ANALYSIS OF SATELLITE SERVICING COST BENEFITS

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I INTRODUCTION

Projection of future costs depends very strongly on a series of assumptions, which must be carefully stated so that the conclusions are not endowed with more meaning than is justified. When the assumptions are clear the reader will be able to alter those that are inapplicable to his special set of circumstances and observe the results as tailored.

For the purposes of this paper, cost avoided in selecting one course of action over another is defined as "Cost Benefit." This paper addresses the methodology for preparing a cost benefit analysis pertinent to establishing the relative values of performing satellite servicing in various ways. It further applies the methodology to the benefits that could be realized by the user community in the timeframe of 1983 through 2005.

II SUMMARY AND CONCLUSIONS

Under the auspices of NASA/JSC a methodology was developed to estimate the value of satellite servicing to the user community. Time and funding precluded the development of an exhaustive computer model; instead, the concept of Design Reference Missions was involved. In this approach, three space programs were analyzed for various levels of servicing. The programs selected fall into broad categories which include 80 to 90% of the missions planned between now and the end of the century. Of necessity, the extrapolation of the three program analyses to the user community as a whole depends on an average mission model and equivalency projections.

The value of the extimated cost benefits based on this approach depends largely on how well the equivalency assumptions and the mission model match the real world. A careful definition of all assumptions permits the analysis to be extended to conditions beyond the scope of this study.

Currently "reasonable" assumptions reveal that on-orbit servicing of a space resource, compared to the expendable spacecraft approach provides a positive cost avoidance. Of the various servicing modes, on-orbit refurbishment of a satellite is superior to returning it to earth for refurbishment and relaunch. It is also found that making use of a space station as a service base, where applicable, provides the greatest potential cost avoidance.

The study estimate indicates that on-orbit servicing can provide the user community with a potential cost avoidance of close to $1.5 billion in 1982 dollars or $13 billion in inflated current dollars in the period of 1983 through 2005.

III METHODOLOGY

The development of a logical progression of tasks is second in importance to the clear enunciation of consistent groundrules and assumptions. Figure 1 illustrates the steps established to guide the analysis of cost benefits pertaining to satellite servicing. The objective of the study was to estimate the total cost avoidance accruing to the space-user community through implementing on-orbit servicing of satellites. The first step in accomplishing this end was to define that user community. The Mission Model developed to provide such a definition was derived from two basic sources:

1. NASA STS Mission Model, JSC-13829, Oct 1977
2. STS Flight Assignment Baseline, JSC-13000-6, Mar 1980

The first of these is the most extensive, with a cutoff date of 1993 (after allowing for the STS schedule slip). Therefore, it was necessary to extend the model for cost analysis through extrapolation. Conservative annual traffic growths of 10 and 15% were used depending on the most recent published manifests.

In compiling the Mission Model the planned space programs were classified into four groups: 1. Low earth orbit (LEO); 2. sun synchronous orbits; 3. geosynchronous orbit (GEO); and 4. all others. The final classification was too diverse to be used in estimating the cost benefits. It is unrealistic to develop individual costs for each identified space mission. The approach used is to define a mission representative of each class and apply any cost benefit realized in analyzing that mission to the entire class. Thus, the second step is to select the representatives or design reference missions (DRM's). The Space Telescope is a well known example of a LEO mission, though it is probably much more complex than the average LEO satellite in the Mission Model. This factor is taken into account by the normalization procedure explained below. It is also apparent that the detail planning of the actual program does not lend itself to generic comparative costing. For this reason certain liberties were taken with the Space Telescope in defining the LEO design reference mission. Figure 2 shows the parameters used.

For the Sun Synchronous class a hypothetical program representative of earth resources and certain DoD space programs was defined. Figure 3 presents the parameters for this design reference mission.

The GEO class is represented by a communications platform that is in the formative stages of planning. Figure 4 shows its parameters.

