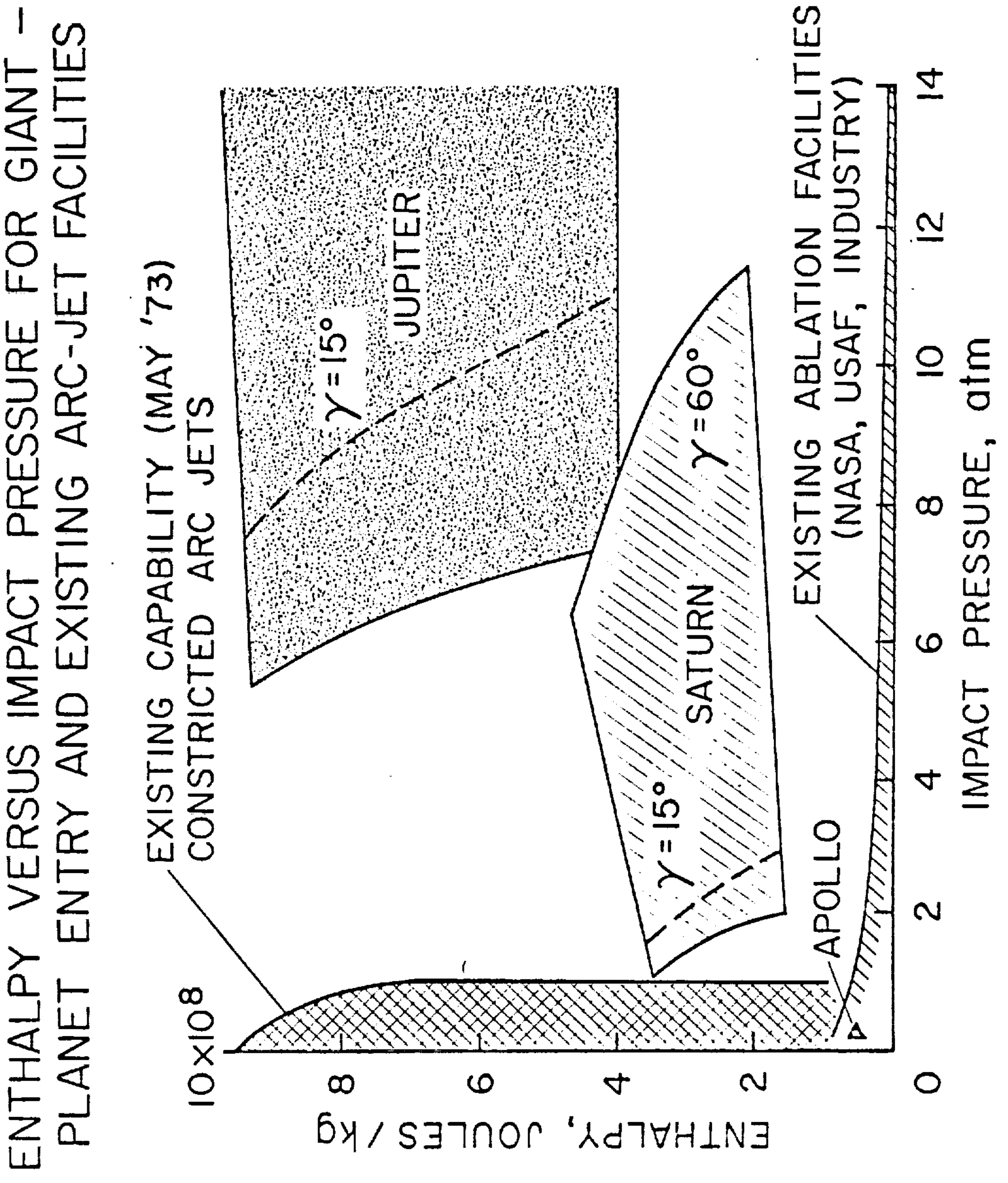
