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REUSABLE AEROSPACE PASSENGER TRANSPORT: STUDY OF INCREMENTAL DEVELOPMENT APPROACHES

EXECUTIVE SUMMARY REPORT

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ABSTRACT

This report summarizes the results of studies of economical orbital transportation systems, exploring, in particular, possible options for time-phases and incremental development of such systems. The major conclusions are:

1. Incremental development is a practical way for development of an economic logistics system, minimizing development risk and annual funding, and offering planning flexibility at only a nominal penalty in total systems cost.

2. The most promising first development appears to be that of a reusable payload carrier with a capacity of 9 to 12 passengers.

3. Systems comparisons show that, for the foreseeable variations of the mission market, a partially reusable concept could bring about most of the program savings that can be expected from reusability at moderate development risk and funding rate.

4. A further development leading to a fully reusable system has high risk and uncertain payoff. Conceivably, at that time, a more advanced concept might be introduced.

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ADVANCED SYSTEMS OFFICE
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM X-53595

REUSABLE AEROSPACE PASSENGER TRANSPORT: STUDY OF INCREMENTAL DEVELOPMENT APPROACHES EXECUTIVE SUMMARY REPORT

INTRODUCTION

Launch vehicle concepts suitable for economical, high density, earth-to-orbit passenger transportation have been under study by MSFC for some time. Studies entitled, "Reusable Orbital Carrier Vehicle" were performed by Lockheed Aircraft Corporation under Contract No. NAS8-2687 and by North American Aviation, Inc., under Contract No. NAS8-5037. These investigations were completed in March 1964.

Later studies entitled "Reusable Orbital Transport" were performed by Lockheed California Company under Contract No. NAS8-11319 and by General Dynamics under Contract No. NAS8-11463. These studies were completed in mid-1965 and were primarily point design studies which reflected requirements that were sufficiently ambitious to permit recognition of trends.

The FY-65 funded investigations emphasized the following areas:

1. Assessment of the relative advantages of horizontal and vertical launch mode of fully and partially reusable orbital transport vehicles. This subject was investigated by Martin-Denver under a contract (NAS8-20277) entitled, "Reusable Orbital Transport; Launch Mode Comparison."

2. Exploration of ways to arrive at a balanced development plan including complementary as well as evolutionarily related launch vehicle systems to be most responsive to the changing needs of earth orbital logistics activities. This area was investigated by Lockheed California Company under a nine-month study contract (NAS8-20294) entitled "Reusable Aerospace Passenger Transport, Study of Incremental Development Approaches and Applications." The cost of the study was approximately $ 237,000.

The purpose of this report is to present a concise summary of the study described in item 2. The effort described in item 1 has been summarized in a separate report, NASA TM X-53652 dated Sept. 7, 1967, entitled: Comparison Study of Reusable Aerospace Passenger Transport Launch Modes, Executive Summary Report by C. M. Akridge.

The documents listed in the Bibliography at the end of this report may be obtained by Government offices and contractors with a need-to-know from the Scientific and Technical Information Facility, S-AK/RKT, P. O. Box 33, College Park, Maryland, 20740.

SCOPE AND OBJECTIVES OF THE STUDY

The objective of the study was to describe the evolution of an earth-to-orbit transportation system that would be able to adapt in an optimum way to an increasing transport volume. The study investigated and compared alternate routes available for development of a reusable system in an incremental fashion as an extension of presently approved launch vehicles and spacecraft.

The different approaches were evaluated from the standpoints of systems utility, development risk, and cost. The yardstick used for comparison was the previously defined two-stage, all-reusable launch vehicle system.

STUDY APPROACH AND SIGNIFICANT RESULTS

Approach

As in any other business venture, the improvement of operating efficiency of space transportation requires the initial outlay of R& D funds which are then to be recovered from the savings of the new system. In other words, R& D expenditures have to be justified in terms of the expected results. In the real world we have to find a balance between downpayment, installments, and interest-rate with respect to the utility of the system, its effectiveness, and its development risk as related to uncertainties of the mission market and to possible deviations from anticipated systems characteristics.

In pursuit of this problem the study investigated and compared alternate routes available for development of a reusable orbital transport system in an incremental fashion as an extension from presently approved launch and space vehicles. It was assumed that such building-block systems development would be most adaptable to the conceivable variations of space transportation requirements, and that it would minimize the development risk.