The third step in the analysis, as shown in Figure 1, is the definition of mission scenarios. These permit the costing of the service operations as well as the hardware involved. Four service scenarios are considered:

1. Expendable satellite, i.e., no service
2. Return to earth, refurbishment, and relaunch
3. On-orbit service performed from the STS Orbiter
4. On-orbit service performed from a manned space platform.

This completes the framework and the cost analysis proceeds for each of the design reference missions and for each of the applicable service scenarios. For all classes of missions the expendable case is considered the baseline against which cost avoidance will be judged. Once the gross program costs are determined, the option providing the maximum cost differential is selected as the optimum scenario for performing the mission. The avoided cost resulting from selecting a servicing option in preference to the expendable baseline is then "normalized" by computing a "Cost Avoidance Factor" which is simply the cost avoided per unit spacecraft mass per year of mission operation.

To apply these results to the user community as a whole, an average spacecraft mass and an average mission duration is selected. The kilogram years product is then multiplied by:

1. The population for the mission class in a given year
2. The fraction of the total population designed for service
3. The applicable Cost Avoidance Factor.

The output is a time-phased cost benefit.

To this point, constant year dollars have been used to express the cost benefits. The final step is to include projected inflation and present the results in "Then Year" dollars.

IV GROUNDRULES, ASSUMPTIONS, AND MODELS

The need to reduce the analysis to a tractable level leads to some hard decisions on the assumptions to be accepted. Figure 5 enumerates those pertinent to this study. The term "sunk costs" refers to the expectation that the charges for the use of future NASA-developed space vehicles will be treated in the same way as are those of the STS. That is, the user will not be charged for the development of the vehicle but only for the recurring costs associated with its utilization.

A cost differential between expendable spacecraft and those designed for service is necessary to account for the man interface and mechanisms required to allow equipment changeout in orbit. The assumptions that the serviceable spacecraft development is 25% more and that production is 10% more than the cost of the expendable satellite are based on somewhat larger values for the Space Telescope program, adjusted for the expectation that as the state-of-the-art matures the cost differential will decrease.

The RCA "Price H" model was used to estimate parametrically the space vehicle costs. "Price L" was used to estimate the on-orbit maintenance tasks. EVA and other STS charges are derived from the NASA Space Transportation Cost Reimbursement Guide, 1980.

Figure 6 tabulates the cost elements evaluated for the various mission classes and the sources used in preparing the estimates. Other cost models are available and may be preferable for specific cases.

The RCA cost model "Price H" assesses the cost to develop and product space hardware against required schedules. It uses a weight-based set of cost-estimating relationships (CER's) and complexity of design factors as its infrastructure. It also includes a computation of integration cost.

The Price L" computes the cost of operations and maintenance support from the "Price H" files. It is capable of detailing the maintenance and spares policy based on input MTBF values.

The Richardson model computes the cost of facilities and site preparation based on a dollar-per-square-foot construction data base.

The fraction of the space-mission population that will be designed for service and, therefore, have planned service as part of the mission requiring costing is estimated in Figure 7. The minimum fraction is taken to be 10% and the growth is expected to be greatest for the low earth orbit missions reaching nearly 100% by the year 2000. The growth in the case of the sun synchronous missions is expected to be lower but approaching 70% by 2000. The added advantage of space-platform based servicing is expected to result in a higher growth rate for GEO satellites, but with their later start, 35% of the population is estimated to be serviceable at the end of the century.

The complete definition of the missions to be costed must include an accurate scenario. Figure 8 shows the events that make up the various options costed for the LEO missions. Figures 9 and 10 define the Sun Synch and GEO missions.

V ANALYSIS RESULTS

The total cost estimates for the three Design Reference Missions and their service scenarios are presented in Figure 11. In each case the cost avoided is the difference between the cost of the expendable spacecraft mission and the service option.