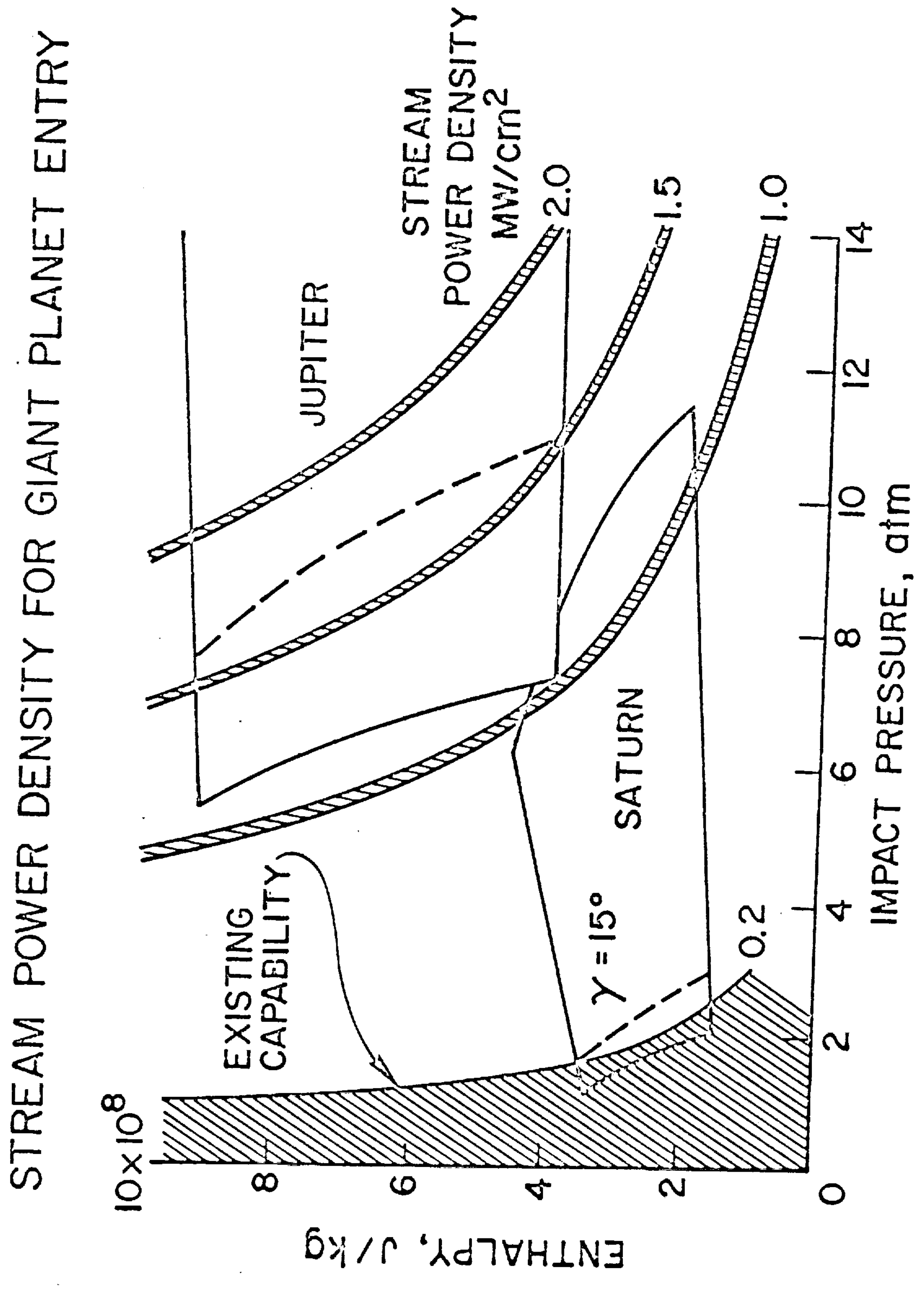