Concepts Evaluated

Figure 1 illustrates the basic systems, identified as A through E, that were considered in the Incremental Development Approaches (IDA) shown in Figure 2. Table I shows the make-up of the IDA's.

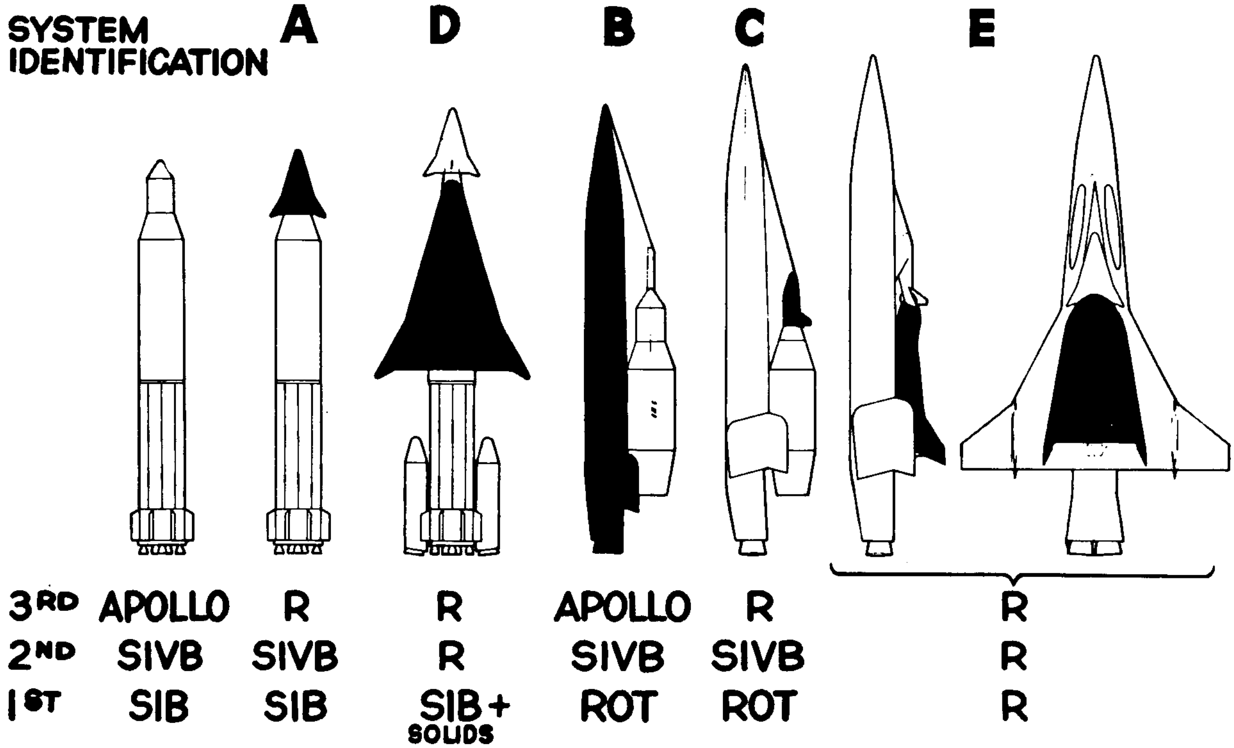

FIGURE 1. BASIC SYSTEMS EVALUATED

TABLE I. INCREMENTAL DEVELOPMENT APPROACHES, CONFIGURATIONS

BASIC INCREMENTAL CONFIGURATIONS	INCREMENTAL DEVELOPMENT APPROACHES							
	1	2	3	4	5	6	7	8
A	X	X	X	X	X			
B						X	X	X
C				X	X		X	X
D		X	X					
E			X		X			X

IDA's 1 through 5 begin with the development of the manned lifting entry spacecraft first, while IDA's 6 through 8 feature the reusable rocket airplane first stage as the initial step. IDA's 4 and 7 end with partially reusable systems using the S-IVB as second stage. IDA's 3, 5, and 8 lead to fully reusable systems.

