

## **ACTS Aeronautical Experiments**

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### **Abstract**

This paper discusses a series of aeronautical experiments that utilize the Advanced Communication Technology Satellite (ACTS). As part of the ongoing effort to investigate commercial applications of ACTS technologies, NASA's Jet Propulsion Laboratory and various industry/government partners developed a series of experiments that utilize the ACTS Mobile Terminal (AMT) [1] and the Broadband Aeronautical Terminal [1] to investigate aeronautical uses of the ACTS. This paper - discusses these experiments including the experiment configurations, technologies, results, and future implications.

### **introduction**

Since shortly after the launch of the ACTS in September, 1993 the NASA/JPL developed ACTS Mobile Terminal (AMT) has been conducting land-mobile satellite experiments in conjunction with a variety of industry partners [2]. Much has been learned about the land-mobile K/Ka-band communications channel as a result of these experiments [3]. A natural extension of these experiments was to investigate the aeronautical K/Ka-band communications channel by installing and testing the AMT in an aircraft, these experiments became known as the Aero-X Experiments [4]. The use of K/Ka-band for aeronautical communications has the advantage over lower frequency bands of having spectrum available and requiring smaller antennas, while eliminating the one major drawback of this frequency band, rain attenuation, by flying above the clouds the majority of the time. Building on these Aero-X aeronautical experiments the ACTS Broadband Aeronautical Terminal was designed to operate at higher data rates (i.e.,  $\geq 384$  kbps vs. 4.8 kbps for Aero-X), and without restrictions on the flight path or aircraft dynamics. The specific experimental objectives of the Broadband Aeronautical Terminal are to: (1) demonstrate and characterize the performance of high data rate aeronautical Ka-band communication (2) characterize the propagation effects of the communications channel during take-off, cruise, and landing phases of flight, (3) provide the systems/technology groundwork for an eventual commercial Ka-band aeronautical satellite communication system.

## **Aero-X Experiments and Results**

During the spring/summer of 1994, a joint experiment between NASA Lewis Research Center (LeRC) and the Jet Propulsion Laboratory (JPL) was conducted to 1) demonstrate that with current technology it is possible to make low rate full duplex voice calls into the Public Switched Telephone Network (PSTN) from an airplane via a satellite, 2) understand what are the critical elements in maintaining an aeronautical link and, 3) gain a better understanding for the K/Ka-band aeronautical environment. The Aero-X experiment would culminate with a series of demonstrations across the United States showing this technology to various commercial and government entities.

The Aero-X experiment was the fourth experiment conducted by JPL under the ACTS Mobile Terminal (AMT) project. The previous experiments had already proven the communications equipment could provide reliable voice links into the PSTN from a mobile van at encoded voice rates of 2.4, 4.8, and 9.6 kbps. The Aero-X experiment would integrate the existing equipment from the van into a Learjet Model 25. JPL and LeRC were responsible for integrating the AMT terminal into the plane. LeRC was also responsible for overseeing the development of three new phased array antennas and an antenna controller for the plane. The following sections will describe the individual subsystems, the success of the demonstrations, and describe the qualitative results of the experiment.

### ***Technology***

#### **ACTS Mobile Terminal**

The ACTS Mobile Terminal (AMT) is a proof-of-concept K/Ka-band mobile satellite communications terminal developed by NASA at the Jet Propulsion Laboratory. The AMT was designed to demonstrate the viability of speech at 2.4, 4.8, 9.6 kbps, and data transmission at 2.4, 4.8, 9.6, 64 kbps, in the K/Ka-band mobile satellite communications environment. The AMT components used for Aero-X are: a speech coder/decoder (CODEC) utilizing LPC-10, CELP, and MRELP algorithms, a differentially coherent modem supporting data rates from 2.4 to 64 kbps, IF converter (IFC), RF converter (RFC), terminal controller (TC), and data acquisition system (DAS). The mobile terminal, integrated into a Learjet airplane, and the fixed terminal configurations are shown in Figure 1. For a more detailed discussion of the AMT subsystems, refer to the ACTS Mobile Terminals paper in this journal [5].

