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SUMMARY REPORT

TECHNOLOGY REQUIREMENTS FOR POST-1985 COMMUNICATIONS SATELLITES

PREPARED UNDER CONTRACT NO. NAS2-7073

BY
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SUNNYVALE, CALIFORNIA

FOR
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SUMMARY REPORT

TECHNOLOGY REQUIREMENTS FOR POST-1985 COMMUNICATIONS SATELLITES

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1.0 INTRODUCTION AND SUMMARY

1.1 Need for the Study

The first commercial communication satellite was launched in 1963. It weighed 38 kg and could provide 240 circuits. Present INTELSAT IVs weigh 730 kg and provide 6,000 voice circuits across the major oceans to form a global communications network interconnecting over 80 nations of the world. Global communications services have been immensely improved and rates have been significantly reduced due to continued improvement of communications satellites during the decade since that first communication satellite. Even improvements of ocean cable have been stimulated by satellites through cost competion improved services and introduction of wholly new services such as transoceanic television. International and domestic common carrier satellites need no special stimulation of technology to insure their future development. Many other types of service of potentially great national and international benefit could be economically provided by means of satellite communications. Examples are distribution by satellite of educational TV programs and biomedical support services.

Many opportunities have been neglected for the development of such specialized communications systems and services. If these specialized communications services are to develop and flourish, attention must be given to their unique technical requirements and the best means for providing them in the future. How such services are provided in the future,and to what extent,is highly dependent on the technology available for providing quality services at an acceptable cost. The purpose of this study is to derive the technical and functional requirements for a variety of these services from a postulated needs model (a representative set of future user needs for services), and to identify the technology advancements required.

1.2 Needs Model

A suitable needs model was developed by various means, including updating and refining the needs model defined in the "Information Transfer Requirements Study", NASA CR-73421, performed for NASA by Lockheed Missiles & Space Company in March 1971.

Additional data were obtained from "A Study of Trends in the Demand for Information", CR-73426, performed by the Stanford Research Institute under NASA Contract in February, 1970. A special study report "World Communications" by Arthur D. Little was also used; it defines markets and technologies and forecasts future trends of the common carrier terrestrial and satellite networks. Considerable work was performed in refining the needs model and forecasting future demands and technology growth that have an impact on future networks. Future demands for services are a critical element in determining key technology developments required to satisfy future needs.

The needs model was based on 322 separately identified needs for long distance communications. These discrete needs were formed into 32 different generic types of service and were further categorized by functional similarity into seven basic groups. Future demands were forecasted on the basis of historical trends and of estimated attainable levels of technological improvement which would reduce costs, improve service, and therefore stimulate the future trend of demand growth.

1.3 Conceptual Spacecraft and Data Base

Conceptual spacecraft and networks for the 1980-1985 period were formulated for each major category of service. These conceptual systems were based upon improvements over the systems which are now being planned and developed and which will be implemented in the 1975-1980 period. Extensive use was made during the study of the technologies developed and documented for the INTELSAT V satellite study program. Additional baseline data were obtained from the technical descriptions of ATS-F (Advanced Technology Satellite) and original filings before the FCC for domestic satellite networks.

Optimized conceptual domestic satellite designs developed for the 1975 to 1980 era are generally consistent with applications filed with the FCC for domestic satellite network franchises, with NASA reports on the ATS-F satellite, with reports on Aeronautical and Tracking and Data Relay satellites, and with results of extensive domestic satellite optimization studies performed under Lockheed's Domestic Communications Satellite Programs. Definition of "Space Shuttle/Tug" systems and operating requirements for the 1985 era were obtained from the "Payload Effects Follow-on Study", NASW-2312, performed for NASA by Lockheed.

1.4 Methodology

The study methodology is similar to the methodology presented for communication system planning by Arthur D. Hall of Bell Telephone Laboratories in "A Methodology for Systems Engineering", D. Van Nostrand Company, 1965. Analysis of competing conceptual systems was used to determine the most cost effective concepts and technologies for meeting needs. Fig. 1 presents a flow diagram of the study methodology for determining key technologies.

1.5 Study Results and Recommendations

The study shows that the 1985 demand for satellite communications services for a domestic region such as the United States, and surrounding sea and air lanes, may required on the order of 100,000 MHz of bandwidth. Use of 36 MHz bandwidth transponders would create a need for some 3,000 satellite transponders "on-orbit". This level of demand can be met by means of the presently allocated frequency bands and developing technology, if properly utilized.