The cost-avoidance factors computed from the individual avoided costs are shown in Figure 12. This figure also defines the specific classes and scenarios analyzed in this study. Figure 13 plots the potential cost avoided for each type of mission vs time. The cumulative results for the three mission types are also plotted. This figure gives the results in constant 1982 dollars. The benefits returned by the GEO mission are seen to accrue starting in 1997, because the projected initial operating capability for both the OTV and the SOC is 1992 (and the first benefits accrue 5 years later).

The potential cost benefit to the user community in inflated dollars is shown in Figure 14.

VI EFFECT OF PARAMETER VARIATION

Since the cost model computes the cost benefits as a population multiplied by the Cost Avoidance Factor (CAF), a change in either can dramatically affect the results. A larger population leads to greater cost benefits and vice versa. The CAF is the unit cost avoidance multiplied by an average spacecraft mass and the average mission life. If the 2500 kg and 5 years estimated were actually 5000 and 10 respectively, the cost benefit would quadruple.

GLOSSARY OF TERMS

CAF	COST AVOIDANCE FACTOR
EVA	EXTRAVEHICULAR ACTIVITY
GFO	GEOSYNCHRONOUS ORBIT
LEO	LOW EARTH ORBIT
LMSC	LOCKHEED MISSILES & SPACE COMPANY, INC.
MTBF	MEAN TIME BEFORE FAILURE
S&R	SERVICE & REFURBISH
STS	SPACE TRANSPORTATION SYSTEM

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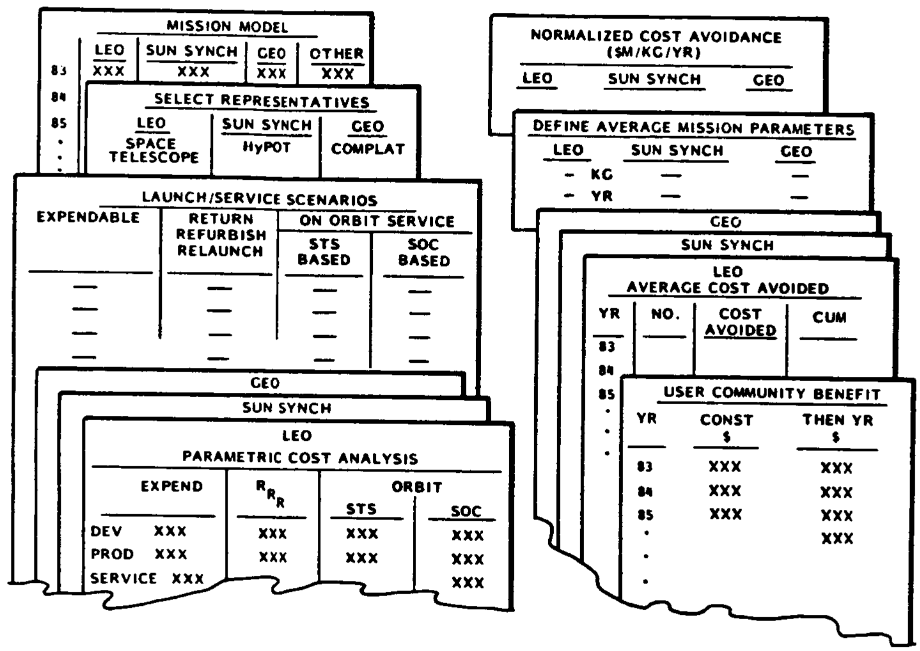

Fig. 1 Satellite Service Cost Benefit Methodology

- USER – NASA
- QUANTITY – 1
- ON-ORBIT MASS 10,554 kg (23,268 LB)
- PLANNED REVISIT CYCLE – 5 YEARS*
- PLANNED RETURN TO EARTH/REFURBISH CYCLE – 15 YEARS*
- ORBIT
  - 28.5° INCLINATION
  - 593 km (320 nmi) CIRCULAR ALTITUDE

