"A QUANTITATIVE REVIEW OF ACTS EXPERIMENTS OPERATIONS"

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I. INTRODUCTION

The launch and subsequent operations of NASA's Advanced Communications Technology Satellite (ACTS) in September 1993 introduced a new era in U.S. satellite communications. After arriving at its geosynchronous station of 100 degrees West longitude sixteen days following launch, ACTS continues (as of this writing) operating superbly. Over three years of payload operations have successfully been completed incorporating over one hundred users of the system.

The ACTS Program was conceived to develop the high-risk, high-cost, advanced communications technologies usable in multiple frequency bands that would be applicable to a wide range of future communications systems for U.S. industry, NASA, and other domestic government agencies. These technologies were to enable the growth in capacity and effective use of the frequency spectrum, and enable the U.S. industry to maintain a competitiveness in the international communications satellite market. The approach to this was to develop and flight test the key technology areas that were identified as hopping spot beams; on-board digital communications (baseband processing); use of Ka-band; and very wide bandwidth transponders (microwave switch matrix).

The paper begins with a discussion of the ACTS system and experiments program. Although originally planned for only a two year operations period, the program's success warranted extending the program for two more years and usage still remains strong. After ACTS stationkeeping fuel is expended in June 1998, the system will be operated in an inclined orbit that could extend operations for up to another thirty months. Users of the payload (experimenters) are managed under an Experiments Program at NASA's Lewis Research Center. A steady use of ACTS by industry, government, academia, and NASA-sponsored demonstrations is presented.

Section III describes the spacecraft and experiments operations. The experimenters are scheduled to use the system as efficiently as possible while meeting individual requirements as best as possible. Section IV presents data from experiment operations collected over three and a half years showing the usage of the spacecraft payload in terms of utilization and efficiency. The results indicate a satellite that has been heavily used while supporting multiple simultaneous applications. Finally, in Section V a look at the users is presented including highlights of some of the latest experiences from the group of experimenters.

II. ACTS PROGRAM OVERVIEW

System Description

ACTS has been presented at many conferences in the past where one can find papers providing a more thorough discussion of the system. A recent system reference is provided [1] along with references to specific parts of the system in the following overview.

The significant technologies being validated as part of the ACTS Program can be grouped into several areas. The first is a multibeam antenna (MBA) that provides a rapidly reconfigurable pattern of 47 narrow, 0.3 degree, high gain, hopping spot beams; one 1-degree steerable beam; and three fixed spot beams [2]. A separate transmit and receive reflector (2.2- and 3.3-m diameter, respectively) are in an offset Cassegrain configuration and use a fixed network of horns in beam forming networks to develop the individual beams. A stationkeeping accuracy of 0.05 degree and antenna pointing requirement of 0.025 degree are being met or exceeded in order to maintain the accurate pointing of these thin beams.

The second is a baseband processor (BBP) that is a high speed digital processor on-board the satellite which demodulates, stores, and regenerates the baseband signals received before being re-transmitted. It efficiently uses transponder capacity by routing individual, 64 kbps, circuit-switched messages and provides single hop interconnectivity in a full mesh network [3]. The third is a microwave switch matrix (MSM) which is a dynamically reconfigurable, intermediate frequency, 3 x 3 switch capable of routing high volume point-to-point traffic and point-to-multipoint traffic over channels each having 900-MHz of bandwidth.

The other technology areas include the development of Ka-band components which were part of the flight and ground segment hardware at 20 and 30 GHz; very small aperture terminals using antennas with diameters of 1.2 m to handle high transmit and receive throughput rates (1.544 Mbps) [4]; high data rate terminals capable of operating at 622 Mbps [5]; network control techniques by using advanced algorithms to provide flexible and efficient demand assigned multiple accessed (DAMA) communications in a mesh network [6]; and adaptive signal fade compensation using techniques such as forward error correction and burst rate reduction which are activated on an "as-needed" basis independently on the uplink and downlink.