Comparative evaluations were performed between the basic three-stage liquid rocket vehicle configurations (spacecraft counting as a stage) and alternate systems of potential economic and/or operational promise for the same time span and mission market spectrum. The comparison involved:

1. An integrated second stage (manned spacecraft functions integrated into second stage).

2. An advanced airbreather, reusable, first-stage booster including considerations of a joint development of an aerodynamic cruise and boost capability.

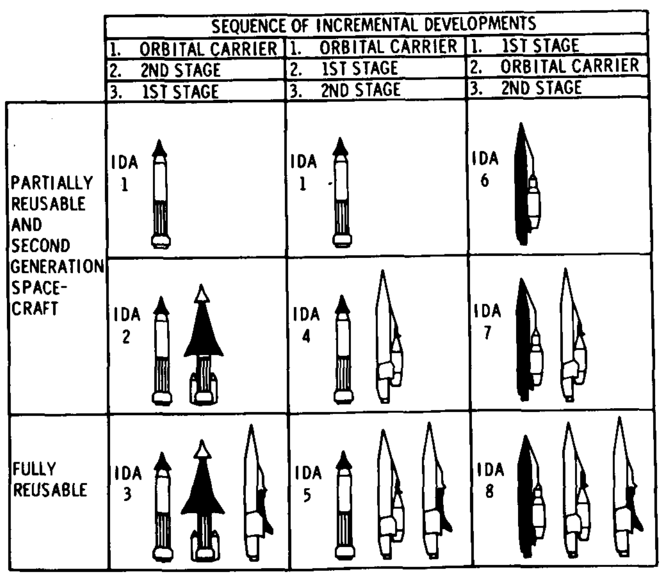

FIGURE 2. INCREMENTAL DEVELOPMENT APPROACHES (IDA)

Evaluation Model

Figure 3 illustrates the functional flow through the evaluation model. The major ingredients of the model, in addition to the candidate systems, are the mission model, systems characteristics, and the evaluation criteria. Figure 4 shows the major elements of the mission market model and the relationship of the model to other tasks. Figure 5 indicates the traffic rates projected for the different program levels.

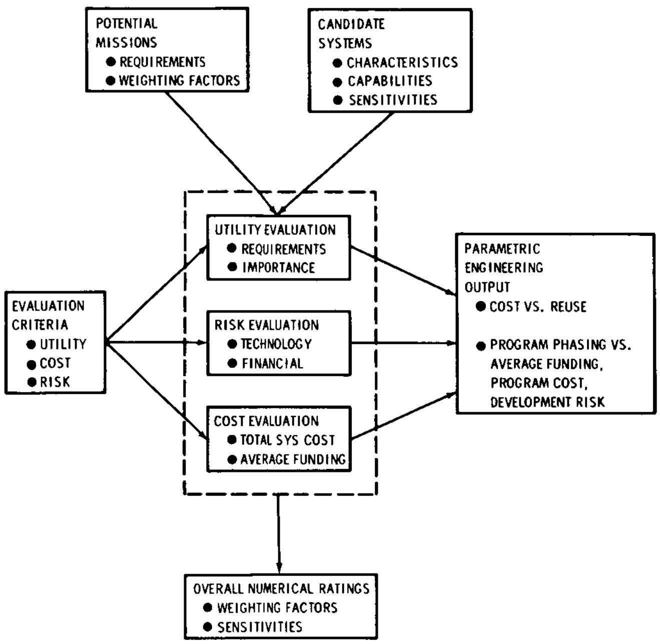

FIGURE 3. EVALUATION MODEL

The evaluation criteria include utility, development risk, and cost. Utility, as used here, means systems utilization in the operational and development phases. Development risk is expressed first in terms of first-stage oversizing required (in percent of gross weight) to guard systems performance against technology uncertainties and secondly in terms of financial R& D risk if first-stage oversizing is not made. Cost includes total program cost as well as average annual funding rates to fly all of the postulated missions by the IDA under consideration and also supplementary flights of smaller expendable vehicles as required.