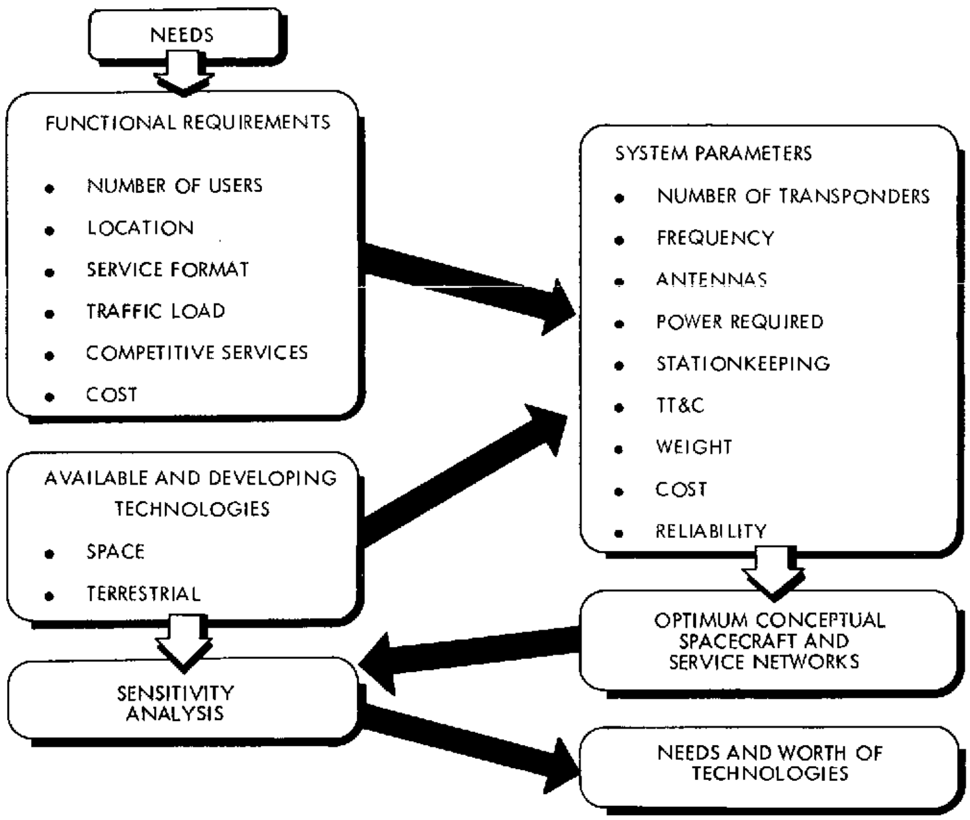

Fig. 1 DIAGRAM OF STUDY SEQUENCE

Key Technologies

The key technologies needed for meeting future demands and increasing the cost effectiveness of satellites within the available bandwidth are, in order of recommended priority:

1. Technologies for: improving antennas to provide 20 to 30 steerable or switched beams from one lightweight antenna; improved antenna beam shaping; greater isolation between adjacent beams of a spacecraft; antenna sidelobes reduced to less than -25 dB; and high speed switching of antenna beams and transponders.

2. Solid-state transponders for 12 GHz and possibly higher frequencies with increased DC-to-RF power conversion efficiency, reduced transponder costs, and reduced weight for required reliability and life.

3. Switched or steered beam antennas with 10 dB or higher gain for aircraft.

4. Continued development of improved video channel compression technologies and hardware.

Development in the following areas should continue at the present level. This will bring about the level of capabilities forecasted for these technologies by 1985, and will complement the key technologies listed above.

- Ion propulsion
- Power subsystems and components utilizing solar power
- Attitude control
- Thermal control
- Integrated micro-electronics
- Laser communications
- On-orbit chemical thrusters and propulsion
- Tracking, telemetry and control components
- Built-in automated control and test capabilities for spacecraft and earth terminal components

Development Plan Costs and Savings

The recommended development program for improving the technologies listed is defined in Section 13. It would cost about $170 million over a 7-year period. The minimum cost savings in a 7-year period after 1985 has been estimated for 42 identifiable "Space Shuttle/Tug"-launched communications satellites; this savings is $565 million. It is believed, however, that considerably more than 42 spacecraft will be launched. It is estimated, for example, that 39 international and domestic satellites will be purchased or will be on-orbit during the years from 1975 to 1980.

Estimated cost savings of $624 million due to the recommended technology improvements for 42 satellies, if the "Space Shuttle/Tug" were not used, are defined in Paragraphs 10.6.2, 10.6.3 and 10.6.4 of the Final Report,"Technology Requirements for Post-1985 Communications Satellites", CR-114680.

Effect of Space Shuttle on Spacecraft and Launch Costs

Use of the "Space Shuttle" instead of the Delta booster could reduce the cost of the typical spacecraft, including launch services, by about $15 million.

This savings includes a $6 million reduction of interest on money invested for the basic spacecraft and launch services. No savings are included due to possible on-orbit refurbishment, which is estimated to have less effect on the cost of commercial communications satellites than the transportation cost reduction due to the use of "Space Shuttle/Tug".

Modification of the conceptual Delta-launched spacecraft to a conceptual "Shuttle"-launched spacecraft configuration results in a 20 to 30 percent reduction of spacecraft cost and about a 50 percent increase in spacecraft total weight. The weight increase results from less expensive design and manufacturing techniques which can be used to take advantage of the reduced transportation cost per kilogram placed in orbit; the net effect is to reduce total spacecraft costs.

The "Space Shuttle/Tug" has a greater impact on communications satellite cost effectiveness than the improvements attainable from the recommended development plan. It also reduces the need for technology improvements focussed primarily on reducing spacecraft weight or improving capability for a given weight. The "Space Shuttle" makes technologies for conserving the available RF spectrum more important by reducing the need to conserve spacecraft weight: lower cost "Shuttle"-launched spacecraft will lead to greater utilization of the available RF spectrum and hence the greater need for conservation.

Effect of Cost and Weight Saving Technologies Alone

Technology improvements in the Delta-launched spacecraft could provide a 20 percent reduction of weight and cost of each subsystem and corresponding cost savings per spacecraft.

2.0 NEEDS MODEL

The condensed needs model for 1985-1995 is as follows (for complete descriptions refer to the Final Report, NASA CR-114680):

1. Elementary and Secondary Schools - National, Regional, State

   - Instructional television, video tape and audio distribution
   - Computer-assisted instruction and program distribution
   - Computer services: remote batch processing, information retrieval
   - Interactive, time-shared, multiple-access computer services
   - Expanded services to home and remote areas
   - Extensive voice, digital, and video services for "Third World" nations

2. Higher Education Network - National, Regional

   - Instructional, video tape and audio distribution
   - Computer assisted instruction and program distribution
   - Computer services - remote batch processing, information retrieval
   - Interactive, time-shared, multiple-access computer services

3. Library Network - National, Regional

   - Subject and abstract searches, automated abstracting and indexing
   - Automated location and retrieval of books, papers, reports
   - Remote reproduction of library reference data
   - Communications with library from home, office, aircraft, trains, etc.