The advanced technologies developed for ACTS are usable in frequency bands other than the 30/20-GHz Ka-band and can support a wide range of future communications systems. The advantages realized by these technologies are the basis for providing low cost satellite communications especially to regions where terrestrial service is too costly or completely impractical. Also, the technologies provided by ACTS are necessary for developing tomorrow's networks that will use both satellite and terrestrial services seamlessly interconnected.

Inclined Orbit

The spacecraft's projected operational lifetime is through July 1998 based on stationkeeping fuel projections made in May 1996. Afterwards, operations will continue with the spacecraft in an inclined orbit. By eliminating the last North-South stationkeeping maneuver, the operational life may be extended by up to thirty months or nearly through the year 2001. Feasibility of continuing payload operations is being investigated by NASA and its contractors, Lockheed Martin Astro Space (spacecraft) and Comsat Laboratories (control station). The spacecraft's inclination is projected to increase by approximately 0.8 degrees per year. During the inclined phase, the spacecraft's spotbeams must remain pointed as they currently are to maintain a control beam on the Master Control Station in Cleveland, Ohio. This will be done by adjusting the roll and pitch of the spacecraft. The end of life is, therefore, determined by the physical limitations of the range of the momentum wheel pivot on the spacecraft used in adjusting the spacecraft's attitude. This results in a maximum usable orbit inclination of about 2 degrees.[7]

Experiments Program

Besides building and launching a satellite with advanced communications capabilities to flight test and verify the technologies, NASA wanted to make the system available to a wide variety of users so that the system's capabilities could be tested with many different applications and to many different audiences. More formally, two primary goals were set: 1) to conduct a complete set of technology verification experiments that would evaluate and characterize the ACTS technologies; and, 2) to conduct a balanced set of experiments and demonstrations that would evaluate the potential voice, video, and data user applications enabled by the ACTS technologies. Initially, ACTS was to operate for two years. The program's success prompted NASA to continue operations for the system's useful life, as was mentioned, into an inclined orbit phase beginning in 1998.

An experiments program was organized to seek users of the system and to manage the experiment operations. One of the main differences of the ACTS Program compared to other NASA science missions was that NASA was not funding experimenters to use the system as typically occurs with its science missions. Yet by launch, 47 applications experiments were identified and selected from 78 proposals to participate in the program. Today, 85 experimenters involving 105 organizations have used, or are using ACTS. Figure 1 shows the history of experiments starts and completions over the duration of the program.