ENTHALPY VERSUS IMPACT PRESSURE FOR GIANT – PLANET ENTRY AND EXISTING ARC-JET FACILITIES
EXISTING CAPABILITY (MAY '73) CONSTRICTED ARC JETS
JUPITER
$\gamma = 15°$
SATURN
$\gamma = 60°$
$\gamma = 15°$
APOLLO
EXISTING ABLATION FACILITIES (NASA, USAF, INDUSTRY)
ENTHALPY, JOULES / kg
10×10⁸
8
6
4
2
0
2
4
6
8
10
12
14
IMPACT PRESSURE, atm

Figure 6-53

domains lie below and to the left of that for Jupiter, and one may note that existing facilities are very close to being able to simulate these entries now.

Why is it that arc jets and other facilities as we know them have operating domains that lie close to the axes in this plot (Figure 6-53)? The reason is a simple one, namely that the stream power density required to produce the Jupiter entry environment is very large, (see Figure 6-54). Figure 6-54 shows essentially the same information as Figure 6-53, but with the addition of lines of constant stream power density. For example the line that lies closest to the Jupiter entry trajectory for an initial entry angle of 15 degrees corresponds to a stream power density of one and one half megawatts per square centimeter of stream area impinging on the heat shield nose. Present arc heater technology is such that only two-tenths megawatt per square centimeter has been achieved at Jupiter-entry enthalpy. I should also point out that the shuttle TPS devices that are described in Figure 6-52 are creampuffs by comparison. Their operating domains all lie very close to the origin of Figure 6-54 (32MJ/kg; 0.2 atm).

Figure 6-55 is a plot that shows the present arc heater power supply capability at Ames Research Center. The supply will produce an output, under ideal conditions, as a function of run duration along the top curve on the graph. For shuttle TPS testing, it will generate up to seventy-five megawatts for periods of 1/2 hour if an exact match between arc heater and power supply were achieved. Because a perfect match is not ordinarily possible, one must take a small penalty as shown by the cross-hatched band below the line of ideal output. Thus, our shuttle arc is designed for sixty megawatts, and will operate in the cross-hatched band near 2,000 seconds. For short run times, like the ten seconds corresponding to entries into giant planet atmospheres, we expect that the power supply will, under ideal