*SELECTED FOR COST COMPARATIVE PURPOSES

Fig. 2 Space Telescope Reference Definition

- USER – U.S. GOVERNMENT
- CONSTELLATION
  - 9 TOTAL (3 EACH IN 3 PLANES)
  - 98.5 DEGREE INCLINATION
  - ORBIT ALTITUDE 833 km (450 nmi) CIRCULAR
- MASS ON-ORBIT 3400 kg (7500LB)
- MISSION DURATION – 15 YEARS
- PLANNED REVISIT CYCLE – 5 YEARS
- OPERATIONAL ORBIT ATTAINMENT FROM LEO
  - SELF CONTAINED TWO-WAY CAPABILITY

Fig. 3 HyPOT Mission Definition

- USER - COMMERCIAL
- CONSTELLATION
  - 3 (SEPARATE LONGITUDES)
  - 0° INCLINATION
  - SYCHRONOUS ALTITUDE
- MISSION DURATION: 15 YEARS
- PLANNED REVISIT CYCLE: 5 YEARS
- MASS ON-ORBIT 4,540 kg (10,000 LB)
- SERVICE
  - DEPLOYMENT/CHECKOUT
  - REMOTE REFUELING
  - ORU CHANGEOUT

Fig. 4 Communications Platform Mission Definition

- THE TIME FRAME OF INTEREST TO THIS ANALYSIS IS 1983 - 2000
  - AVERAGE MISSION DURATION FOR THE USER MISSION MODEL IS 5 YEARS
  - AVERAGE SPACECRAFT MASS IS 2500 kg (5500 LB)
  - COST BENEFITS ARE REALIZED ONLY AT THE END OF THE PLANNED LIFE, i.e., 5 YEARS AFTER LAUNCH
- ALL COSTS ARE COMPUTED IN CONSTANT 1982 DOLLARS
- ALL OPERATIONS COST ARE BASED ON PLANNED OPERATIONS (NO EMERGENCY SERVICE)
- OBSOLESCENCE IS NOT EVALUATED
- NASA SUPPORT SYSTEM DEVELOPMENT COSTS ARE SUNK
  - STS - OTV - SOC
- BOTH SATELLITE ON-ORBIT SERVICE AND GROUND REFURBISHMENT RETURN THE SPACECRAFT TO ITS INITIAL OPERATING CONDITION WITH ITS ORIGINAL LIFE EXPENTANCY
- STS IS USED TO LAUNCH BOTH EXPENDABLE AND SERVICEABLE SPACECRAFT
- SERVICEABLE SATELLITE DEVELOPMENT COSTS ARE 20 PERCENT GREATER THAN THOSE FOR EXPENDABLE ON THE AVERAGE
- AVERAGE PRODUCTION COST OF THE SERVICEABLE SATELLITE IS 10 PERCENT GREATER THAN FOR THE EXPENDABLE
- ON THE AVERAGE THE COST OF A SHARED STS FLIGHT, e.g., SATELLITE ON-ORBIT SERVICE OR EARTH RETURN IS 1/2 THE DEDICATED COST
- GROUND REFURBISHMENT OF SATELLITES AND ORUs ARE 1/3 THE UNIT PRODUCTION COST
- COST ESTIMATING RELATIONSHIPS ARE BASED ON THE USAF UNMANNED SPACECRAFT COST MODEL V, SEPT 1981
- ESCALATION INDICES USED ARE FROM THE RCA "PRICE" MODEL (NASA CONTROLLER INDICES END AT 1988)