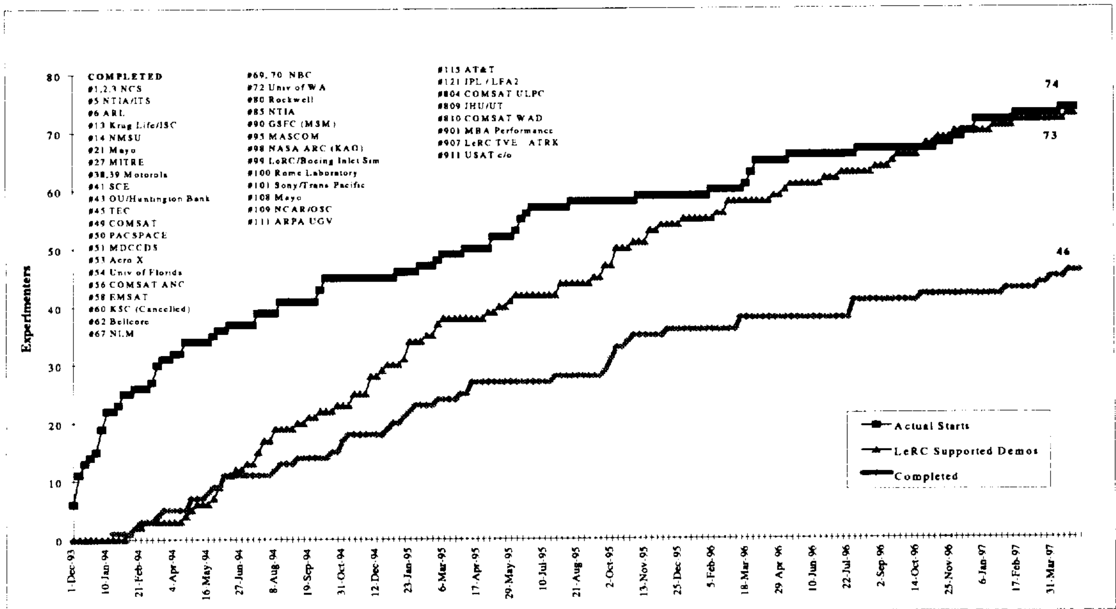

Figure 1: ACTS Experiments Starts/Completions

The ACTS system is available to industry, universities, and other government agencies as well as to support demonstrations of Ka-band communications and new service applications. Over seventy (as of this writing) NASA sponsored short duration demonstrations have also been performed covering a wide variety of applications to diverse audiences (Table 1).

III. EXPERIMENT OPERATIONS DESCRIPTION

Spacecraft Operations

ACTS payload operations are generally scheduled 24 hours per day, every day of the year. This includes usage of the two primary communications paths through the satellite - the baseband processor (BBP), and the microwave switch matrix (MSM). The BBP and MSM operate quite differently. The BBP's digital switch that demodulates the uplinked signals, stores, switches and then remodulates the signals for downlinking, operates with a unique demand-assigned multiple access, TDMA protocol and incorporates frequency division multiplexing. The MSM is a hard-limited, three-channel, 900 MHz, wide-band, frequency translator and amplifier or bent pipe. It switches up to three uplinked signals to three downlink locations using either static beams or spacecraft-switched TDMA. Frequently the BBP and MSM are simultaneously operated in a mixed-mode; however, bus electrical power and antenna switching capability limit the full use of these two modes when operating together.

System Constraints and Outages

The ACTS system offers considerable flexibility to meet experimenters' spacecraft time requests within the spacecraft and ground segment limitations. Spacecraft constraints were identified so that known outages could be coordinated and experiment operations maximized around them. Experiments are often operated simultaneously whenever possible during normal business day hours to reduce congestion and scheduling conflicts. Requirements to use the spacecraft and earth stations are examined for each experiment to determine which can operate simultaneously without interference and which must operate independently. System factors that are part of the analysis include the mode of operation (BBP or MSM), spot beams needed, location of earth stations within a spot beam, number of other users within a spot beam, availability and compatibility of earth stations needed, and steerable beam antenna use.