STREAM POWER DENSITY FOR GIANT PLANET ENTRY

Figure 6-54

AMES DC POWER SUPPLY COMPARED TO GIANT-PLANET ARC REQUIREMENTS

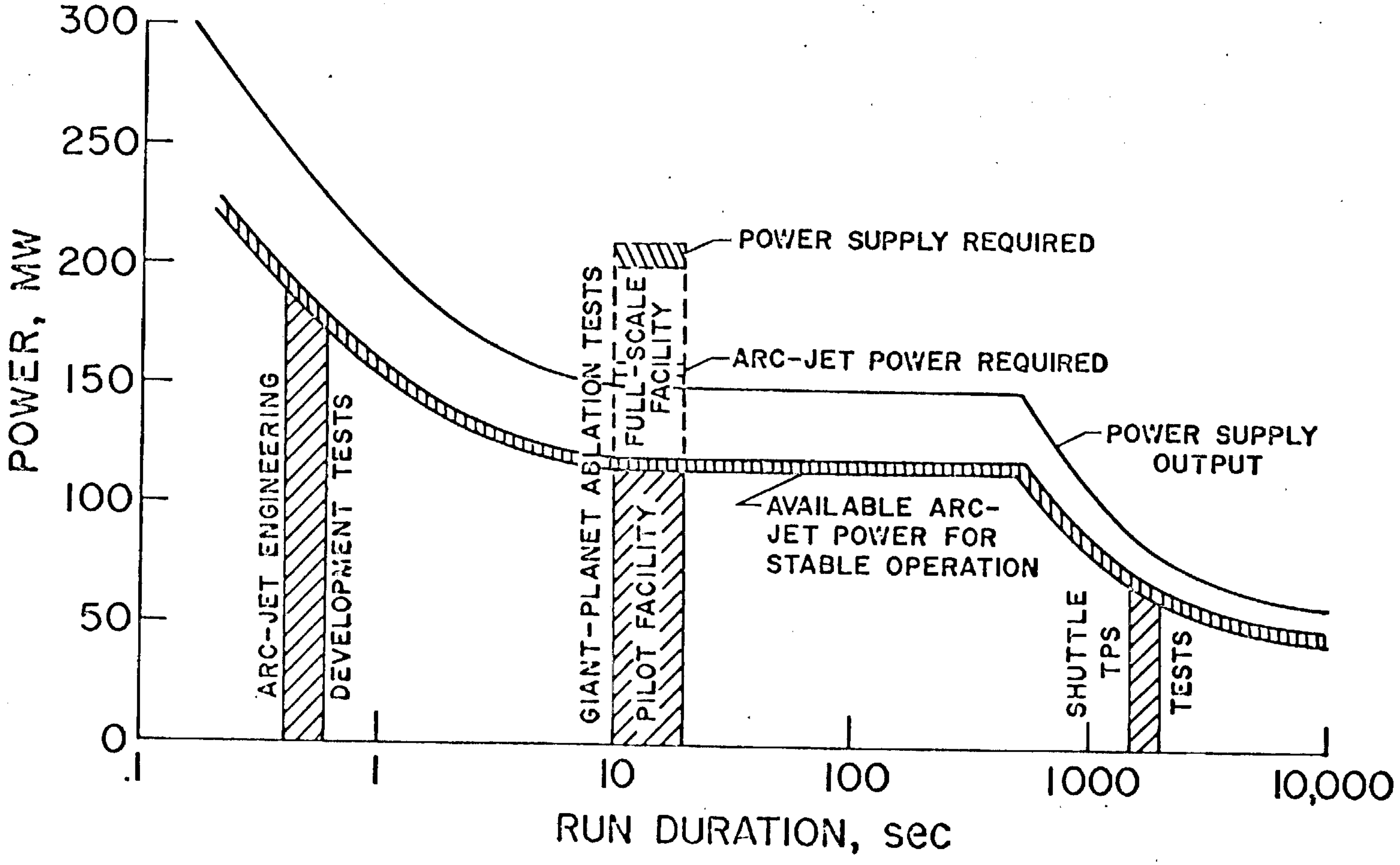


Figure 6-55

conditions, produce one hundred and fifty megawatts of D.C. power. We believe we can certainly deliver one hundred and ten megawatts to the giant planet pilot facility. If we elect to operate the pilot facility in a heat-sink mode for times less than one second, we can perhaps deliver as much as one hundred and seventy-five megawatts to the heater.

To accomplish a Jupiter entry simulation, we estimate that it is necessary to deliver 160 MW to the arc heater, as is also shown on Figure 6-55. Even the present power supply would not be sufficient to do this task if the atmosphere model of Jupiter remains as it is thought to be today.

Figure 6-56 shows our giant-planet facility development plan in terms of arc heater performance. The device shown in Figure 6-51, representative of present technology, can generate a little over one atmosphere impact pressure at twenty megawatts, with corresponding cold-wall heating rates of fifteen kilowatts per square centimeter. The giant-planet pilot facility, as I said, is also a 600 megajoule per kilogram device. We will attempt to generate impact pressures up to six atmospheres at 110 megawatts, with corresponding combined heating rates up to thirty-five $kW/\overline{cm}^{-2}$. With 160 megawatts available, impact pressure can be raised to ten atmospheres at a slightly higher heating rate. But stream size, as is shown, can be increased only slightly.

Owing to the present lack of definitive information both as to the character of Jupiter's atmosphere and to the behavior of heat shield materials at Jupiter entry conditions, it is believed that a probe mission to Jupiter involves several steps which must be taken in sequence, Figure 6-57. First, some arc heater development is necessary to find out whether the required facility can be built. Second, we have to build the facility. Third, we have to find out whether or not a viable heat shield can be built. Only then do we know whether or not a Jupiter

