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SOME POTENTIAL IMPACTS OF LUNAR OXYGEN AVAILABILITY ON NEAR-EARTH SPACE TRANSPORTATION; Gerald W. Driggers, Southern Research Institute, Birmingham, Alabama.

The processing of lunar resources in Earth orbit for purposes of obtaining materials for manufacturing has been suggested by O'Neill and others (1,2). A by-product of such processing should be rather copious quantities of oxygen. This observation has led to some thought and analysis concerning the alleviation of requirements for Earth-to-orbit transportation of propellant for orbital operations (3).

The most immediate application of lunar oxygen available in Earth orbit would be orbit-to-orbit or "tug" type transportation. Three cases have been investigated in this context to quantify savings in total Earth launch mass. The ideal mission velocity was determined by the basic requirements to transport mass from low Earth orbit (LEO) to Lagrangian point 4 (L4) or L5 or synchronous equatorial (sync. eq.) orbit. Empty vehicle return was assumed.

The three cases investigated were: (1) O_2 stockpile at L4/L5; (b) O_2 stockpile in synchronous equatorial orbit; and (c) O_2 stockpile in LEO and L4/L5 or sync. eq. orbits. The possibilities are shown schematically in Figure 1. A low cost (probably low thrust) system to place the O_2 in LEO is assumed, so no H_2 fuel is included in Earth-to-orbit mass computations for transport of O_2 to LEO from sync. eq. The results of the analysis performed relative to the sync. eq. mission are shown in Figure 2. The chemical propulsion requirements are compared to an idealized nuclear stage of the NERVA class. The impacts on Earth launch requirements are dramatic.

Another space transportation area may also be affected by the availability of lunar oxygen in LEO. Although it is not immediately obvious, an O_2 stockpile in LEO can make a new and unorthodox Earth-to-orbit operational mode feasible. The ultimate effect is about a four-to-one reduction in system gross lift-off weight (GLOW) for a payload of some 227 metric tons (500,000 pounds).

The operational mode referred to here has been termed suborbital rendezvous (SOR) by the author. The concept is basically to obtain some of the energy required to reach orbit from Earth supplied propellants and the remainder from LEO lunar oxygen. Two vehicles are involved: the Earth launch element (ELE) and the orbital element (OE). The ELE carries all fuel required and some O_2. The OE supplies O_2 and high efficiency engines. Initial velocity (say through 19,000 ft/sec ideal) is supplied solely by the ELE launch. At a point where the vehicle trajectory is appropriately oriented (perhaps parallel to the Earth's surface), rendezvous and attachment would be effected with the OE which has descended from orbit. With the elements mated, the OE would supply oxygen and the ELE fuel for the remaining flight to orbit.

Although certainly a more complicated scheme than a single-stage-to-orbit (SSTO), this operational concept offers a substantial advantage over the SSTO. That advantage, as mentioned earlier, is a large reduction in GLOW for a given payload mass.

Equations have been derived to analyze the SOR elements taking three velocity increments into account. The first, ΔV_o, is the OE descent from orbit to rendezvous. H_2 must be supplied from Earth for this increment. The second, ΔV_1, is the velocity imparted at Earth launch to the ELE. The ΔV_2 increment is obtained with the ELE and OE coupled. The relationships between ELE propellant mass, total inert mass (including payload) and GLOW are shown in Figure 3 for a set of assumed performance parameters, also shown on the Figure. Note that although ideal velocity equations were used in the assessments, some 3400 ft/sec for drag and gravity losses was included in ΔV_1.

The potential impact of using the lunar oxygen in the SOR mode is illustrated in Figure 4. The SOR/ELE vehicle with payload comparable to the SSTO is only about one-fourth its size. The OE is computed to weigh 1.81×10^6 lb. prior to de-orbit so the total pre-mission mass is about 7.43×10^6 lb. for ELE and OE combined.

The use of lunar oxygen for orbit-to-orbit or Earth-to-orbit transportation will probably be the result of industrialization of space and not a goal in itself. However, the implications of synergism are obvious since reductions in transportation cost for very large activity levels in Earth orbit would offset a substantial portion of the lunar base establishment costs. Although availability of this oxygen is some time away, its potential benefit is substantial enough to warrant near term study of the possible impacts to all cis-Lunar activity.

References

1. O'Neill, G. K., September 1974, Physics Today, p.32-40.

2. O'Neill, G. K., September 1975, Hearings Before the Subcommittee on Space Science and Applications of the Committee on Science and Technology - U. S. House of Representatives, p.111-188.