Table 1: NASA Sponsored Demonstrations

#	Demonstration	Date	#	Demonstration	Date
1	Natl. ISDN Users' Forum	2/9-11/94	39	Industry Demo (SITF/SIS)	5/2-3/95
2	IEEE & Supervisor Demo	2/15/94	40	NTIA/ITS	5/19-20/95
3	AIAA Demo	2/28/-3/02/94	41	Wyoming Heritage Fdtn.	6/1-2/95
4	Local Community Demo	4/20/94	42	Intntl. Mobile SatComm. Conf.	6/6-8/95
5	NASA Frequency Managers	4/28/94	43	Norris Demo	7/31/95
6	General Dailey Demo	5/6/94	44	HDR Demo (GWU)	8/3/95
7	Martin Marietta Appreciation	5/26/94	45	ACT Results Conference	9/11-13/95
8	National Press Club	5/31/94	46	AT&T Demo	9/25/95
9	Experimenters' Working Group	6/1/94	47	JWID	9/27-29/95
10	Brackey Committee	6/8/94	48	ISDN Demo	10/9-10/95
11	OHIO Congressional Delegation	6/10/94	49	ARIES HDR Demo	10/11/95
12	COMSAT Appreciation	6/23/94	50	AT&T Demo	10/13/95
13	Dante - Mt. Sprurr, AK	7/6-29/94	51	Hughes Demo	11/2/95
14	MSFC Director	7/19/94	52	AT&T Demo	11/21/95
15	Natl. Insit.Standards & Tech'gy	7/22/94	53	Bogota Demo	11/24/95
16	AIAA	7/26/94	54	NASA Deputy Assoc. Admin.	12/7/95
17	Natl. Insit.Standards & Tech'gy	7/26/94	55	AT&T Demo (Voice & Fax)	1/4/96
18	MCI	8/10/94	56	NSA Demo (USAT)	2/15/96
19	AT&T	8/12/94	57	ARIES Shipboard Demo	2/26/96
20	Mayo Clinic	9/7/94	58	AIAA Conference	2/26-28/96
21	SCUC	9/19-21/94	59	Congressman Senssenbrenner	4/22/96
22	Dept of Transportation	10/7/94	60	NASA Lewis Dep. Ctr. Director	5/6/96
23	NASA Chief Scientist	10/28/94	61	GLIN Demo	5/13/96
24	Dan Goldin - NASA HQ	11/17/94	62	ICC Supercom	6/24-27/96
25	Natl. Insit.Standards & Tech'gy	11/18/94	63	Montana	7/15-18/96
26	Aerospace States Assoc. Conf.	12/1/94	64	Cleveland Airshow	8/29-9/2/96
27	Amoco	12/8/94	65	Lewis Business Summit	9/19/96
28	National Lab Review Demo	12/8/94	66	SCEC	9/24-26/96
29	US Air Force Demo	12/20/94	67	MASCOM @ Fort Monmouth	10/21-23/96
30	Army Family	12/30/94	68	Tech 2006	10/28-31/96
31	Pacific Telecomm.Conf.	1/23-25/95	69	SEG	11/10-13/96
32	NBC TIVSAT Demo	1/20/95	70	Radiological Soc. North Amer.	12/1-5/96
33	Norris Demo	1/27/95	71	Pacific Telecomm.Conf.	1/20-22/97
34	NBC Mobile Expt. Demo	1/27/95	72	Congressman Kucinich	2/19/97
35	INTEL Demo	2/16/95	73	Take Your kids to work day	4/24/97
36	Ohio University Demo	2/28/95			
37	Norris Demo	3/1/95			
38	Plain Dealer Demo	3/8/95			

At times the spacecraft is not available for experimenters because of system outages due to operations constraints, such as, during the spring and fall equinoxes when the spacecraft's solar panels are eclipsed. Fortunately, this impacts few because it occurs during the first hours of the day, local time at NASA Lewis, when not many experimenters want to use the hours. To conserve weight, the spacecraft's batteries were sized to provide only minutes worth of power to the communications payload. Therefore during the 44 day eclipse season, the payload is shut down so that only essential bus functions remain operating. The payload is typically turned off during the hours of 0600-0830 GMT which allows sufficient time beyond the eclipse period to gracefully shut down the system before the eclipse, and then, to re-energize critical spacecraft components before bringing the system up again after the eclipse. The peak outage is about 70 minutes in duration for two days before and after the equinox. The duration of the outages symmetrically tapers around the equinox.

Another experimenter outage period occurs during payload reconfigurations. This, however, is determined by NASA as the system operator and not by orbital physics. One-half hour is allocated to reconfigure the satellite between BBP and MSM modes, and is often done in a shorter duration. Other short reconfiguration periods of about 15 minutes are needed for changing the connectivity of the MSM between different groups of MSM users.