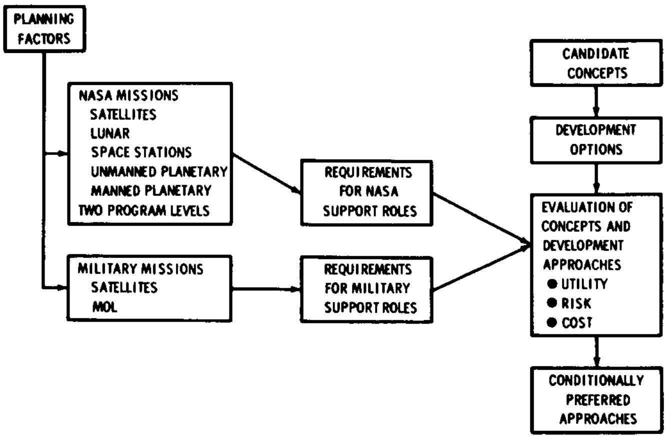

FIGURE 4. MISSION MARKET MODEL

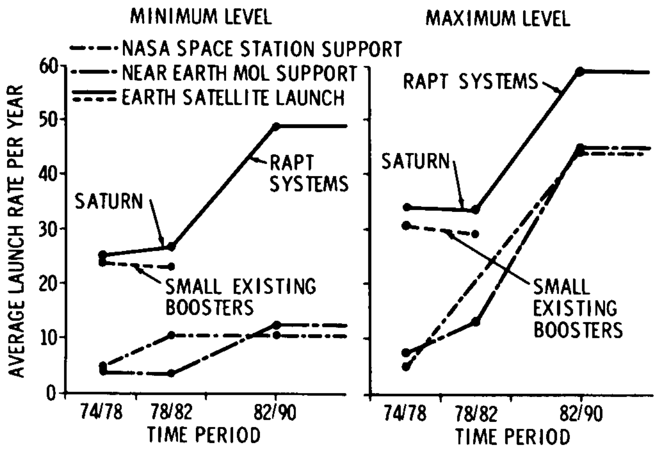

FIGURE 5. PROJECTED TRAFFIC RATES

Evaluation Results

The output of the evaluation model falls into two categories, parametric engineering data and numerical ratings reflecting the relative effectiveness of each IDA. These outputs are discussed in the following paragraphs.

First, the effects of the incremental development sequence on total systems cost, development risk, and maximum average annual funding are discussed for the logistics part of the mission market spectrum. This includes NASA and military (MOL) near-earth station support, manned planetary mission support (assuming orbital launch operations), and synchronous altitude MOL missions performed by the Reusable Aerospace Passenger Transport (RAPT) payload carrier in combination with the Saturn V launch vehicle. Both maximum and minimum levels of activity are considered. Figure 6 points out major

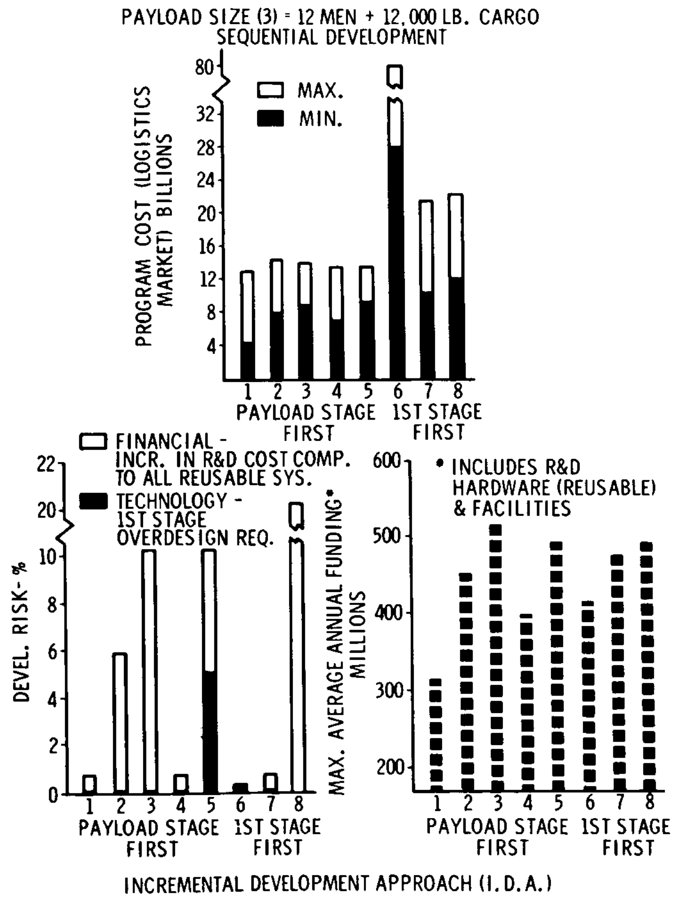

FIGURE 6. CONCEPT COMPARISON FOR LOGISTICS MARKET

disqualification factors resulting in the elimination of grossly unsuitable candidate approaches. The following conclusions can be drawn from the data shown on Figure 6:

1. IDA 6 can be eliminated on a total cost basis.

2. IDA's 2 and 3 show relatively high risk and high funding requirements because of the early development of the reusable second stage. Considering also the marginal aerodynamic and structural compatibility of the S-IB with a lifting reusable second-stage arrangement, IDA's 2 and 3 are eliminated.

Figure 7 compares the total systems cost as a function of time. It was assumed that during the time period until the introduction of a fully reusable

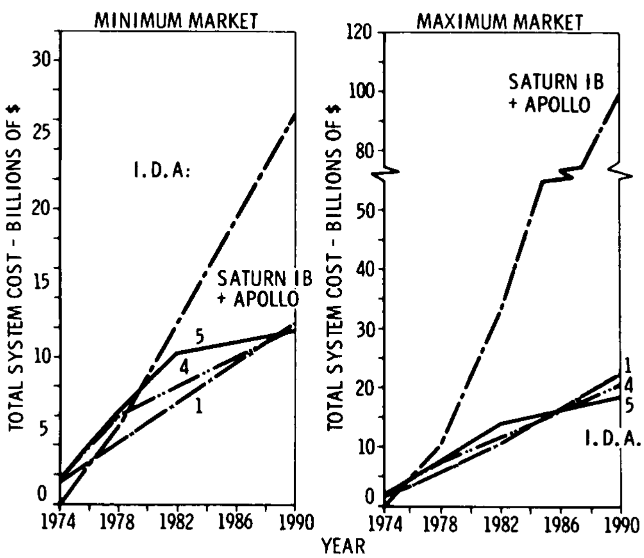

FIGURE 7. CONCEPT COMPARISON FOR TOTAL MARKET

system, smaller vehicles like Thor, Atlas, and Titan-II would be used on a competitive basis. The following conclusions can be drawn:

1. The introduction of the reusable payload carrier reduces cost drastically below Saturn/Apollo costs for both market activity levels (IDA 1).

2. The introduction of the reusable first stage next (IDA 4) makes a slightly more cost effective system than IDA 1.

3. The addition of a reusable second stage in IDA 5 burdens the early program and indicates uncertain pay-off.

Figure 8 shows the effect of development timing, i.e., the effect of the degree of overlap in manufacturing and testing periods of new stage developments. One-hundred percent overlap means concurrent development of the stages, i.e., the all-up approach. Negative overlap means a spacing between developments. The conclusions from Figure 8 are:

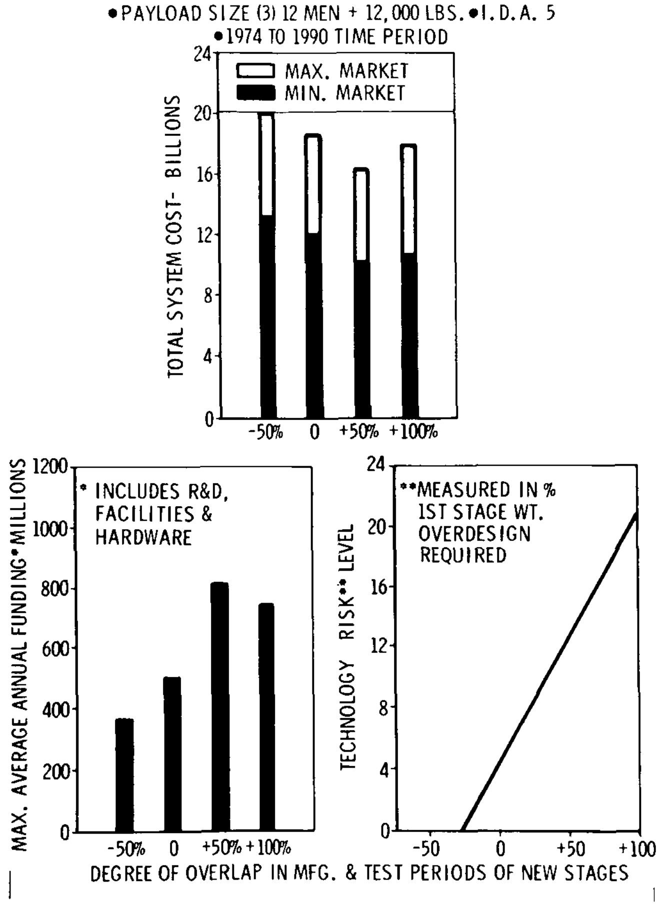

FIGURE 8. EFFECT OF DEVELOPMENT TIMING

1. Spreading out the development period generally increases the total system cost and decreases the average annual funding required. This assumes that the development effort for an increment has been optimized.

2. Technological risk can be reduced by spreading out the program for IDA 5 so that the first stage is developed after the resolution of the critical technology of the upper stages.

3. The sequential development (zero overlap) seems a reasonable compromise between total cost, risk, and average annual funding.

Figure 9 shows relative funding requirements and total program costs for the advanced airbreather developments. Although the airbreather concepts have comparable operating costs, they cannot compete on a real program basis with the reusable rocket concepts because of their high development costs and late availability.

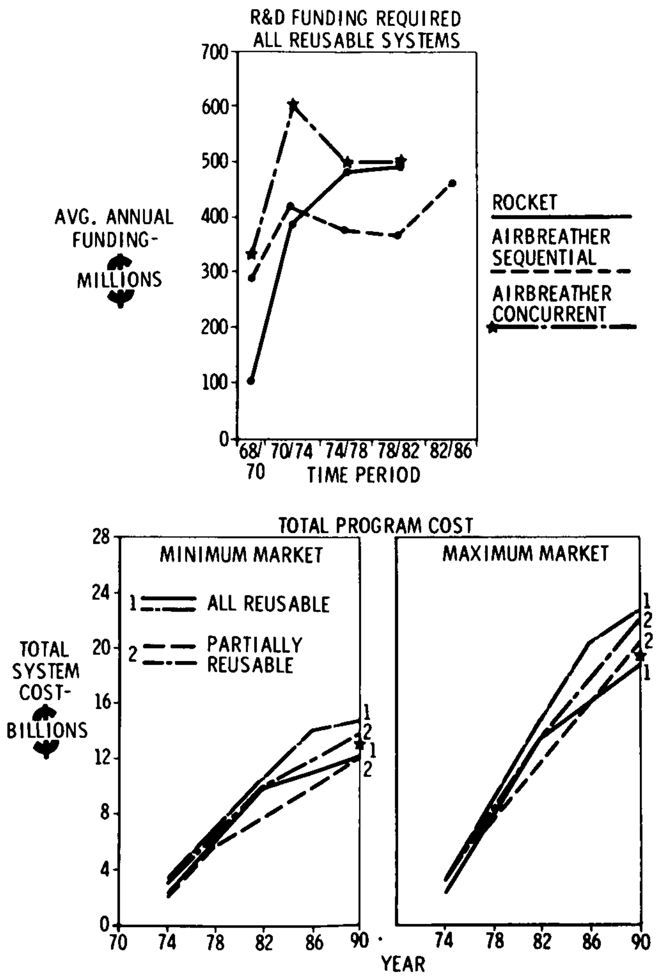

FIGURE 9. AIRBREATHER/ROCKET COMPARISON

Figure 10 shows economic savings potential of the various candidates in terms of direct operating cost. With present estimates, the airbreather does not show any economic advantage over the rocket vehicle, which, in the absence of off-set launch requirements, reaffirms the preference for the all-rocket approach.