Fig. 5 Ground Rules and Assumptions

	SOURCE OF COST ESTIMATE
• HARDWARE	
– SATELLITE	RCA "PRICE H"
– ORBIT REPLACEABLE UNITS (ORU)	RCA "PRICE H"
– SERVICE KITS (ASE)	RCA "PRICE H"
– AGE	RCA "PRICE H"
– FACILITIES	RICHARDSON COST MODEL
• SUPPORT	
– GROUND REFURBISHMENT - SATS, ORU, ASE	"PRICE H"
– TRANSPORT – SATS, ORU, ASE, SPECIALIST	COST REIMBURSEMENT GUIDE
– GROUND OPERATIONS	COST REIMBURSEMENT GUIDE
• LOAD/UNLOAD	COST REIMBURSEMENT GUIDE
• SIMULATION AND TRAINING	LMSC
• POCC	COST REIMBURSEMENT GUIDE
• SATELLITE DOWN TIME	'PRICE L'
– SPACE OPERATIONS	
• EVA	COST REIMBURSEMENT GUIDE
• MMU	COST REIMBURSEMENT GUIDE
• SUPPORT VEHICLES	LMSC
• SOC	"PRICE H" + "PRICE L" (JSC)
• STAY TIME	COST REIMBURSEMENT GUIDE

Fig. 6 Elements of Cost and Sources

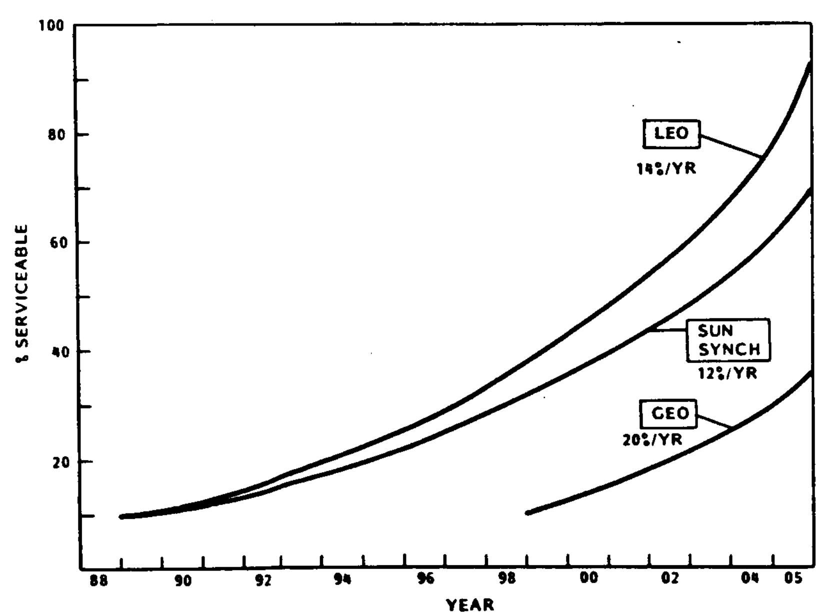

Fig. 7 Serviceability Growth Model

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CASE I - EXPENDABLE

- LAUNCH ST WITH STS
- ST EXPENDED IN 5 YEARS
- REPLACE ST AT 5 YEARS
- REPLACE ST AT 10 YEARS

CASE II - EARTH RETURN, REFURBISH, RELAUNCH

- LAUNCH ST WITH STS
- RETURN ST TO EARTH WITH STS AT 5 YEARS
- RELAUNCH REFURBISHED ST WITH STS
- RETURN ST TO EARTH WITH STS AT 10 YEARS
- RELAUNCH REFURBISHED ST WITH STS
- ST EXPENDED AT 15 YEARS

CASE III - ON-ORBIT SERVICE + RETURN

- LAUNCH ST WITH SPACE TRANS SYSTEM (STS)
- SERVICE ST IN ORBIT WITH STS AT 5 YEARS
- SERVICE ST IN ORBIT WITH STS AT 10 YEARS
- RETURN ST TO EARTH AT 15 YEARS

CASE IIIA - ON-ORBIT SERVICE

- LAUNCH ST WITH STS
- SERVICE ST WITH STS AT 5 YEARS
- SERVICE ST WITH STS AT 10 YEARS
- ST EXPENDED AT 15 YEARS

Fig. 8 LEO Scenarios

CASE I - EXPENDABLE

- LAUNCH THREE HyPOTs FOR EACH OF THREE STS FLIGHTS
- HyPOTs HAVE FIVE YEAR LIFE
- LAUNCH NINE MORE HyPOTs AT 5 YEARS
- LAUNCH NINE MORE HyPOTs AT 10 YEARS
- HyPOTs EXPENDED AFTER 5 YEARS