4. Teleconferencing and "Electronic Travel" Network - Global, National, Regional

   - Electronic meeting and travel viewing
   - Computer support and printout of notes and papers, answering of queries

5. Biomedical Network - National, Regional

   - Improved quantity and quality of 1975-1985 era services
   - Emergency telemetering of biomedical data from aircraft, ships, etc.
   - Continuing home education for health-care specialists in remote areas

6. Commercial Broadcast - Time Zone and National Coverage

   - Audio and video services delivered by cable to homes in urban areas, voting feedback, electronic ordering
   - Semi-direct broadcast by satellite to small, remote rural communities for community cable TV and to large apartment buildings, hotels, resorts, etc.

7. Public Broadcast - Regional and National Coverage

   - Semi-direct broadcast to urban and suburban areas
   - Direct-to-home broadcast by satellite to remote rural areas
   - Broadcast by satellite to aircraft, ships, trains
   - Audio broadcast service to automobiles and trucks

8. Public Telephone - Global and National Coverage

- Point-to-point switched distribution of telephone, videophone, video, slow-speed and high-speed data
- Increased use of leased circuits for forming dedicated networks
- Extensive voice and data service to moving vehicles
- Development of direct satellite telephone communications for remote areas

9. Business Networks - National and International

- Use of communications and display consoles to reduce the need for paper reference and files
- Real-time management information systems
- Extensive international management information and control networks
- Development of totally integrated computer-monitored-and-controlled operations from raw material through final delivery

10. Value Transfer Network - National and International

- Development of a cashless and checkless society

11. Securities and Commodities Exchange - National, and International

12. Reservations and tickets - National and International

- Automated search and confirmation of reservations, electronic ticketing

13. General Computer Utilities - National International

- Extensive regional and national time-share computer networks
- Interactive systems; small local computers interacting with large central computers and data storage units on a time-shared basis
- International remote job entry systems for aiding the Third World nations

14. High-Speed, Special Computer Net - National, International

- Time-shared and remote job entry of problems for very high-speed super-computers

15. General Services Administration Network - National

- Management information and control network with assurance of privacy and data control by each using agency

16. State Administrative Networks - State and Regional

- Same type and degree of services as provided for federal agencies

17. National Law Enforcement Networks - Regional, National

- Computer crime information network - encoded data
- Transmittal of fingerprints, photographs
- Closed-circuit voice and video network

18. Emergency and Disaster Network - Regional, National

19. NASA Space Operations Network - Global

- Relay of tracking, telemetry, and command data between earth operations centers, and orbital and space exploration spacecraft
- Data buffering, error checking, and correction by data relay satellite
- Deep-space experiment data gathering, monitoring, and control

20. Earth Resources and Ocean Data Collection - Global, National

- Relay of data by satellite from remote earth-monitoring stations, ocean buoys, ships, aircraft, balloons, migratory animals

21. Marine Communications Network

- Marine communications for transoceanic ships; television programs, computer support, navigation and position, collision warning, traffic control, administrative communications
- Weather forecasts, emergency and rescue communications
- Fishing reports and conditions
- Telephone service - worldwide ship-to-shore, ship-to-ship

22. Aircraft Network - Global, National, Regional

- Continuous monitoring of aircraft position and performance
- Computer-assisted air traffic control and collision avoidance
- Emergency location, communication, and rescue aid

23. United Nations Network - Global

- Telecommunications (hotlines) and video teleconference meetings between diplomats and heads of states throughout the world

24. Electronic Mail - National

- Electronic distribution of mail directly between consoles

25. Ground Vehicle Communications Network - State, Local, Regional

- Low-cost, lightweight systems for emergency communications
- Extensive digital and voice communications and position fixing for law enforcement, fire fighting, forest, and service agencies, etc.

26. Electronic Newspaper - Regional, National

27. Electronic Publishing - National, Global

- Electronic transmittal of text and graphics directly to users
- Publications transmitted to aircraft, ships, buses, trains, resorts, etc.

28. RF Environment - Global,National

- Monitor and measure RF environment, communications channel discipline
- Conduct RF communications experiments

29. Language Translation and Communications Augmentation - Global

30. Religious Programs and Education - National, Regional

- Numerous private networks for carrying audio and video programs to religious and limited audiences with special interests

31. Home Communications - National, Regional

32. Area Support - Global

- Provide extensive audio, narrowband and wideband data and video communications between 500-2000 ground stations throughout an area

3.0 STUDY METHODOLOGY

Fig. 1 presents a flow diagram of the study metholody and sequence. Technology growth was forecasted on the assumption that there would be no special stimulation; i.e., that the study recommendations had not been followed. The forecasted technology capabilities were used to formulate conceptual systems that would satisfy the future service demands of the needs model.

The methodology provides insight into technology requirements relevant to user service needs. Accurate forecasting of the future is, of course, not possible. Fortunately, highly accurate forecasts are not necessary. The approach used ensures a conservative determination of useful future technology developments by considering worse case conditions, that is, the maximum expected demand and the minimum expected technology growth. This results in somewhat overestimating absolute needs for technology development but the results are relatively safe for the purposes of assessing technologies and determining priorities. An opposite bias that assumes minimum service demands and possibly unattainable rates of forecasted technology growth, on the other hand, will tend to indicate no need for technology stimulation or special development. In the latter case, meaningful priorities cannot be established. Therefore, the preferred biases are high demand and unstimulated technology growth. The study results appear quite credible if one considers the fact that forecasts of future communications growth have nearly always been too low.

