WEIGHTS OF ENVIRONMENTAL-CONTROL SYSTEMS

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The purpose of this paper is to present some generalized relationships that can be used for estimating the weights of environmental-control equipment and expendables required for supporting human beings on space missions.

It may not be obvious how this information relates to the exploitation of extraterrestrial resources. However, most of the kinds of operations with which we are concerned in the Working Group require the active participation of human beings. And, of course, human beings need life support. So it is important to know what weight penalties are associated directly with the use of people. In other words, how much does it cost in weight to keep a man going--and how would this affect the economics, for example, of extracting useful products from lunar surface materials.

The weight relationships I am going to present are based on a recently completed analysis of practically all of the principal spacecraft studies conducted by aerospace companies during the past three or four years. In each case for which data could be obtained we attempted to extract from contractors' reports the weights of the environmental-control systems. These were further broken down into dry weights and weights of expendables. In our terminology dry weights consist of weights of equipment used in environmental-control systems,

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while wet weights are total weights of equipment plus expendables such as food, oxygen, atmospheric nitrogen, water, and emergency supplies. Dry weights are useful in making cost estimates, and wet weights are necessary inputs for preliminary design and for determining overall mission requirements.

In any such analysis of weights from a large number of different contractors, it is very important that all the data be placed on the same basis. To this end a set of definitions was adopted and adhered to strictly as possible.

Environmental-Control System Dry Weights

Under our definition, the dry weight of the environmental-control system includes those specific items of equipment employed in (1) breathing-gas supply, (2) carbon dioxide removal, (3) humidity control, (4) trace contaminants removal, (5) fresh water supply, (6) thermal control, and (7) waste management. It also includes spare parts, equipment and tankage for replacing materials lost through leakage and for providing contingency supplies. Our dry weight does not include the weight of radiation shields or external radiators, nor does it include a prorated weight penalty for electrical power.

Although our survey of environmental-control-system weights covered a wide variety of types ranging from open systems for short missions up to nearly-closed systems for long interplanetary flights, we found that dry weights could be correlated by using a single mathematical expression. This expression had the form:

$$W_D = A\, N^{\alpha}\, T^{BN^{\beta}}$$

where A, α, B, and β are constants

N = number of men in the crew

T = unresupplied duration of mission in days

and W_D = dry weight in pounds

The constants in the above expression were determined by using a computer program in which calculated values were compared with values obtained from reports. Combinations of the constants were changed until the relative variance reached a minimum, resulting in the equation:

$$W_D = 117\ N^{0.58}\ T^{0.33N^{0.11}}$$

A plot of the final relationship is shown in Fig. 1. It should be emphasized that this is purely empirical and was based primarily on missions involving crews of 2 to 6 men (for which the data were most plentiful), but it also produces dry weight estimates within useful limits for missions requiring larger crews. The range of mission duration is from 1 to 1,000 days and a great variety of mission types were represented--from both brief and extended earth orbital flights, through lunar mission, planetary fly-bys, planetary excursions, lunar base models and reentry. Finally, the range of mission types extends from completely open systems to nearly-closed systems employing oxygen and water regeneration.

This relationship enables one to estimate the dry weight of an environmental-control system from the duration of the mission and the crew size, independent of system type. Implicit in the empirical formula is the assumption that the system has been conscientiously selected to be consistent with the mission, and that total system weight has been minimized.

For the data we had available (23 cases) the mathematical expressions produced system dry weights within ± 20 percent of those obtained from contractors' reports in all but 2 instances.

Environmental-Control System Total Weights

Total weights of environmental-control systems can be estimated by adding weights of expendables to the dry weights. The expendables include metabolic supplies, reactants, make-up for leakage of atmospheric gases, and metabolic stores for contingencies. For estimating purposes we assumed a leakage rate of 1 lb per man-day and that the length of the contingency period was proportional to the square root of the mission duration.

The final estimating relationship for total environmental control system weight became

$$W_T = W_D + N(19\ T^{\frac{1}{2}} + 2\ T)$$

where W_D is system dry weight (a function of N and T) as indicated earlier.