CASE II - EARTH RETURN, REFURBISH, RELAUNCH

- LAUNCH THREE HyPOTs ON EACH OF THREE STS FLIGHTS
- REPLACE NINE HyPOTs AT 5 YEARS USING THREE STS FLIGHTS
  - 1ST REPLACES 3 WITH 3 NEW
  - 2ND REPLACES 3 WITH 3 REFURBISHED FROM FLIGHT NO. 1
  - 3RD REPLACES 3 WITH 3 REFURBISHED FROM FLIGHT NO. 2
- REPEAT REPLACEMENT AT 10 YEARS
- HyPOTs EXPENDED AT 15 YEARS

CASE III

- LAUNCH THREE HyPOTs WITH EACH OF THREE STS FLIGHTS
- SERVICE EACH HyPOT FROM STS AT 5 YEARS
- SERVICE EACH HyPOT FROM STS AT 10 YEARS
- HyPOTs EXPENDED AFTER 15 YEARS

Fig. 9 Sun Synch Scenarios

CASE I - EXPENDABLE

- LAUNCH COMPLAT WITH OTV USING STS
- LAUNCH THREE MORE AT 5 YEARS
- LAUNCH THREE MORE AT 10 YEARS
- OTV EXPENDED AT 10 YEARS
- COMPLAT EXPENDED AT 15 YEARS

CASE III - STS BASED ON-ORBIT SERVICE

- LAUNCH COMPLAT AND OTV USING STS
- OTV PLACES COMPLAT INTO SYNC EQ ORBIT
- OTV RETURNS TO STS
- STS RETURNS OTV TO EARTH
- OTV IS REFURBISHED
- OTV IS REUSED TO LAUNCH COMPLATS NO. 2 AND 3
- SINGLE OTV SERVICES THREE COMPLATS AT 5 AND 10 YEARS
- OTV RETURNS TO STS
- STS RETURNS OTV TO EARTH FOR REFURBISH, REUSE
- COMPLATS EXPENDED AT 15 YEARS

CASE IV - SOC BASED ON-ORBIT SERVICE

- LAUNCH THREE COMPLATS WITH STS
- SOC HAS OTV AVAILABLE
- OTVs PLACE THREE COMPLATS INTO SYNC EQ ORBIT
- OTV RETURNS TO SOC AFTER EACH USE
- OTV REFURBISHED AT SOC
- SINGLE OTV SERVICES THREE COMPLATS AT 5 AND 10 YEARS
- COMPLAT EXPENDED AT 15 YEARS