4.0 FUNCTIONAL AND TECHNICAL REQUIREMENTS

Functional and technical requirements were determined for each of the needs of the 1985 to 1995 time frame. Requirements were based on the numbers of users for each service, required coverage, type of service and number and type of channels required. All services can be provided by means of three types of communication channels: voice/data (slow speed), video, and high speed digital data channels. Functional requirements reveal the need for improved technical capabilities such as antenna beam contouring and improved control of side lobes for better use of the available frequencies.

5.0 CATEGORIZATION OF REQUIREMENTS

The 32 different needs were grouped into seven categories of service on the basis of similarity of functional and technical requirements. Some needs such as "Area Support Networks" for developing nations and regions such as Alaska were subdivided and listed with more than one functional category. The categories listed can be further subdivided for examining particular functional requirements in greater detail and this is done in paragraphs 10.3.4 and 10.6.5.3 of the Final Report, "Technology Requirements for Post-1985 Communications Satellites." The arabic numeral assigned to each service listed corresponds to the sequential numbering of the needs model from which the service was taken. The seven basic categories are:

I. Television Service

1 Public Schools
2 Higher Education
3 Teleconferencing
5 Biomedical
7 Public Broadcast
16 State Government
23 United Nations
32 Area Support
30 Religious
31 Home TV

II. Digital and Voice Service

3 Libraries
8 Public Telephone
9 Business
10 Value Transfer
11 Securities and Commodities
12 Reservation and Ticket Service
13 General Computer Services
15 General Services Network
16 State Administrative Network
17 National Law Enforcement
18 Emergency and Disaster
24 Electronic Mail
27 Electronic Publishing
29 Language Translation
32 Area Support Network (Telephone)

III. High Speed Data Relay

14 High Speed Computer Network

IV. Mobile Services

21 Marine
22 Aircraft
25 Ground Vehicle

V. NASA Tracking and DATA Relay Network

19 NASA Space Operations Network

VI. Earth Resources Data Collection

20 Earth Resources Data Relay

VII. RF Environment Monitoring and Testing

28 RF Environment Monitoring and Testing

6.0 FORECAST OF TECHNOLOGY GROWTH

Despite recent funding curtailment for research and development, it is concluded that funding levels will grow in the future and that technology will grow faster in the future than it has in the past for reasons presented in paragraph 7.1.1 of the final report volume. Fig. 2 shows trends of satellite cost per two-way voice channel-year due to technology growth. The solid line is the trend due to improvements of spacecraft and boosters in constant 1972 dollars. Use of earth station improvements such as TDMA (Time Division Multiple Access), TASI (Time-Assigned Speech Interpolation) and data or signal compression may eventually reduce costs by a factor of 3 x to 5 x as indicated by the cost trend of the dashed line.

The point "INTELSAT V (A/C)" shown is based on use of forecasted technology growth to modify a conceptual INTELSAT V based on present technology and