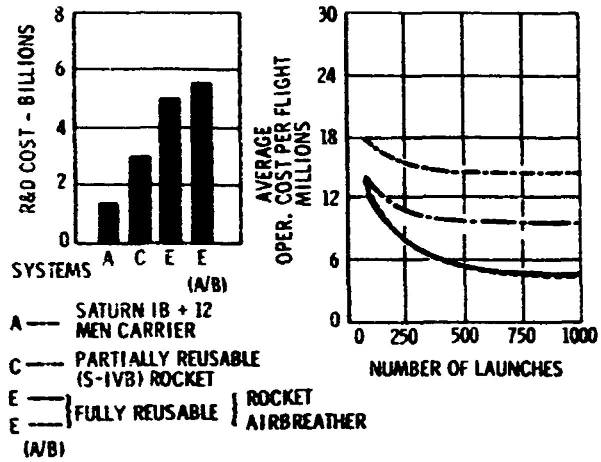

FIGURE 10. R& D INVESTMENT VERSUS ECONOMICAL GROWTH POTENTIAL

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Incremental development of an economical orbital logistics system is feasible and is desirable based on the following:

1. Only limited technological and financial risk would be involved.

2. As development increments lead to configurations which are ends in themselves, no loss would be incurred if the evolutionary process is halted after a certain increment.

3. Annual funding required for sequential development would be about two-thirds of that required for the all-up development of a fully reusable (ROT-type) launch system.

4. Sequential development would lead to about four to eight percent increase in total program cost (full length of the program) over an all-up development. If only part of the program were implemented, the incremental approach would result in substantial savings.

5. The most logical first development step appears to be a reusable and probably maneuverable 10- to 12-man spacecraft. Indications are that this new spacecraft, combined with the Saturn IB, and subsequent introduction of more advanced booster stages could be useful for several decades.

6. Systems comparisons show that for the foreseeable variations of the mission market a partially reusable concept (reusable ROT-type first stage, expendable second stage, plus a reusable spacecraft as previously mentioned) would be able to bring about most of the program savings that can be expected from reusability. A further development increment providing a reusable second stage has high risk and uncertain payoff. Quite possibly in that time frame, a switch to a more advanced launch systems concept might be made.

Critical Observations

The study relied heavily on conceptual systems inputs generated during a previous study by the contractor (Lockheed) under the title "Reusable Orbital Transport Studies." It might have been desirable to treat a greater variety of conceptual approaches and evaluate them against a wider spectrum of program options. For instance, a second pass at spacecraft and second-stage configuration based upon the "decoupled landing mode" may have shown improved launch vehicle compatibility for IDA's 2 and 3.

Another area that could have benefited from additional effort is that of partially reusable concepts. The partially reusable concept of IDA 4 is actually burdened with the provision for a further development step, the reusable second stage, which would make the concept fully reusable. One could rationalize, on the basis of program duration and the associated danger of obsolescence, that such an additional development step should not be considered. This in turn would open up completely new possibilities for the design of partially reusable concepts.

Typical contenders for this class of vehicles are the 1.5-stage lifting entry concepts advocated by McDonnell under the name "Model 176" and by Lockheed, Sunnyvale, under the name "Starclipper," as well as two-stage systems along the lines of the General Dynamics/Convair "Near-term Reusable Launch Vehicle."

The study conclusions with respect to incremental development, concerning risk, funding level, development phasing, etc., are generally valid. Also valid is the assessment of the Saturn/Apollo systems application to space station logistics and the strong recommendation for a new reusable manned spacecraft development. The definition of subsequent development increments can benefit from additional systems studies.

Recommendations

For better preparation for a potential implementation of step "one" of such a transportation system evolution (a new spacecraft on Saturn IB derivatives), it appears advisable to analyze in detail:

1. The functions applicable to such a spacecraft/launch vehicle combination in the framework of orbital, or more specifically, space station logistics, namely:

   a. movement, handling, storage, and evacuation of materials

   b. movement, evacuation, and rescue of personnel

   c. impact on facilities and services on the ground.

2. Other missions requirements having an impact on the vehicle systems design such as:

   a. additional spacecraft requirements (24-hour orbit, lunar, etc.)

   b. additional launch vehicle requirements (unmanned planetary, higher orbital payloads, space rescue).

3. Spacecraft design considerations including:

   a. Synthesize design based on cost-considerations such as:

      (1) What systems does it pay to recover vs which should be expended?

      (2) How do design features impact operating costs?

   b. Hypersonic L/D and subsonic L/D;

   c. Landing modes;

   d. Systems integration for nominal mission, abort, and escape;

   e. Integration of space propulsion and cargo provisions.

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This report has also been reviewed and approved for technical accuracy.

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