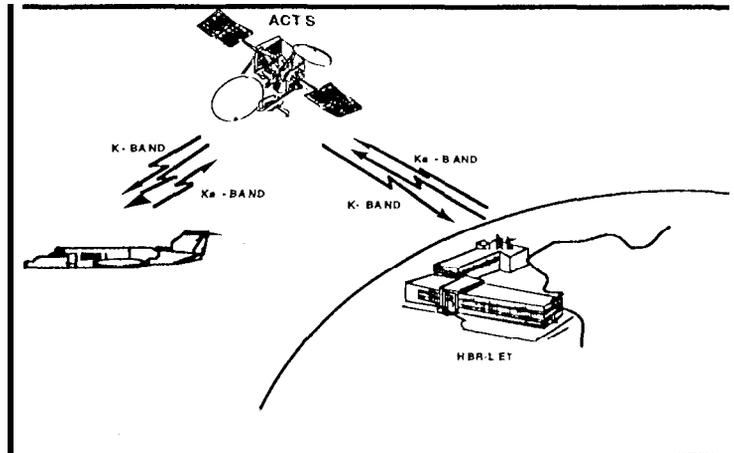


Figure 1 Aero-X Experiment Configuration.

### Steerable Phased Array Antennas

Three electronically steerable phased array antennas were used on the Aero-X experiment. Two antennas, one developed by Martin Marietta and the other by Boeing, were used to receive signals from the satellite. The receive antennas were developed under a cooperative effort between LeRC and the United States Air Force based on the Rome Labs/MILSTAR Program Office integrated circuit active phased array contracts. On the transmit side, a single antenna was developed by Texas Instruments. The specifications for the antennas are listed in Table 1. The Learjet and the Martin Marietta receive array mounted in the Learjet window is shown in Figures 2 and 3.

Table 1 Aero-X Phased Array Antenna Specifications.

| Item                             | Texas Instruments | Martin Marietta | Boeing  |
|----------------------------------|-------------------|-----------------|---------|
| Type                             | Transmit          | Receive         | Receive |
| Frequency (GHz)                  | 29.3              | 19.7            | 19.7    |
| No. Of Elements                  | 32                | 16              | 23      |
| Polarization                     | Linear            | Linear          | Linear  |
| Scanning Range w/o Grating Lobes | +/- 30°           | +/- 600         | +/- 600 |
| EIRP (dBW)                       | 23.4              |                 | -       |
| G/T (dB/K)                       | -                 | -15             | -21     |