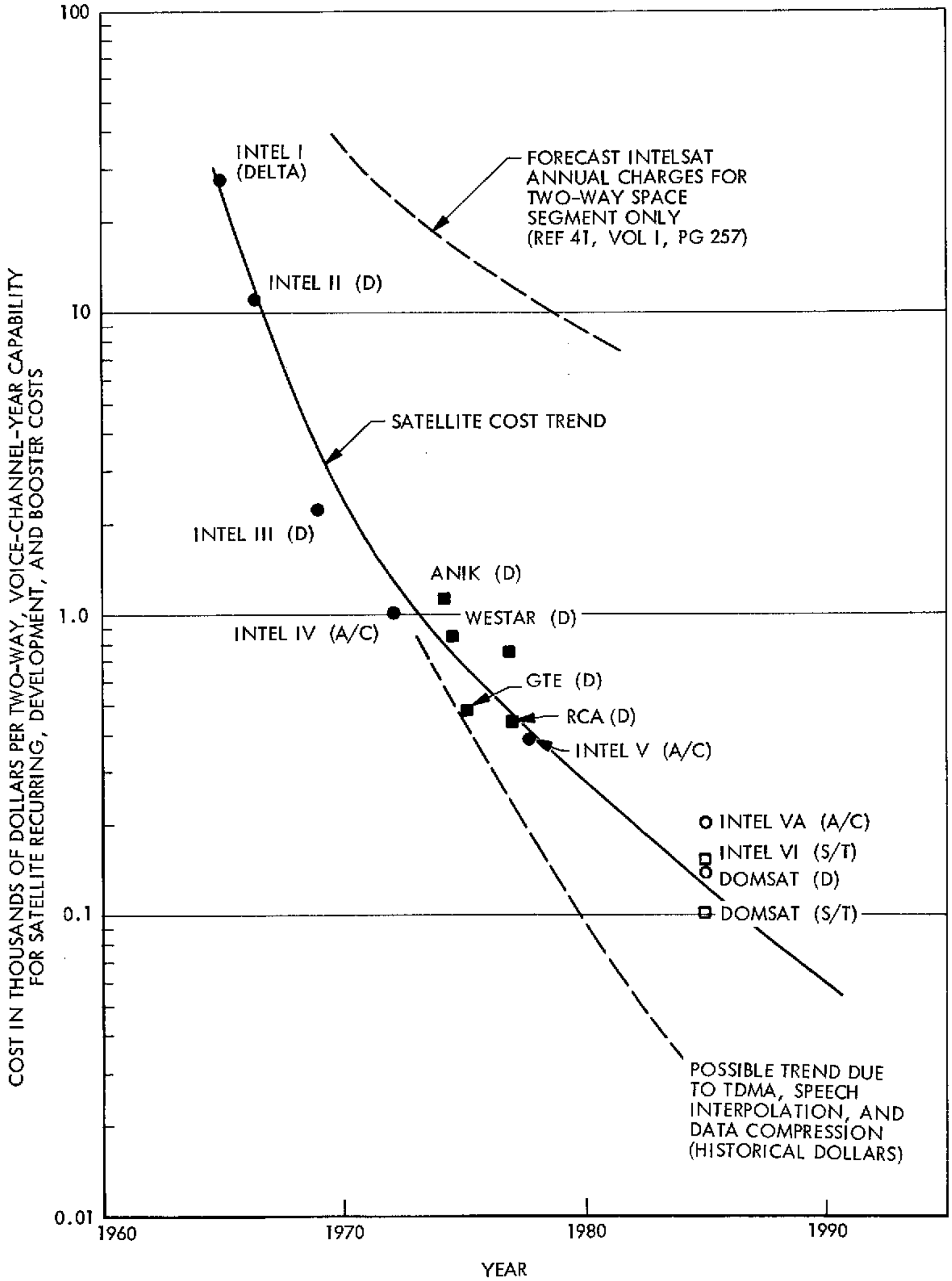

Fig. 2 SATELLITE COST TREND PER TWO-WAY VOICE CHANNEL-YEAR

using an Atlas/Centaur booster. The INTELSAT VI (S/T) data point is based on modification of the INTELSAT VA conceptual spacecraft to a "Shuttle/Tug"-launched configuration. The 1985 DOMSAT data points were similarly derived from present day domestic satellite (DOM SAT) spacecraft for "Shuttle"-launched spacecraft in 1985.

Analysis of the trend of communication satellite technology development presented in Fig. 2 indicates that:

1. The cost per two-way voice channel per year in 1972 dollars can be reduced approximately 10 percent per year due to improvements in earth stations.
2. The cost per two-way voice channel per year in 1972 dollars can be reduced an additional 15 percent per year due to improved spacecraft and booster system technology.
3. A potential 50 percent improvement in spacecraft cost effectiveness can be realized over a ten-year period due to the "Space Shuttle/Tug" system allowing increased capability at a lower transportation cost.

Booster costs and capabilities have a strong impact on spacecraft weight, size, configuration and cost. The "Space Shuttle/Tug" is expected to result in a 20 to 30 percent reduction in total spacecraft cost and possibly a 50 percent increase in spacecraft total weight. The result is about a 40 percent reduction in the average cost per kilogram of spacecraft. Development of the "Space Shuttle" reduces the technology requirements for providing special services and has a greater ability to reduce costs and constraints than on-orbit refurbishment. On-orbit refurbishment was not considered in determining individual spacecraft cost effectiveness for the 1985 to 1995 time frame because it appeared to be a secondary factor for synchronous communications spacecraft.

The available and developing technologies could fulfill most forecasted 1985 to 1995 demands if service costs were not of major importance. Future development and utilization of satellites is dependent on costs and service quality of satellite systems as compared with terrestrial systems utilizing coaxial cables, radio relay stations and light pipes.

7.0 FORECAST OF THERRESTRIAL COMMUNICATIONS GROWTH

The forecasted growth of terrestrial systems includes demands which can be filled by satellites if they are sufficiently cost effective. The forecasted growth of the telephone system shows an increase of 3,500,000 equivalent interstate voice circuits from 1972 to 1985.

Telephone System tolls are expected to decline in fixed-year dollars but at a much slower rate than the declining costs of satellite communications. The study of terrestrial communications growth substantiates the demands and functional requirements of the needs model. Terrestrial systems will continue to grow, provide improved services at reduced rates and carry most of the nation's communications. There is, however, a need for satellite systems to augment the established terrestrial networks, provide improved services to remote areas, improve system flexibility and stimulate the development of new and improved services by providing effective competition.

8.0 COST EFFECTIVENESS OF DOMESTIC SATELLITE SYSTEMS

The cost effectiveness of domestic satellite systems in competition with the established terrestrial telephone network was determined to test the viability of satellite systems. Various types of conceptual satellites based on available technology and with 12, 24, 36 and 48 transponders were tested. A 48 transponder satellite is the most cost effective and can compete with the present long distance tariff rates at distances of 200 miles or greater, if short term (15 minute) periodic outages are allowed. Such outages are believed to be acceptable for high quality services provided at lower costs than the present services. Large TITAN booster launched spacecraft are not being developed by commercial communication companies due to the high costs and financial risk per launch. Technology advancements are steadily increasing the capacity of Delta and ATLAS/CENTAUR launched spacecraft and increasing system cost effectiveness.

9.0 AVAILABLE FREQUENCY SPECTRUM

A critical factor in filling growing future needs is the availability of sufficient frequency bandwidth at usable frequencies. It is concluded that the presently allocated frequenciew are adequate for filling the forecasted future demands-if the frequencies are properly controlled and utilized.

Link calculations presented in paragraph 10.3 of the Final Report volume show the earth station and spacecraft communication requirements that best meet the functional requirements for each type of service. The results of communications link analyses are summarized in Tables 1, 2 and 3. Table 1 shows the available frequencies, bandwidth and numbers of available orbit slots if the earth station antenna apertures listed in Table 2 are used. Table 3 lists for comparison the number of channels and bandwidth determined from the functional requirements of the needs model and the total usable bandwidth if antenna apertures listed in Table 2 are utilized.

