and c) savings in orbital labor cost (the least certain factor). If the other elements of the orbital operations cost are included in a more specific analysis, the effect of the orbital burden rate is likely to become more important even than reusability.

2) It is not necessary that the post-Saturn ELV attains reusability from the start; it is more important that it be designed so that a reusable mode of operation could be introduced during the first five years of operations.

3) If its development cost is taken as $\$6 \times 10^9$, it should be amortized during the first ten years of its operational life, even if no reusability is attained during this period; in case of reusability, amortization in eight years or less is indicated.

4) It is, therefore, important for the post-Saturn ELV configuration selected to have a low rate of obsolescence; this will be assured if the vehicle is characterized by: a) adequate orbital payload capability (i.e., ≥ 1.0 Mlb) to assure a useful life $\geq$ 15 yr; b) a shape which offers as few volume restrictions as possible to a payload weight of this magnitude; c) highest possible operational simplicity and reliability; and d) advanced chemical engines (high-pressure O_2/H_2) and a design that permits the vehicle to be adapted to more advanced propulsion systems (nuclear and/or air-breathing engines) as the state-of-the-art advances.

References

[1] "Reliability of U. S. rockets," Space Technology Labs., Inc. STL Rept. 8659-6054-RS-000 (November 1962).

[2] Koelle, H. H. and Huber, W. G., "Economy of space flight," *Handbook of Astronautical Engineering*, edited by H. H. Koelle (McGraw-Hill Book Co., Inc., New York, 1961), Chap. 1.9, pp. 1–65.

[3] Marshall, A. W. and Meckling, W. H., "Predictability of the costs, time and success of development," Rand Corp., Rept. P-1821 (October 1959; revised December 1959).

[4] Noah, J. W., "Identifying and estimating R and D costs," Rand Corp., Memo. RM-3067-PR (May 1962).

Discussion by H. H. Koelle (see also accompanying paper by Koelle, p. 620)

Dr. Ehricke deserves the credit for discovering the fact that orbital labor rates can be substantial in extensive space operations. This factor has been neglected until now. He has opened the door for intensive investigations in this area which, hopefully, will lead to a better understanding of what we refer to as "orbital operations."

One of the strong points of his analysis is the consideration of actual reliabilities and reliability growth for all individual steps of orbital operations in a fairly sophisticated manner. This gives considerable insight into the actual problems of orbital operations. The introduction of several new parameters, describing individual orbital activities and supporting elements, bring out clearly the importance of individual assumptions and permit a ranking of these parameters according to sensitivities.

Since the original paper was written in early 1963, one might be cautioned in using the absolute figures given in the examples. For example, the Saturn V payload capability, considered for the 1970's, will probably be larger than those assumed, and the availability of a post-Saturn vehicle is now more likely around 1980 and not 1975 as assumed. But the sample calculations can be repeated as new data become available, and this fact does not reduce the importance of this paper.

A weak point of the paper is the fact that not all recognizable parameters have been introduced at that point in time. This was probably wise, as it kept the problem within manageable limits. On the other hand, some very important influence factors might not show up in this initial investigation. Parameters of this type are R&D cost for orbital support equipment, launch rate limitations, propellant requirements in orbit, and others. Most of these will shift the comparison of smaller launch vehicles with larger launch vehicles in favor of the larger launch vehicles. It is also to be expected that the permissable time for orbital operations will be less than half a year for a particular mission. Future studies will probably show that several other parameters, besides orbital labor rate and individual reliabilities, will be very influential in determining the total "orbital burden rate."

The author has to be congratulated for his pioneering paper, which not only will stimulate other investigators, but will also permit us to look at "orbital operations" more realistically than in the past.