IV. SPACECRAFT USAGE

Experiment Hours

The communications payload on ACTS has been tested with multiple users covering a wide variety of applications and continues to provide excellent service. While at one time only a twelve hour day was being considered for operations, the interest expressed in the program from the many organizations prior to launch prompted operations to be extended to a full 24 hours per day, 365 days a year. On weekdays, a period from 0800 to 2000 local time at Eastern Time (EST or EDT) is called prime time; all other weekday and weekend hours are considered off-prime. The prime time hours are when the bulk of activity occurs because of the overlap with the normal business day. However, the off-prime hours are used often to support experiments that preclude others from simultaneously operating with them, or when preferred due to time zone changes (e.g., Pacific coast), night operations (e.g., Keck telescope in Hawaii), 24 hour/day operations (e.g., Army field exercises), and off-peak hours availability of other application equipment involved in the experiment (e.g., supercomputer time, bank networks).

Over the three and a half year period since operations began from December 01, 1993 through May 06, 1997, over 34,000 hours of experiment time has been logged on the system (Figure 2, right scale). Of these hours, about 67% of usage has occurred with the Baseband Processor mode and 33% with the Microwave Switch Matrix mode. A set usage plan dividing spacecraft time between the two modes was never mandated that would define this result. Scheduled hours are provided to best meet all experimenters' requests. The data plotted is from experiment time "as scheduled", as opposed to actual hours used. Spacecraft schedules are well archived while the actual hours sometimes vary from the scheduled and are not always archived. The difference is considered negligible for the purposes of this paper.

Figure 2 shows great variations in usage that have occurred from week to week, and the occasional spikes of activity such as during the May '94 and Sept. '94 periods. Each spike in the figure can usually be traced to a particular experimenter or event that drove system operations. In May '94, Huntington Bank/Ohio University were involved in a 24 hour/day test over a week long period in an emergency communications restoral experiment. In September 1994, the U.S. Army requested to use ACTS to support 24 hour/day operations during Operation Uphold Democracy in Haiti. Also, a general cyclical pattern can be noted over a year's time with the low point occurring around the winter holiday season (late November - early January).