Results of Link Calculations

Tradeoff analyses based on the link calculations indicate that, for mobile users who have to use L-band (1550 MHz) and higher frequencies, either services will be improved or costs will be lowered by use of steered or switched narrow beam directional antennas on the user vehicles. Results from the link calculations and tradeoff studies were used for formulating conceptual spacecraft. The studies show that most domestic needs, including semi-direct TV distribution, can be satisfied by Delta-launched spacecraft. Recent improvements in data compression, for example, essentially halve the radiated power and bandwidth required per video channel.

10.0 COST MODEL FOR CONCEPTUAL SYSTEMS

Costs of eleven different spacecraft programs were analyzed and the following (1975) model for costing conceptual spacecraft was developed:

Sat cost $\approx$ (no. transponders) x \$0.5 + \$2 + (sat wt kg) x \$0.004

"Sat cost" is the recurring satellite cost in millions. The initial development costs (non-recurring) for commercial spacecraft are about twice the cost per production spacecraft (recurring cost) for the 1980 to 1985 time frame. One transponder and related equipment is estimated to cost \$0.3 million in 1972 dollars in 1985 compared to \$0.5 million for the 1972 era spacecraft. Transponder costs were appropriately reduced in the case of low frequency, narrow bandwidth solid-state transponders. Analysis of costs indicates that NASA spacecraft costs were 50% more than comparable commercial spacecraft due to special test, reporting and reliability requirements, use of more advanced technology and experimental equipment development.

Table 1

AVAILABLE FREQUENCIES AND BANDWIDTH

SERVICE	ALLOCATED FREQUENCY IN GIGAHERTZ	USABLE BANDWIDTH IN MHz	DEGREES OF USABLE EQUATORIAL ARC	NUMBER OF SATELLITE SLOTS	TOTAL AVAILABLE BANDWIDTHS IN MEGAHERTZ
DEDICATED VIDEO SERVICES	0.7	340*	80	2 @ 30°	600
	2.5	380*	80	8 @ 10°	3,000
	11.7-12.2	1,000	90	30 @ 3°	30,000
					33,600
COMMON CARRIER AND HIGH SPEED DATA	3.5-4.2	1,000*	80	16 @ 5°	16,000
	6.625-7.125	1,000*	60	20 @ 3°	20,000
	17.7-19.7	2,000	20	20 @ 1°	40,000
	19.7-21.2	1,500	20	20 @ 1°	30,000
					106,000
AERONAUTICAL AND MARINE	1.5	23	80	2 @ 80°	46
	43.0-48.0	2,500	10	1 @ 10°	2,500
					2,546
GROUND VEHICLE	43.0-48.0	5,000/2	10	1 @ 10°	2,500
RF ENVIRONMENTAL MONITORING	40.0-41.0	4,000	10	10 @ 1°	2,000

*WITH ORTHOGONAL POLARIZATION

Table 2

EARTH STATION REQUIREMENTS

FREQUENCY (GHz)	BANDWIDTH PER CHANNEL	SERVICE	EARTH ANTENNA GAIN (dB)	EARTH ANTENNA APERTURE M	MAXIMUM BEAMWIDTH	SATELLITE RF POWER WATTS/ CHANNEL	SATELLITE ANTENNA GAIN (dB)
0.4	2 KHz	DATA COL	0	1	180°	7	18
0.7	30 MHz	TV	24	3	10°	13	32
1.5	25 KHz	AEROSAT	3	2	180°	20	32
2.5	30 MHz	ETV	35	3	3°	15	32
4.0	34 MHz	DOMSAT	43	5	1-1/2°	10	32
12.0	34 MHz	DOMSAT	55	7	0.3°	16	32
20.0	1 GHz	DATA	60	7	0.2°	100*	55
40.0	1 GHz	DATA	60	3	0.2°	32**	60
43.0	20 KHz	MOBILE	32	0.2	4°	32**	47

*10 dB RAIN MARGIN
**20 dB RAIN MARGIN

Table 3

COMPARISON OF FUNCTIONAL REQUIREMENTS AND AVAILABLE BANDWIDTH

	DEDI-CATED VIDEO SERVICE	COMMON CARRIER AND HIGH SPEED DATA	AERO-NAUTICAL AND MARINE	STATE AND GROUND VEHICLE	TRACKING AND DATA RELAY	RF ENVIRON-MENTAL MONITOR
VIDEO CHANNELS						
GLOBAL	—	—			10 *	
NATIONAL	200	500 *			10 *	
REGIONAL	1,000	—			—	
VOICE/DATA CHANNELS						
GLOBAL	—	—	—	—	50	
NATIONAL	500	280,000	—	—	50	
REGIONAL	6,000	—	3,000	50,000	—	
HIGH SPEED DATA						
GLOBAL	—	—			2 GBps	5 GHz
NATIONAL	1 GBps	12 GBps			2 GBps	—
REGIONAL	1 GBps	—			—	—
TOTAL TRANSPONDERS	1,500	1,000	200	150	36	10
TOTAL PER REGION	300	—	30	10	12	—
REQ RF BANDWIDTH (MHz)	(60,000)	(34,000)	(80)	(500)	(5,000)	(5,000)
COMPRESSED BANDWIDTH (MHz)	(15,000)	(24,000)	(9)	(150)	(4,200)	(50)
BASE BANDWIDTH (MHz)	(1,210)	(15,000)	(9)	(150)	(4,100)	—
AVAILABLE BANDWIDTH (MHz)	(33,600)	(108,000)	(2,546)	(2,500)	(8,400	(2,000)

* VIDEO AND DATA CHANNELS

Although the cost model is quite simple, it is adequate for the purpose. Very detailed cost models are available but the slightly increased accuracy is inconsistent with the uncertainties of the forecasted 1985 needs and technology capabilities.