GIANT-PLANET ARC FACILITY DEVELOPMENT PLAN

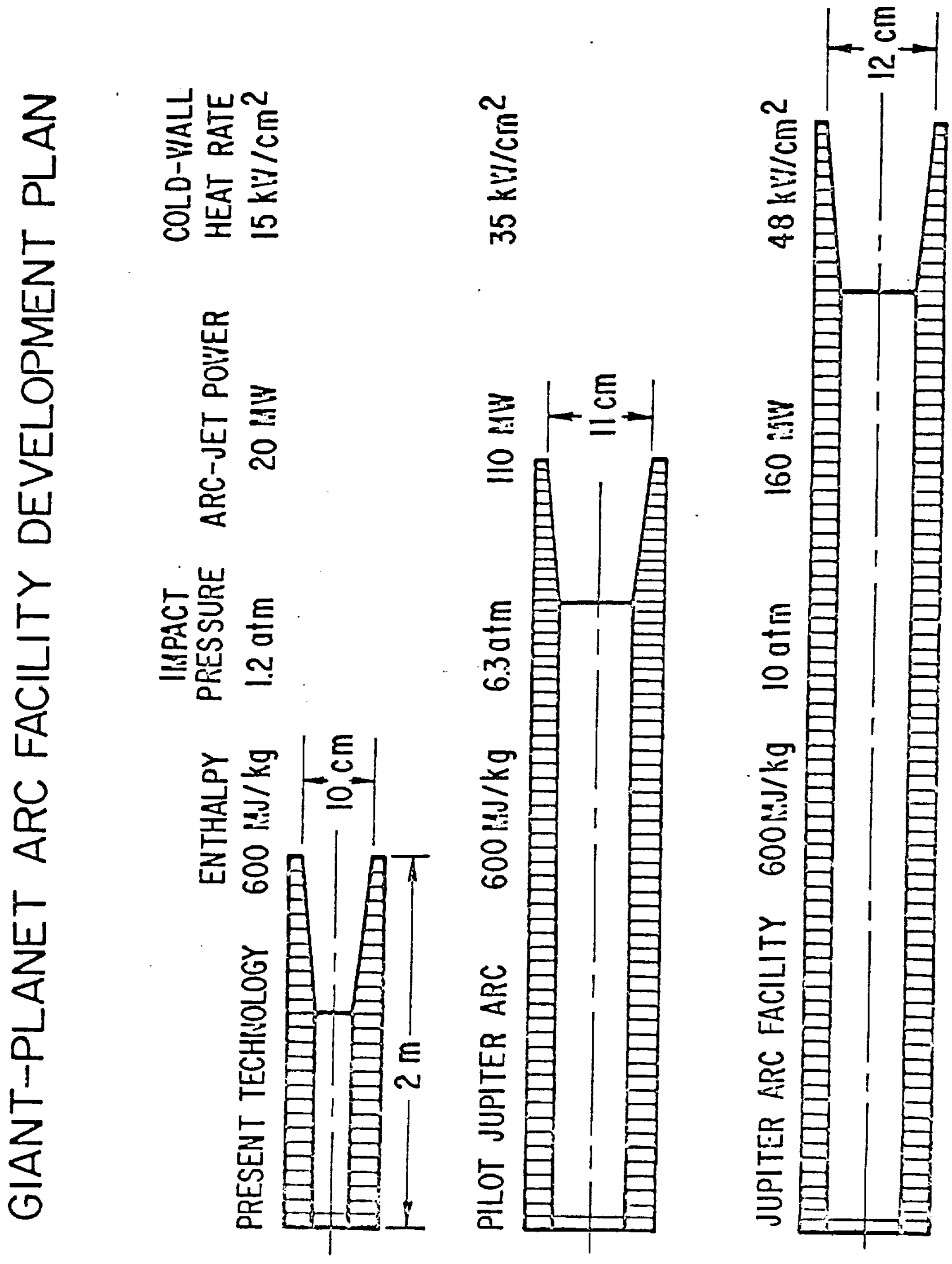


Fig. 10

Figure 6-56

SEQUENTIAL STEPS FOR JUPITER PROBE MISSION

1) Engineering Arc Development

2) Build Facility

3) Heat Shield Design

→ Mission Feasibility Established

4) Spacecraft Design

Figure 6-57

probe mission is feasible. Finally, assuming successful completion of all foregoing steps, we can start designing a space craft.

Figure 6-58 shows our time schedule. Actually, design work was started on the pilot arc about two months ago, so we are now slightly ahead of schedule. We expect the pilot facility to be operational in the middle of fiscal year 1976. Thereafter, both arc development testing and some heat shield materials testing will be carried out. If it turns out that the Jupiter entry environment is more benign than is now thought, it may develop that the pilot arc facility can simulate the Jupiter probe entry environment as well as those of Saturn and Uranus. Otherwise, we will have to go through the complete cycle shown on Figure 6-58 which would permit us to say whether or not we have a viable heat shield design sometime during the middle of 1980. Thereafter, mission approval and probe construction would consume the remaining time prior to spacecraft launch in 1984.

DR. NACHTSHEIM: Questions?

MR. SEIFF: Howard, is any attention being given to using this existing facility to achieve 600 megawatts?

MR. STINE: Megajoules per kilogram

Mr. SEIFF: -- per kilogram?

MR. STINE: It is not water cooled, Al. You can't run it more than one-half second at a time.

MR. SEIFF: It doesn't get the right pressure; but is there any attention being given to evaluating materials in there? It has the correct enthalpy, apparently.