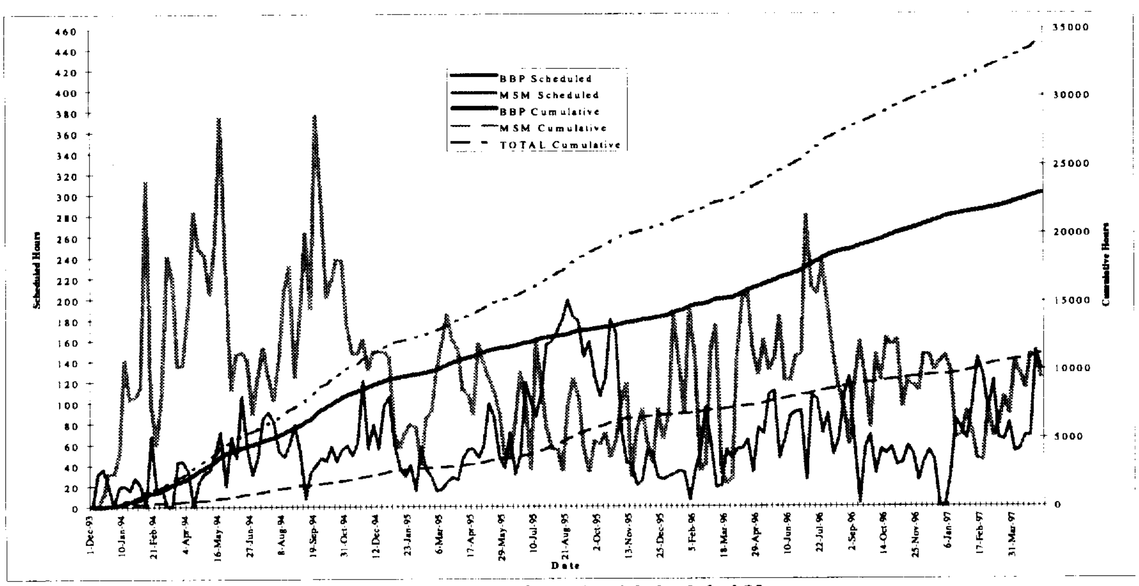

Figure 2: Spacecraft Payload Scheduled Usage

Utilization

Considering the half-billion dollar investment made in ACTS, minimizing unused time of the system is always desired. The method chosen to monitor used time is through a parameter defined as the *utilization* which is the number of hours that the communications payload is used for either experiment or checkout activities divided by the total number of hours that the payload is available for use. Unavailable periods include payload shut-downs during eclipses (about 2 ½ hours per day during spring and fall eclipses), and payload mode reconfiguration periods (about 1-2 hours per day to change between BBP and MSM modes). A average utilization of 98% has been achieved over the program as shown in Figure 3. This shows an improvement over the first month of the program when cumulative utilization was at it lowest value of only 58%. By the end of the first year it had increased to 93%. A 60 day moving average shows that utilization was greater than 98% for the last two years during which only 16 days were less than 100%. Overall, the system has averaged 22 hours a day of scheduled activities throughout its first 3 1/2 years of operations lifetime. Further analysis could be done to determine system availability taking into account rain outages and system reliability, based on the utilization.

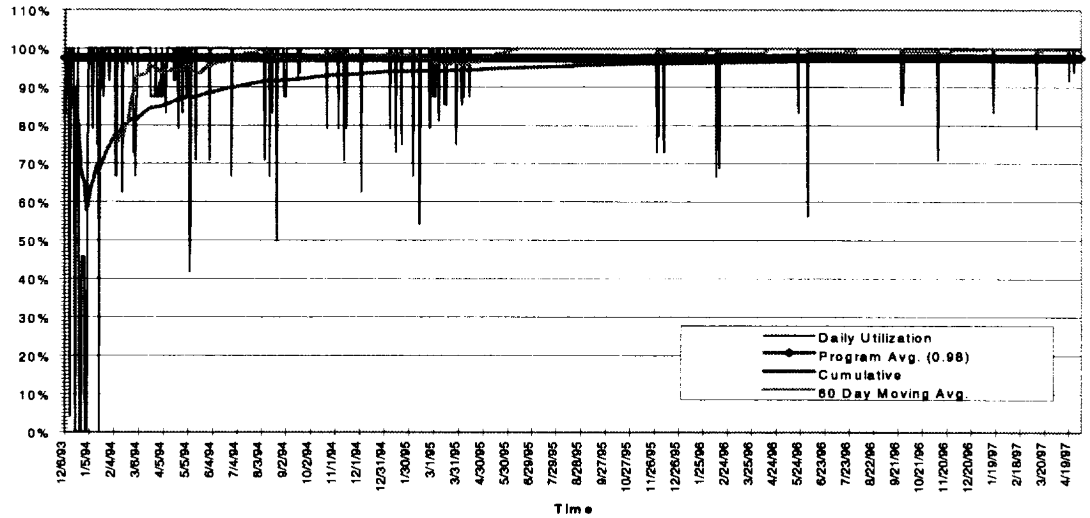

Figure3: Payload Utilization

Experiment Efficiency
Key features of ACTS, such as the hopping spot beam antenna, baseband processor, and microwave switch matrix allow for multiple users of the satellite to operate simultaneously. A measure of how many users were simultaneously active at once is made by a parameter called *experiment efficiency.* This is defined as the number of experiment hours supported in a period divided by the number of hours that the communications payload is available to support experiment activity during that period. The efficiency figure takes into account application, technology and demonstration users of both modes of operation (BBP and MSM) but does not include time used for system engineering, and earth station installation and checkout.