11.0 CONCEPTUAL SATELLITE SYSTEMS

Conceptual satellite systems were formulated for each of the seven types of services. Baseline systems were derived from spacecraft presently being developed for the 1975 to 1980 time frame. The system concepts, costs and attainable reliability were defined for the baseline spacecraft. The baseline (1975) and the 1980 to 1985 spacecraft are defined in paragraph 10.5 of the final report. The minimum expected technology improvement and change from the baseline systems was used for formulating future conceptual spacecraft.

Table 4 lists the estimated costs for seven different types of satellite networks for the 1985-1995 time frame. The Delta launch capability is maintained to provide continuity with spacecraft presently being developed. The service costs corresponding to the conceptual systems are consistent with the historical and forecasted future trends of spacecraft system cost reductions. Cost savings due to technology improvements of the conceptual spacecraft are converted to savings for Space"Shuttle/Tug"launched spacecraft on the basis of reduced transportation costs.

12.0 SENSITIVITY ANALYSIS

The potential cost savings due to improvement of spacecraft and earth station technology parameters were determined for each of eight types of system. Savings for spacecraft subsystems are primarily due to discrete 20 percent reductions of cost and weight of each subsystem. Such reductions are feasible. This mode of sensitivity analysis was used because there is a consistent need to reduce spacecraft costs and improve communications cost effectiveness. Economically attractive cost and weight reductions generally result in improved spacecraft cost effectiveness. Additional technology improvements were evaluated which were determined to be important to improving cost effectiveness as determined from analysis of network functional requirements and communications service parameters.

Table 4

COSTS OF CONCEPTUAL NETWORKS

(IN MILLIONS OF 1972 DOLLARS)

	VIDEO NETWORKS BIOMED EDUCATION ETC.	COMMON CARRIER AND HIGH SPEED DATA	AEROSAT AND MARINE VOICE AND DATA	SPACE TRACKING AND DATA RELAY	EARTH RESOURCES DATA COLL	RF ENVIR MONITOR AND TEST
SATELLITE:						
NO TRANSPONDERS	30	48	16	20	30	20
WEIGHT, KG	495	470	435	515	290	450
NO SAT + 1 SPARE	6	6	5	5	4	4
DEVELOPMENT COSTS	25	35	15	35	22	35
RECURRING COSTS	80	110	35	75	35	60
LAUNCH COSTS	50	50	40	40	30	30
8% DISCOUNT COST	110	140	64	107	62	90
EARTH STATIONS:						
7 YR OPERATION AND AMORTIZATION COST	80	125	180	45	105	45
COVERAGE	NATIONAL	NATIONAL	NATIONAL	GLOBAL	GLOBAL	GLOBAL
NUMBER	410	50	30,000	3	60,010	3
COST	25	50	70	10	40	10
TOTAL COST FOR SEVEN YEARS	345	360	334	303	254	260
COST PER TRANSPONDER/YEAR	0.33	0.21	0.75	0.54	0.40	0.62

The parameters used for the evaluation of each subsystem of each of eight different types of spacecraft are as follows:

Transponders

- Improved efficiency by 10%
- Reduce weight by 20%
- Reduce costs by 20%

Power Subsystem

- Reduce cost 20%
- Reduce weight 20%

On-Orbit Propulsion Subsystem

- Reduce costs 20%
- Reduce weight 20%

Tracking, Telemetry, and Command

- Reduce costs 20%
- Reduce weight 20%

Antennas

- Improved shaped beams
- Reduce side lobes
- Improve switched or steered beams

Attitude Control Technology

- Reduce costs 20%
- Reduce weight 20%

Spacecraft Structure and Thermal Control

- Reduce costs 20%
- Reduce weight 20%

Analysis of functional and technical requirements for each of the basic 32 service requirements of the needs model is defined in Section 5.0 of the Final Report volume.

Table 5 presents a summary of the results of the sensitivity analysis. Potential savings in millions of 1972 dollars are listed for each subsystem of each of the eight types of networks listed.

Key technologies for meeting future demands and increasing the cost effectiveness of satellites within the available bandwidth are presented in order of recommended development priority in the following section.

13.0 CONCLUSIONS AND RECOMMENDATIONS

Key Technologies

Key technologies and developments worthy of special attention for meeting the communications requirements of the 1985 to 1995 era are as follows:

Table 5

SUMMARY OF SENSITIVITY ANALYSIS
(COST SAVINGS IN MILLIONS FOR 1985 ERA SATELLITES)

SPACECRAFT:	VIDEO	COMM CARRIER DIGITAL AND VOICE	HIGH SPEED DATA	EARTH VEHICLE VOICE AND DATA	AEROSAT AND MARINE	SPACE TRACKING DATA RELAY	EARTH RESOURCES DATA COLL	RF ENVIR MONITOR AND TEST	TOTAL
TRANSPONDERS	16	21	21	16	6	10	4	13	107
ANTENNAS	20	37	37	25	25	10	0	8	162
POWER	9	7	7	9	4	3	2	2	43
STABILIZATION	2	3	3	3	2	3	2	2	20
PROPULSION*	3.3	2.5	2.5	3.3	2.0	3.0	2.3	1.5	20.4
STRUCTURES AND THERMAL	2.2	2.3	2.3	2.3	1.7	2.3	1.0	1.2	15.3
COMMAND AND TELEMETRY	1.2	1.8	1.8	1.2	0.9	1.2	0.9	0.9	9.9
EARTH TERMINAL:									
ANTENNAS	10	4	4	100	100	0	0	0	218
DATA COMPRESSION	30	20	0	0	0	0	0	0	50
TOTAL	93.7	98.6	78.6	159.8	141.6	32.5	12.2	28.6	645.6

*BASED UPON OPERATIONAL USE OF ION PROPULSION BEFORE 1980.