GIANT-PLANET ENTRY ENVIRONMENT FACILITY
TIME SCHEDULE, FISCAL YEAR

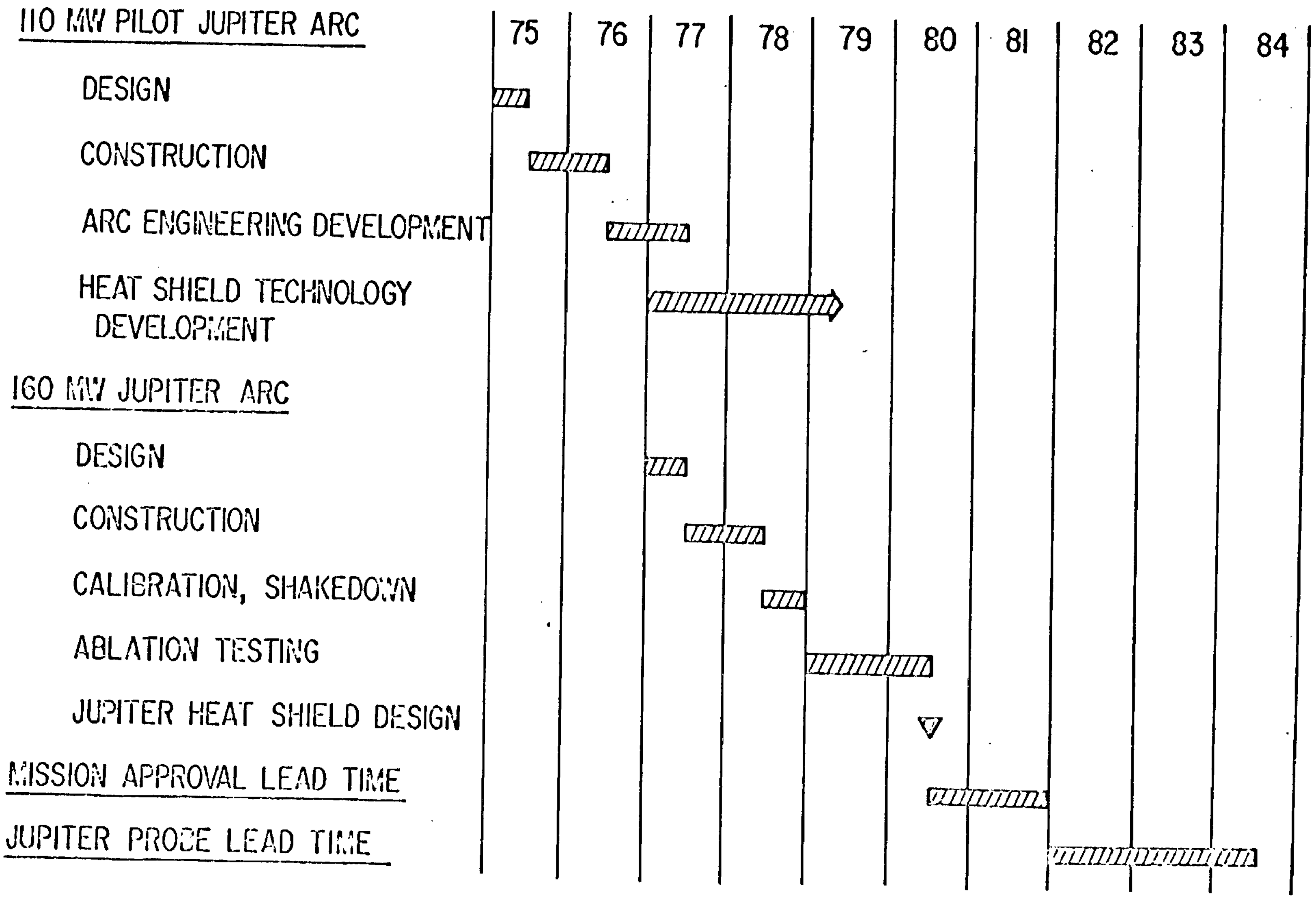


Figure 6-58

MR. STINE: Well, it will sickle through a piece of aluminum bar four inches thick in a half a second, but it won't quite get a piece of graphite hot enough to start ablating. It just barely starts, and then the run is over.

MR. SEIFF: Oh; the run time is too short. That is its limitation.

MR. STINE: Longer than a shock tube but shorter than the time it takes for the material to respond.

MR. NICOLET: What about the possibility of looking at aerothermal environments with that. Would it take a sizable model?

MR. STINE: It's got a ten centimeter diameter nozzle exit. Yes, we did do that, actually.

MR. NICOLET: You did look at aerothermal environments?

MR. STINE: Yes; well, we tried to determine what the device was putting out. We measured the heating rates: convective and radiative; we measured enthalpy, of course, impact pressure, and things of that nature; hydrogen-beta line broadening, things of that sort; some spectra.