3. Driggers, G. W., August, 1975, Proceedings AAS 21st Annual Meeting, in press.

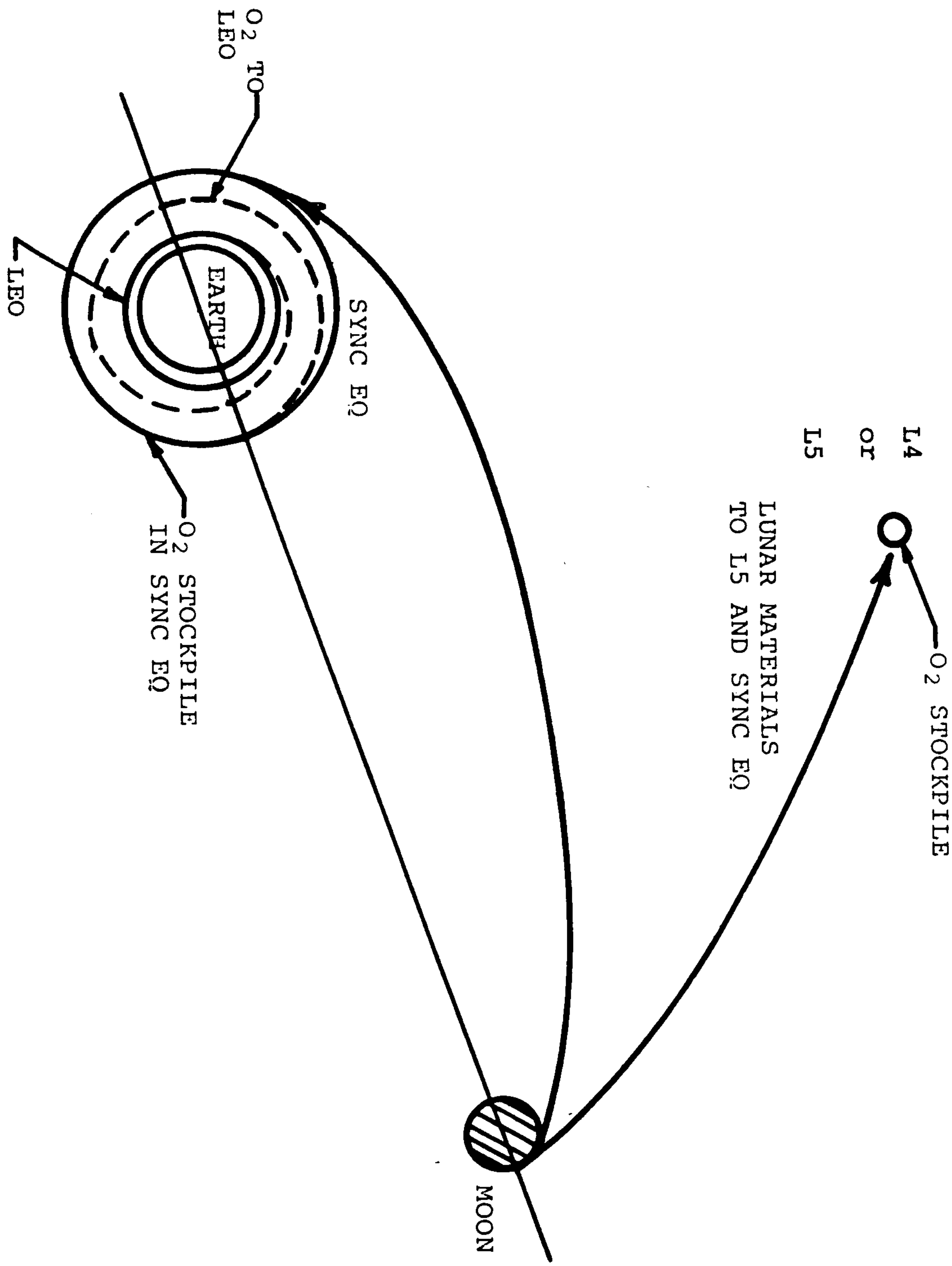