1. Develop technologies for improving the following antenna characteristics.
   - Provide 20 to 30 steerable or switched beams from one lightweight antenna
   - Provide improved antenna beam shaping to allow more controlled distribution of radiated energy and gain
   - Provide -30 dB or greater isolation between adjacent beams of a spacecraft antenna
   - Reduce antenna side lobes by more than -25 dB with lightweight antennas
   - Develop improved high speed switching of antenna beams and transponders
2. Develop solid-state transponders for 12 GHz and possibly higher frequencies with the following improved characteristics.
   - Increased DC to RF power conversion efficiency
   - Reduced transponder costs
   - Reduced weight for required reliability and life
3. Develop switched or steered beam antennas with 10 dB or higher gain for aircraft.
4. Continue development of improved video channel compression techniques and hardware.

The importance of antenna and transponder technology parameters increase for "Shuttle"-launched spacecraft because the importance of other parameters is reduced. Similarly, the probabilities of spectrum crowding and interference are increased since reduced spacecraft costs stimulate spacecraft growth and usage. Antenna technology improvements to provide cost savings and increased capacity are improved beamshaping, reduced side lobes and switched or steered multiple beams. Transponder improvements to provide increased DC to RF power conversion efficiency can reduce power system weight and costs as well as reduce transponder weight and cost. Earth terminal switched or steered multiple beam antenna improvements and improved data compression technology can reduce overall satellite network costs and can increase the capacity of each spacecraft.

Recommended New Technology Development Plans

The following development plan and funding were arrived at as a consensus by several knowledgeable development specialists as a minimum plan and funding to provide needed technological improvements.

Antenna technology and solid-state transponder technology should be stimulated over the next seven to ten years at the minimum funding levels indicated as follows:

- A funding of $20 million is recommended for spacecraft antenna technology improvements plus $10 million for flight test articles
- Fifteen million dollars is recommended for development of improved aircraft antennas over the next seven years for satellite communications
- A funding level of $1 to $2 million per year is recommended for transponders plus $10 million for development of transponders for flight tests when the technology is ready.
- Funding of up to $1 million a year is recommended for development of improved video channel compression techniques and hardware. Up to $10 million should be funded if necessary to develop low cost earth terminal channel compression hardware when the technology is ready.

Funding for Sustaining Technology Development and Expertise

It is recommended that a total funding of at least $10 million per year be used to maintain limited technology improvements and sustain expertise in the following areas. The selection of the above key technologies is based on the expected continued development and improvement of these technologies.

- Ion propulsion
- Power subsystems and components
- Attitude stabilization and control
- Thermal control
- Integrated microelectronics
- Laser communications
- On-orbit chemical thruster propulsion
- Tracking, telemetry and control
- Automatic control and testing

Flight Testing

Flight testing and demonstration of new technology capabilities is needed to stimulate the use of technology improvements and innovations by reducing the costs and risks for operational spacecraft to use the new technology. The ATS-F and Canadian Technology Satellite (CTS) will demonstrate the available and near term technology capabilities. Communication technology experiments are planned for some operational spacecraft and should nurture technology growth until the "Space Shuttle" system becomes operational in the 1980s.

Technologies such as ion thrusters can provide added weight capacity in orbit for communications and experiments in the late 1970s. Reduced transportation costs due to the "Space Shuttle" will reduce the costs for 1980 era experimental spacecraft and for carrying experiments on operational spacecraft. An experimental test-bed spacecraft should be developed for use with "Space Shuttle" to test technologies, techniques and devices which are radically new, novel, or hold promise of providing a breakthrough in communications.

Value of the Recommended Development Plan

The total recommended development plan would cost approximately $170 million over the next seven to ten years. Prior to the recent cutback in communications programs NASA was funding $2.6 million per year for communications satellite technology improvements*. This was in addition to development and application funds for the ATS-F spacecraft development. The savings resulting from the recommended development plan total $587 million if 42 spacecraft are developed, launched on the "Space Shuttle" and operated over a seven year period between 1985 to 1995. The minimum expected payoff-to-cost ratio on the total recommended development plan is about 3.5 to 1.

Effect of Space Shuttle/Tug on the Need for Technology Improvement

The effect of the "Space Shuttle" on the mix of 42 conceptual spacecraft for the eight types of networks considered in the final sensitivity analysis is to reduce the total costs from $1975 million to $1325. The $605 million saving is in 1972 valued dollars.

The "Space Shuttle" has a greater potential impact on future communications satellites than the recommended development program and attainable technology improvements. Use of the "Space Shuttle" reduces the need for technology improvements for reducing spacecraft weight. The savings produced by the recommended development plan increases from $584 million to $645 million if the "Space Shuttle" is not used.

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*NASA authorization for fiscal 1973, Hearings Before the Committee on Aeronautics and Space Sciences, United States Senate, Ninety-Second Congress, Second Session S.3094: March 14, 15 and 16, 1972.