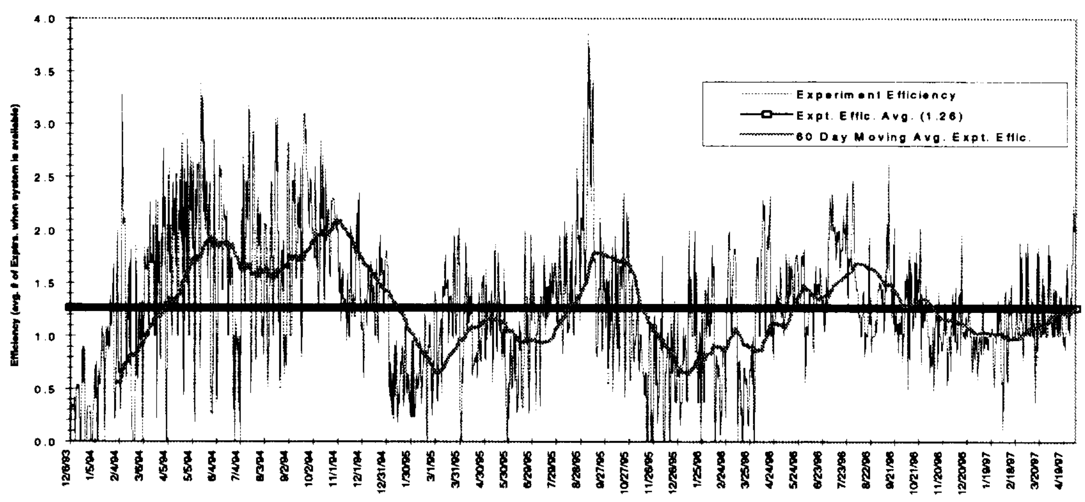

Figure 4: Experiment Efficiency

Experiment efficiency is plotted in Figure 4 and is based on a period of 24 hours from the scheduled experiment activity. Efficiency ranges from 0 to 3.9. The peak was achieved on September 06, 1995, which occurred when multiple experiments were preparing for demonstrations at the ACTS Results Conference (Sept. 11-13, 1995). If just prime time hours (0800-2000 EDT) are examined, the experiment efficiency during the week of Sept. 04-10, 1995 peaked at 5.3 also occurring on September 06, while averaging 3.9 throughout the week. Over the entire 3 1/2 year period, experiment efficiency averages 1.26. The average efficiency for each of the first two years is also 1.26, while for the third year, this figure increases slightly to 1.35. Considering that these figures take into account around-the-clock operations, an average over one exceeds NASA's expectations of the system usage.

An upper limit for experiment efficiency cannot reasonably be determined because of the many variations that experiments can take. For example in the BBP mode and taking into account the system constraints, if the maximum number of T1VSAT's (40) each supported 24 voice circuits of which each circuit was being used by a separate experimenter, 548 users could simultaneously operate! The MSM mode has 3 channels each with 900 MHz of capacity. While generally only one user operates per MSM channel, multiple users can operate in an MSM channel with the TDMA High Data Rate Terminals, or if a channel is frequency multiplexed between users.

V. EXPERIMENT SEGMENTATION

The data presented in Figure 5 shows the breakdown of users on ACTS based on 3 ½ years of operations. As can be seen, the government uses about 80% of the satellite time and is easily the largest user of ACTS. Government organizations generally had greater available resources to support an ACTS experiment. Users from the government include 10 organizations from the Departments of Defense, Commerce, Health and Human Services, and other agencies, plus 4 NASA centers. The heavy NASA usage can largely be attributed to NASA performing long-term technology verification experiments to collect data on system performance during the off-hours that are generally undesirable to other experiments. Industry's use of 11% of the time is split between 16 organizations. These users were involved in telecommunications, medical services, banking, entertainment, aerospace, and utilities. They tended to perform shorter duration experiments which usually included system checkout time scattered over two to three months followed by a short intense month-long period of actual experimentation. The university users comprise 8 organizations and demonstrated applications such as distance learning, tele-astronomy, telecommunications protocol evaluation, and telemedicine. Centers for the Commercial Development of Space, or CCDS, are institutions created by NASA centered at universities located across the United States and chartered to obtain industry participation and commercialize space technology in different technical area. Two were involved with space communications: one in Maryland and the other in Florida.