This expression, shown graphically in Fig. 2, produced total weight estimates generally within ± 40 percent of those obtained from contractors' reports in our survey. This is not unreasonable when one considers the great variety of design philosophies embodied in the reported weights, the different assumptions made about leakage rates and contingency provisions, and the fact that some of the reported weights may have contained components, not itemized, that would not be placed in the environmental-control system under our definition.

These relationships are presented for quick estimating purposes when all the details are not available. Clearly because these are empirical correlations they can be no better than the data on which they are based. And at the moment we have no way of knowing whether the weights so estimated are generally optimistic or pessimistic.

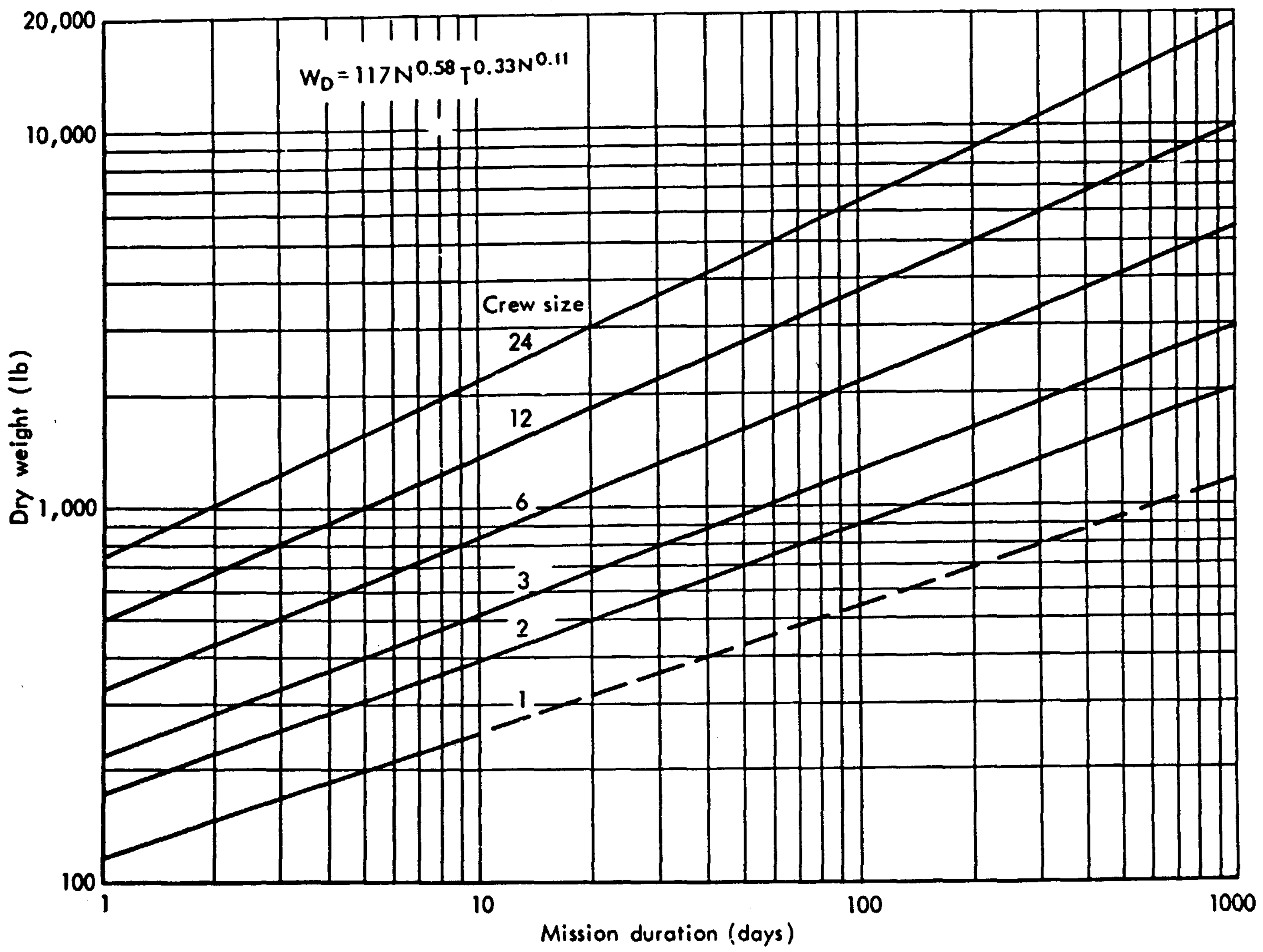

Fig. 1—Dry Weights of Environmental-Control System

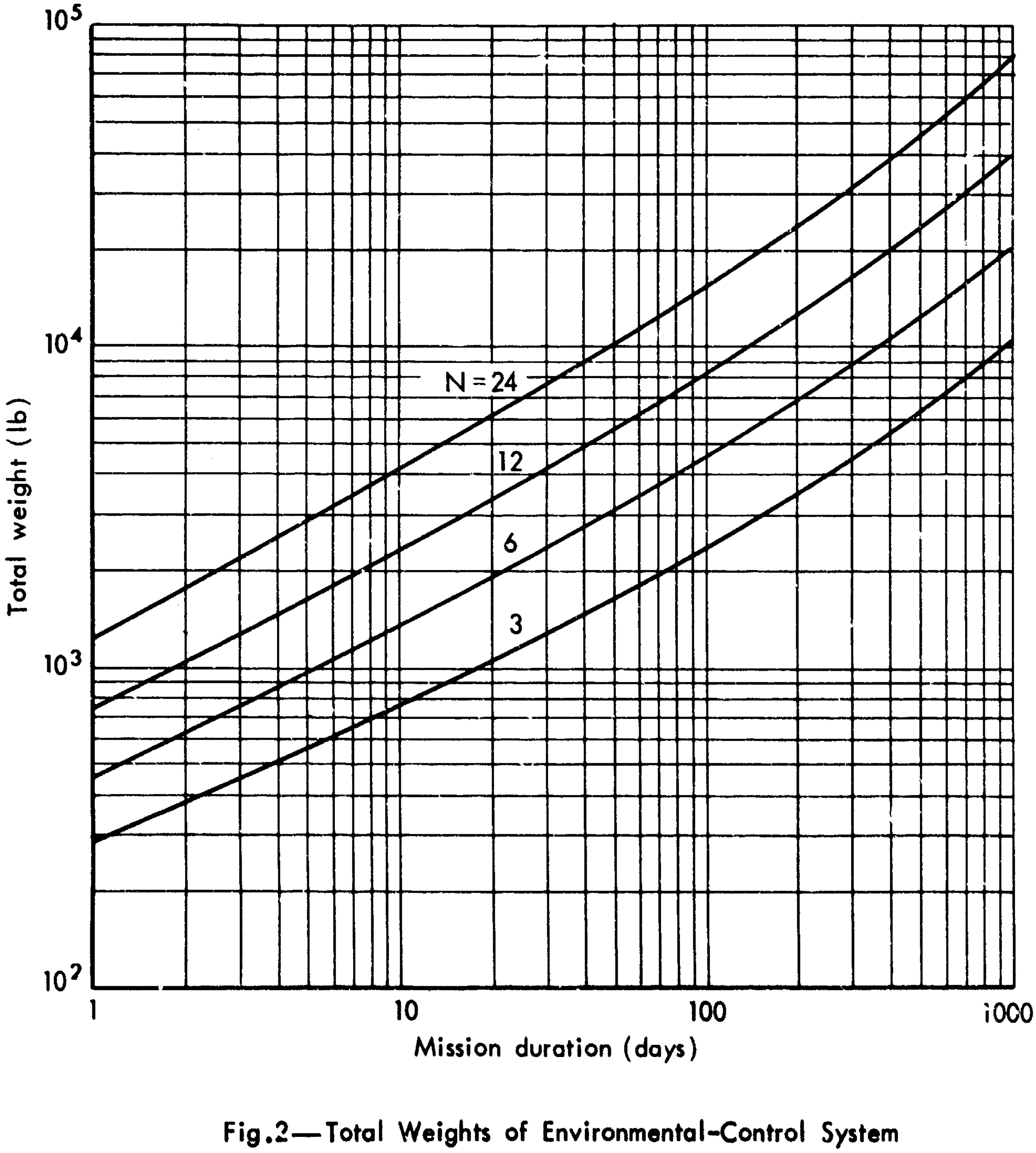

Fig. 2—Total Weights of Environmental-Control System