Economic Analysis of Materials Processing in Space

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Theme

AN economic analysis using econometric and cost benefit analysis techniques was performed to determine the feasibility of space processing of high purity tungsten targets for medical x-ray tubes, turbine blades for jet aircraft engines, and electrophoresis for biological applications.[1] The analysis involved a) developing a generalized decision-making format for analyzing space manufacturing, b) a comparative cost study of the selected processes in space vs Earth manufacturing, and c) a supply and demand study of the economic relationships of one of the manufacturing processes. Three space processing concepts were explored to some degree. The first involved the use of the shuttle as the factory, with all operations performed during individual flights. The second concept involved a permanent unmanned space factory which would be launched separately. The shuttle in this case would be used only for maintenance and refurbishment. Finally, some consideration was given to a permanent manned space factory.

A detailed analysis of the cost of operating the space shuttle transportation system was necessary before each manufacturing process could be examined. All products or processes were analyzed as to the costs which will be incurred during space manufacture, the projected demands of such products during the 12 year planning period (1980-1991), and the benefits which can be derived from these improved products. Also, the assumption was made that all costs, including transportation costs must be recovered for the products to be viable.

Contents

The major assumptions used to determine the shuttle transportation cost were : a) traffic volume anticipated[2]; b) various flights levels evenly distributed over the planning period with a maximum number of 986 flights; and c) a cargo payload of 32,000 pounds. Procedures used in this analysis were: a) the use of 1972 dollars; b) transportation costs discounted at rates of 0, 5, 10, and 15 percent; and c) joint costs allocated to user on basis of charge per pound of orbiter cargo capacity. Transportation costs of space processing activities were based on a zero discount rate using $326 per pound assuming 37 flights per year would be reduced to $260 per pound for 82 flights per year. Baseline operational cost per flight is estimated at $10.45 million (1971 dollars) for a total of 439 flights and does not include procurement or development costs.

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The effect of different levels of shuttle activity on the average cost of operation was determined from average cost curves calculated on the basis of various flight activities. The average annual total costs for each activity were discounted using 0, 5, 10, and 15 percent discount rates. In this analysis, only the number of flights and the discount rate were allowed to vary. Total operational costs for the shuttle vary greatly with the level of flight activity varying for $2406.5 million to $8216.4 million for 12 and 82 annual flights, respectively, at a zero discount rate. Costs per pound of cargo vary from $552 to $260. Nonrecurring investment and development costs were contracted in the fiscal years 1975-1980. Only the nonrecurring investments costs of the orbiter and its support ground facilities were included as fixed elements of transportation costs with only $1345 million included as capital amortization. Minimum total operating and capital amortization costs of the space shuttle transportation system for 82 flights per year and 5 percent discount would be $244 per pound of cargo payload. If all development costs are discounted, the maximum cost is $448 per pound of cargo payload. A case for the minimum cost can be made because the development cost is always incurred and is undertaken by the public sector.

Space processing of directionally solidified turbine blades is envisioned as a simple remelt operation in which a precast blade or blades are remelted in a preformed mold. The weight of the large number of blades (172,800) which must be produced annually, the weight of the necessary associated processing facilities, and the long process time eliminates the shuttle as a possible space factory for turbine blades. Therefore, a permanent space factory is required using the shuttle only as a means for maintenance and refurbishment. A shuttle cargo payload of 32,000 pounds gives a maximum allowable weight of blades, molds, and storage facilities as 2 pound per blade. On a monthly basis, 14,400 blades must be produced with time remaining for manual maintenance and refurbishment of the permanent space factory.

Resistance type furnaces, either continuous or batch, hold the best possibilities for space processing. The solidification rate in either case must be high, on the order of 7 in./hr (0.05 mm/sec) to maintain a reasonable number of furnace systems. A multiblade mold must be developed to reduce the total number of furnaces required. The size of the furnaces is much less than the size of the associated storage and handling facilities. Consequently, the latter is of major consideration in determining the size of the space factory required (minimum of 150 m^3). Considering all aspects, a multichamber batch resistance furnace process using a multiblade mold (6 blades per mold) seems to offer the best possibility for turbine blade processing in space.