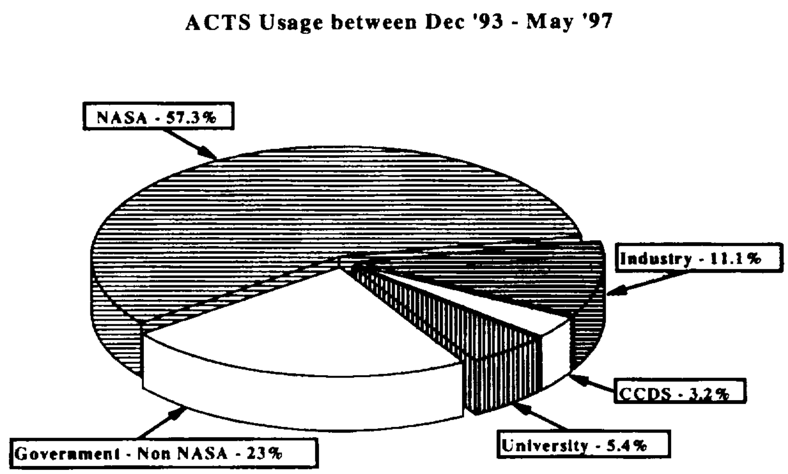

Figure 5: Organizational Breakdown of ACTS Users

Recent activity on ACTS includes several exciting applications and demonstrations.

- In the area of High Data Rate, a link half-way around the world was established between Japan and the U.S. in March 1997 to demonstrate the seamless interoperability of satellites with fiber. Sony Studios, in cooperation with Lockheed Martin, desired to test a two-way link between Sony's High Definition Television studios in California and Japan to perform post-production of a high definition video signal. A fiber link was used between the studio in Culver City, California to the ACTS high data rate terminal at the Jet Propulsion Laboratory in Pasadena, California. The signal was transmitted over ACTS to Oahu, Hawaii. In Hawaii, it was fiber-linked to an Intelsat earth station also on the island and transmitted to Japan over an Intelsat satellite where the signal was routed by fiber to the local Tokyo studio. After the signal was processed, it was sent back to California along the reverse path. End to end throughput rates of 45 Mbps were achieved.

- In January and February, 1997, an ACTS terminal was operating at Palmer Station, Antarctica as part of a Public Television program called "Live from Antarctica-2" and involved two other commercial satellites to complete the final program broadcast. Participating were grade schools across the United States which interacted in real time by live internet access with researchers at the station.
- ACTS has also been busy supporting a Navy Aegis-class cruiser in the Pacific and Atlantic with a 1.5 Mbps link from the ship to its home port in San Diego, California using a broadband mobile antenna developed and supported by JPL.
- Georgetown University's Latin American Satellite Education Program recently completed its experiment. The distance education application involved two universities in Colombia and Ecuador and intended to build a case for business development providing education services to international locations with inadequate communications infrastructure to support terrestrial links.

Other new participants include AT&T, Caterpillar and US Air Force Rome Labs (Syracuse, New York).

VI. CONCLUSION

Operations on ACTS over the last 3 ½ years have provided a successful opportunity to many government, education, and private users seeking to benefit from this advanced Ka-band testbed. Customer satisfaction is maintained in supporting application experiments while also supporting technology verification by NASA. The spacecraft is used on average 98% of the time it's available, continuously by more than one user. Non-NASA organizations use 53% of the systems resources. The data presented was tabulated for the first time after three years of operations and provides an excellent summary of the sustained ACTS system usage and continuation of steady day-to-day operations.

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13. ABSTRACT ***(Maximum 200 words)***

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