Fig. 10 GEO Scenarios

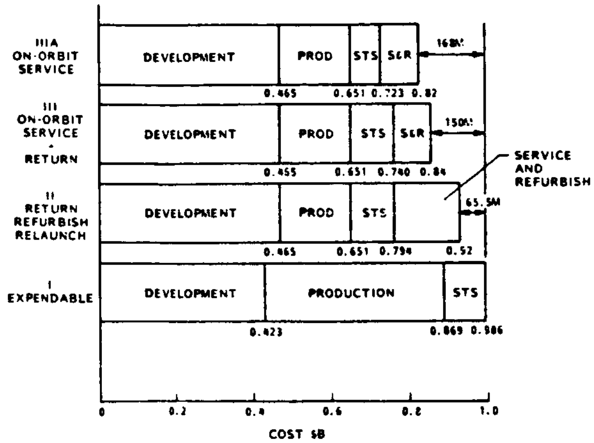

Fig. 11A LEO Cost Estimate

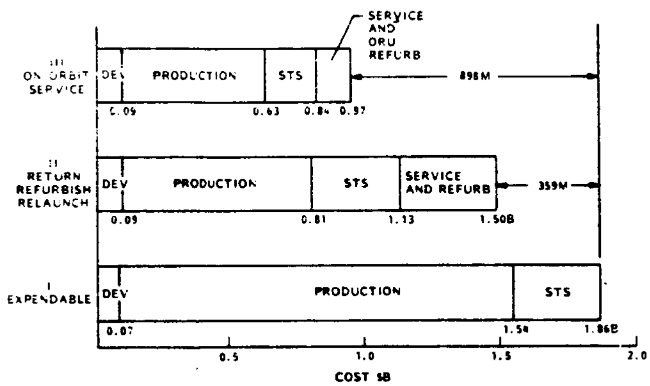

Fig. 11B Sun Synch Options Cost Estimate

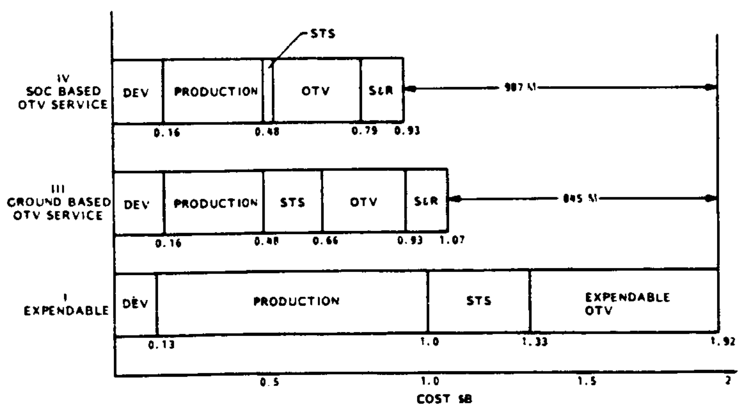

Fig. 11C GEO Cost Estimate

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COST AVOIDANCE FACTOR (CAF) IS:

THE COST AVOIDED RELATIVE TO THE EXPENDABLE SPACECRAFT
PER TONNE SPACECRAFT MASS
PER YEAR OF SPACECRAFT OPERATION

BASIS	RETURN, REFURBISH RELAUNCH	ON-ORBIT SERVICE	
		STS BASED	SOC BASED
LEO			
GROSS ($M)	65.5	168	-
CAF ($M/t/YR)	0.42	1.06	-
SYN SYNCH			
GROSS ($M)	359	898	-
CAF ($M/t/HR)	0.77	1.96	-
GEO			
GROSS ($M)	-	845	987
CAF ($M t YR)	-	4.14	4.83

Fig. 12 Cost Avoidance Factors

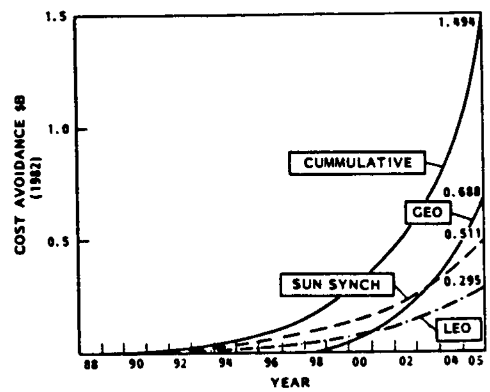

Fig. 13 Potential Cost Avoided by the User Community

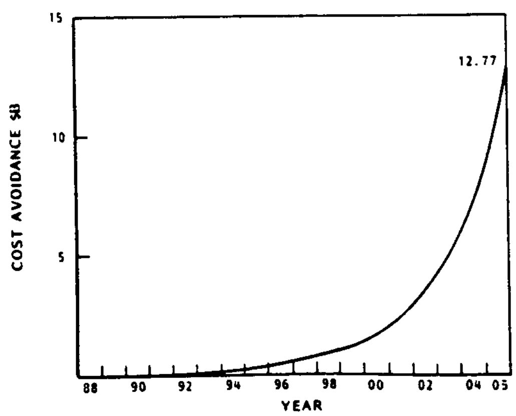

Fig. 14 Potential Cost Avoidance in Then Year Dollars