FIGURE 1. SCHEMATIC OF MATERIAL TRANSFER AND O_2 STOCKPILES

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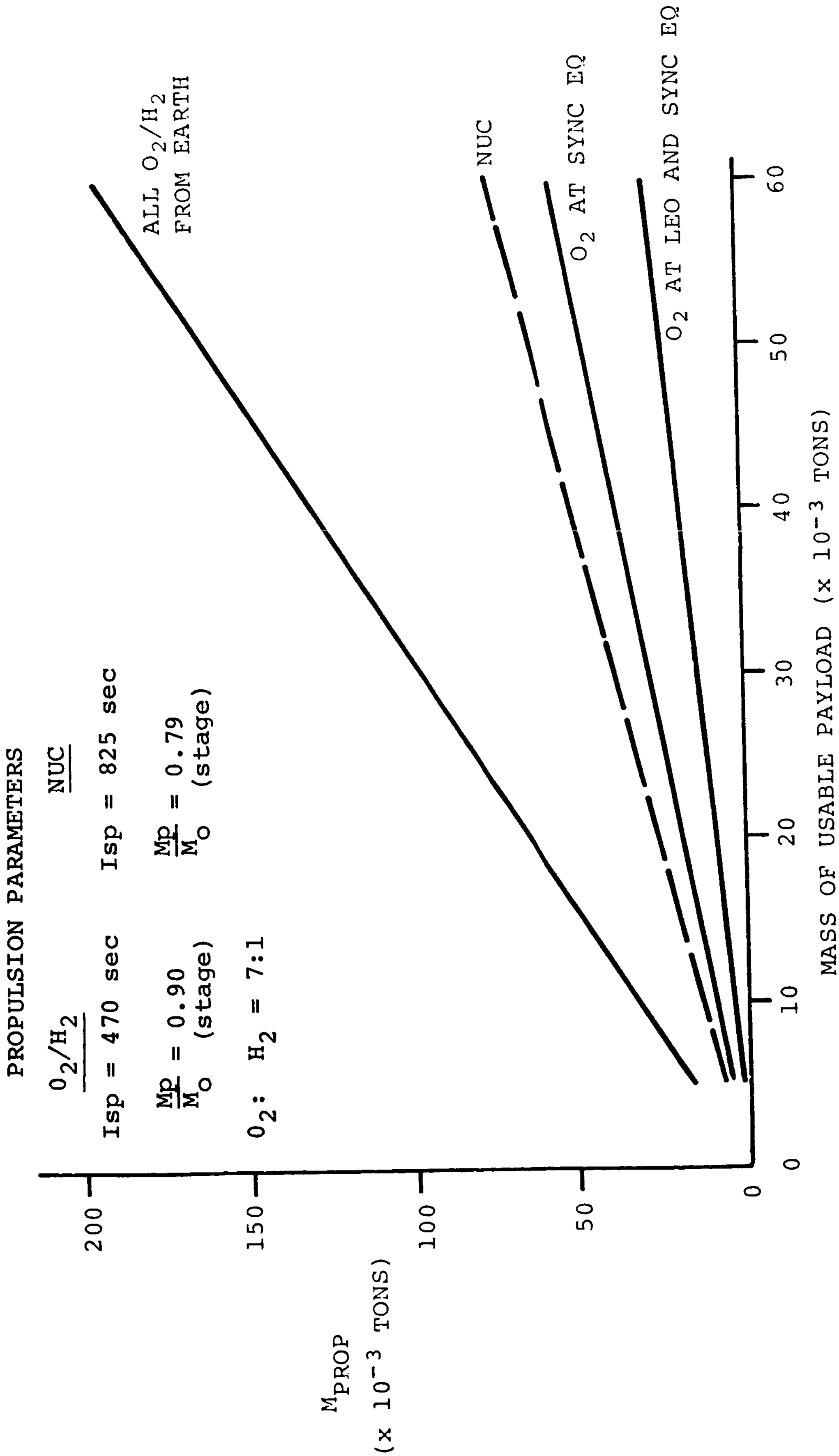