The use of reusable, thin-shelled, precast molds necessitates the use of a storage system during shuttle transportation to the space factor. An allowable mold density was determined on the basis of the maximum weight limitations of 1.0, 1.5, and 2 pounds per blade total for the blades, molds, and storage system. The limitation of one pound imposes restrictions on the density (2.4 gm/cm^3) of the mold and would reduce the number of possible mold material candidates. Increasing the allowable weight to 1.5 pounds per blade increases the allowable mold density to over 5 gm/cm^3 and would no longer be a major factor in the selection of the mold material.

Feasibility of space processing of turbine blades was analyzed by comparing the potential benefits with potential costs. Benefits were estimated by assuming a higher level of blade performance. Potential savings were calculated only for U. S. commercial airlines, using blades for the JT8D-7 and JT9D engines. The analysis showed an adequate demand to justify production of blades both from a quantity and benefits standpoint. Quantities demanded from 1980 to 1984 are 121,987 blades per year and increase thereafter. Benefits of use were computed as $991.50 per blade over the 7.5 year lifetime when used as replacements in existing aircraft. These benefits increase to over $21,000 per blade over the 7.5 year lifespan when used in new aircraft. The use of space processed turbine blades could produce a total dollar savings of 4.381 billion to U. S. airlines for 100 percent adoption over a 10 year period (1980-1989), or for 13 years (1980-1992), of 6.618 billion dollars. Between 1981 and 1992, a total fuel savings of 6.552 billion gallons also could be realized. Comparison of costs and benefits appear to make turbine blades for aircraft a viable candidate for space processing.

High-purity tungsten for medical x-ray tubes was selected for economic analysis because improvement in the quality of x-ray pictures would produce external benefits to individuals, target life could be lengthened, and tungsten targets have a high value per pound. Space manufacturing by containerless levitation melting would be expected to increase the purity of tungsten.[3] The success of space processing of tungsten targets does not appear to be dependent primarily on cost cutting by reducing the rhenium now present in tungsten targets. To be successful, there must be an extension of both target and tube life beyond the average two year intensive use life which now exists. A considerable increase in tube life would be required as the transportation costs associated with shuttle operations exceed the existing Earth production cost. A three-fold increase in target life is required to cover space transportation costs. If the only cause of x-ray tube replacement was failure of the target, a doubling of tube life would amount to a cost saving of little under $2,000 (manufacturer's price) per unit. In this case, tungsten targets would constitute a reasonable candidate for space processing.

In the economic analysis of biological material, the manufacturing processes were restricted to electrophoresis methods. The most promising candidate for space biological processing is the separation of immunoglobulin (IgG) into its four subclasses by means of isoelectric focusing electrophoresis. Only 100 grams of IgG separated into its subcomponents could provide the U. S. needs for a year. This amount could provide serum which would be reproduced in animals. Only one flight per year would be required to provide this amount and could be done in a regular shuttle flight. Benefits of space processing of commercial IgG depend on the extent of improvement of diagnostic tests for agammaglobulinemia resulting from the use of space processed serum and the number of tests performed.

It was assumed in this study that nonexisting engineering technology necessary for the products and processes did, in fact, exist. Thus, during this analysis of space processed materials, and, in particular, of the turbine blades, several problems were identified. On the basis of these problems, a number of recommendations are made for additional economic analysis and engineering and scientific investigations before space processing of material is undertaken.

References

[1] Vachon, R. I., Wilcox, R. C., Lacy, A. W., Hale, C. W., Beckett, S. D., and Canterberry, J. B., "Economic Analysis of Materials Processing in Space," Auburn University, Auburn, Ala., Final Report, Contract NAS8-29881, June 1975.

[2] Shuttle Utilization Planning Office, "The October 1973 Space Shuttle Traffic Model," Marshall Space Flight Center, Huntsville, Ala., NASA Technical Memorandum 64751, Jan. 1974.

[3] Frost, R. T., "Electromagnetic Containerless Processing Requirements and Recommended Facility Concept and Capabilities for Space Lab," General Electric, Philadelphia, Pa., Final Report, Contract NAS8-29680, May 1974.