FIGURE 2. COMPARISON OF TOTAL PROPELLANT MASS REQUIRED FROM EARTH AS A FUNCTION OF O_2 AVAILABILITY IN ORBIT

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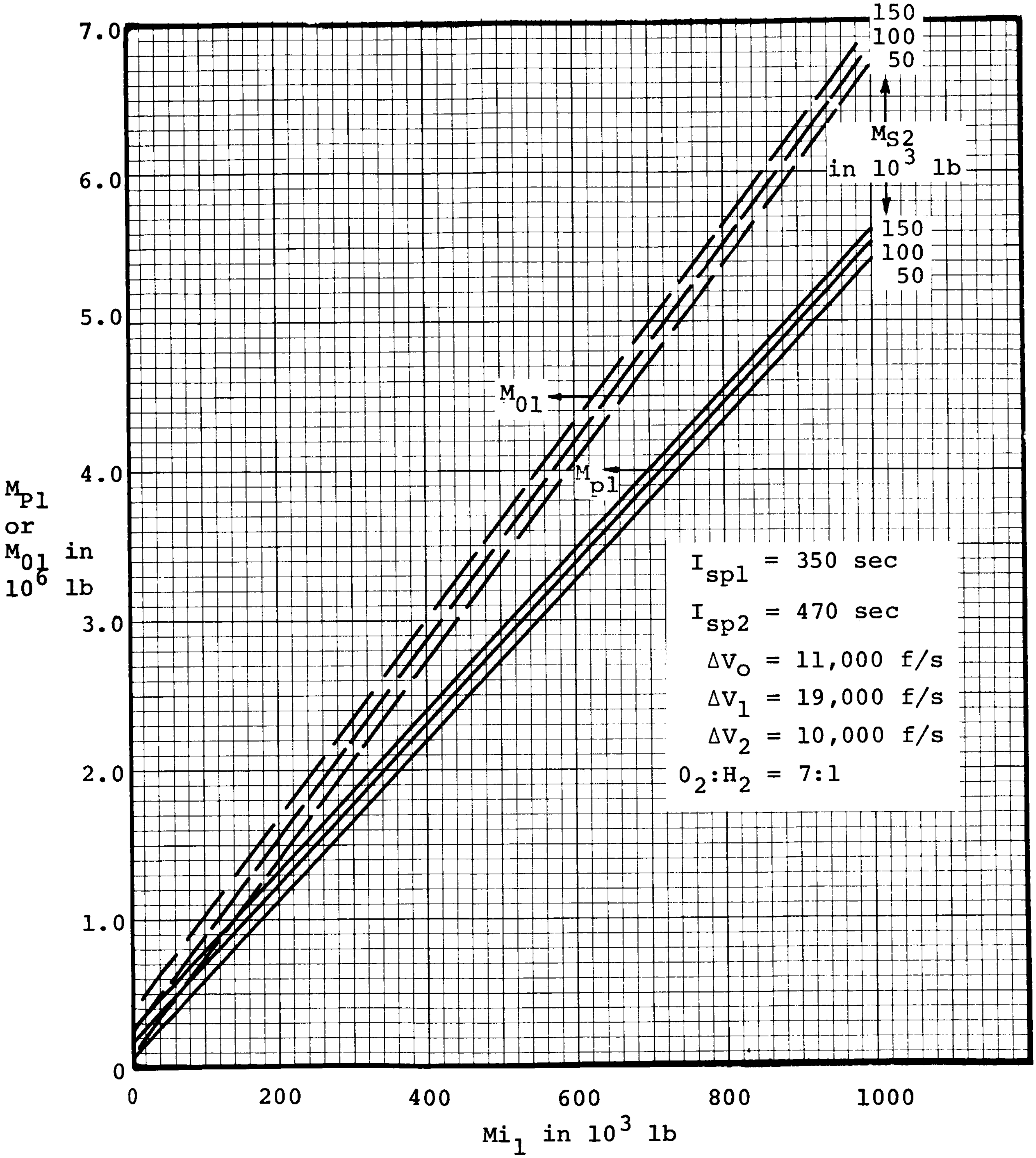

FIGURE 3. EARTH LAUNCH ELEMENT PROPELLANT MASS AND GLOW AS A FUNCTION OF INERT MASS

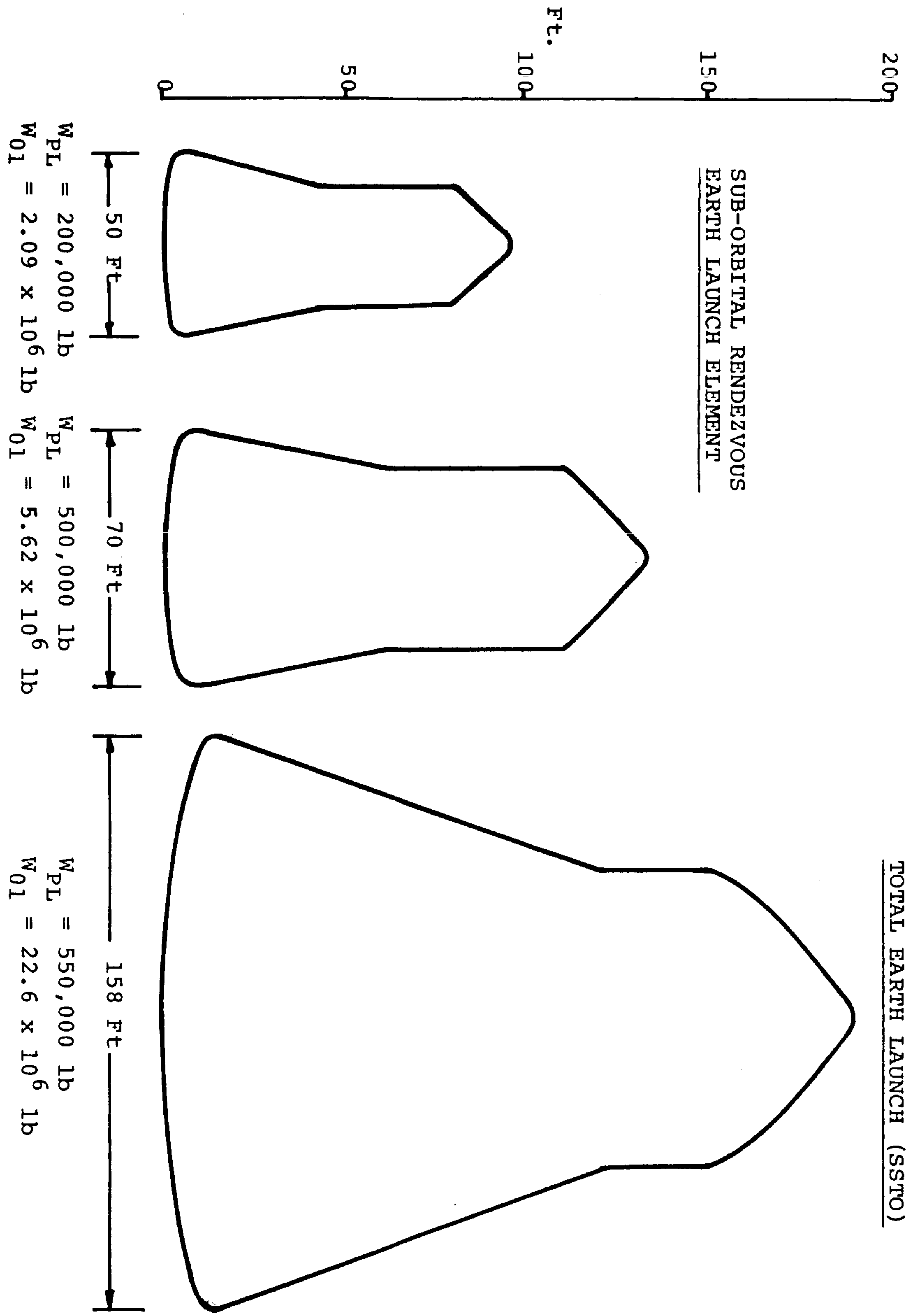

FIGURE 4. APPROXIMATE SIZE COMPARISON FOR TWO SUB-ORBITAL RENDEZVOUS EARTH LAUNCH ELEMENTS WITH A SINGLE-STAGE-TO-ORBIT BASELINE

DISCUSSION (Driggers Paper)

SPEAKER 1: Jerry, I just think a point of clarification might be in order. This did presuppose essentially free source of extraterrestrial oxgyen to support this activity. Is that what your analyses are based upon?

DRIGGERS: Yes.

SPEAKER 2: Jerry, I'm glad you gave this presentation because it builds on some of the material that we studied last summer at Ames. We also treated this problem and found that a round-trip vehicle which made regular trips between low Earth orbit and L-5 would require only about half the propellant, that is, half the hydrogen, to do a round trip with lox available only at L-5 as it would, if it needed to carry all of its propellant from the Earth.

SPEAKER 3: Perhaps this isn't the time to bring up hairy points and perhaps the point isn't as hairy as I think, but has any study been made of the mechanism for converting rocks on the Moon surface into LOX at L-5 or any other point in space, and how much that will cost? Not in terms of money, I mean in terms of mass lifted from the Earth?

DRIGGERS: Well, you have to talk in terms of, again, the overall system concept. You've got to have a base on the Moon; and you're going to convert the material to gain the oxygen in orbit and you've got to have a transportation base on the Moon and a receiving and processing base on orbit. I think the possibility you're talking about is processing on the Moon and then transporting the oxygen.

SPEAKER 3: No, not at all. I assume what you're saying, from your first picture, was that you get a bag of rocks in orbit and first it gets into orbit magically, and then it gets converted to lox magically. And I was wondering if you have any wizards that have worked on the magic recently.

DRIGGERS: Tom Heppenheimer was mentioning the summer study last summer, and this was concentrated on to some extent. The - taking a look at the energy requirements, the mass you're talking about - take those numbers and divide by 0.4, assuming roughly a perfect process, and you'll get the mass of rocks required, assuming 40 percent by weight oxygen. Am I still missing the question?

SPEAKER 3: How do you get it into orbit?

DRIGGERS: Oh, how do you get it there?

SPEAKER 3: Yes.

DRIGGERS: There's several schemes, one of which will be talked about this afternoon. Our last paper is going to discuss one possibility for that. Jerry O'Neill's suggested the electromagnetic leviation device as a mass driver.