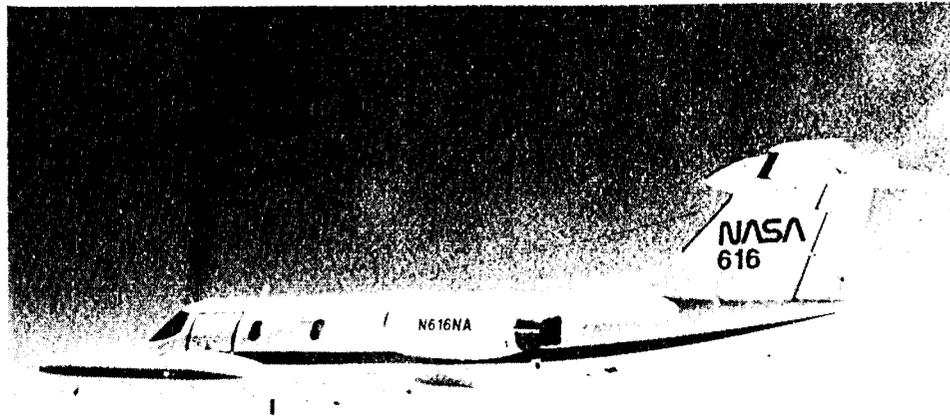


Figure 2 NASA Learjet

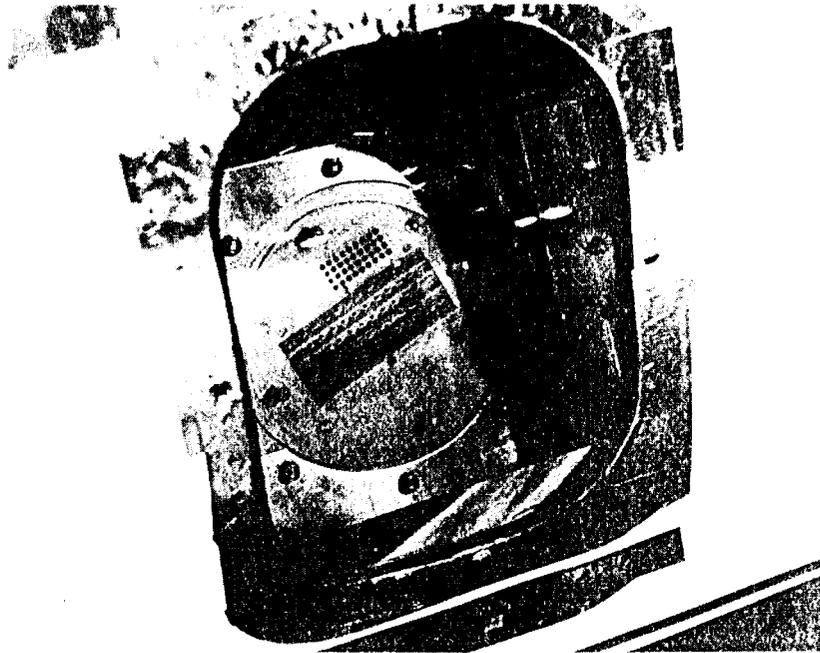


Figure 3 Martin Marietta Receive Phased Array Antenna Mounted in Learjet Window,

Each antenna was mounted just inside a passenger window. The forward windows had the receive antennas mounted to them, one receive antenna per side. The two rear windows had antenna mounting brackets for the transmit antenna. Since there was only one transmit antenna, it had to be physically moved from one side of the

plane to the other depending on the flight path. Figure 4 depicts the antenna mounting and the resultant coverage for the 60° and 120° steering capabilities. Due to the linearly polarization of the antennas and the satellite beam the antenna mounting brackets were designed to allow the antennas to be rotated at the time of installation to minimize polarization losses.

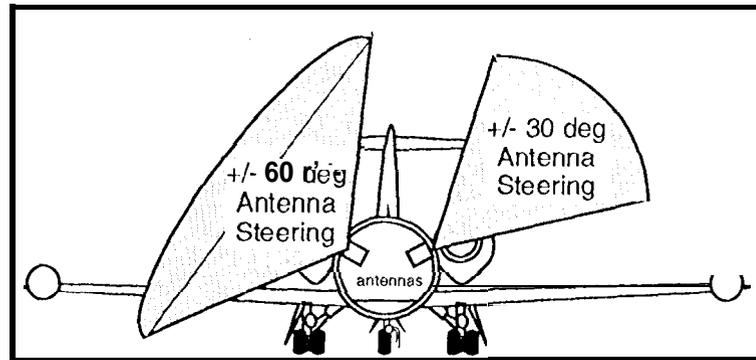


Figure 4 Aero-X Antenna Coverage.

### Antenna Controller

The antenna controller is an open loop satellite tracking system. The controller utilizes Global Positioning System (GPS) and the Learjet avionics to keep on point. The system does not use the pilot signal sent from the fixed station or any of the satellite beacons to aid in tracking the satellite. The antenna controller tracks the satellite by: 1) reading its current GPS position, 2) knowing the position of the satellite, 3) calculating a vector from its current position to the satellite, 4) adjusting for any roll, pitch, or yaw based on a reading the airplane's inertial navigation system ,

### Beam Switching Algorithm

The checkout and experimental portion of the Aero-X project involved flying a tract between Cleveland and Chicago which is covered by the West Scan Sector of ACTS. The West Scan Sector is comprised of twenty-two spot beams as shown in Figure 5. Depending on the exact flight plan, the plane would traverse across at least three spot beams on the Cleveland/Chicago tract, The ACTS satellite has the capability to switch the Cleveland fixed station feed connectivity to any of the twenty-two West Scan Sector spot beam locations, but the operator at the ACTS ground console needs to know the location of the aircraft relative to the spot beams, A laptop computer used in the aircraft was programmed to display the calculated spot beam coverages and overlay the plane's position, An experimenter in the plane could then visually see which spot beam the plane was in and which spot beam the plane was entering and inform the console operator via an HF radio to update the satellite configuration file upload it to the satellite.

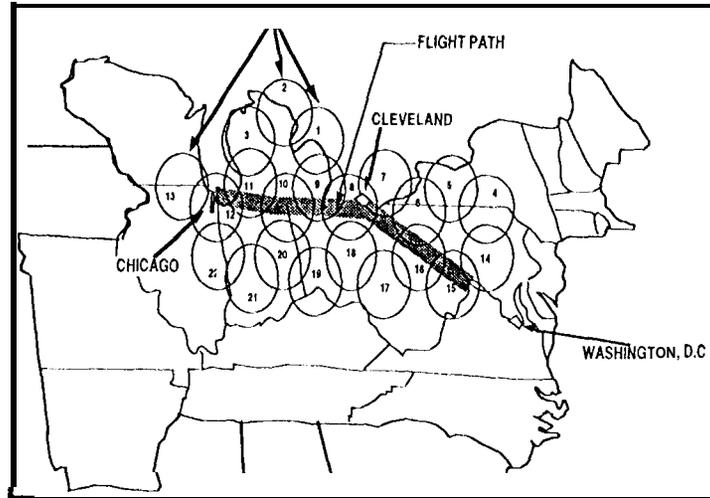
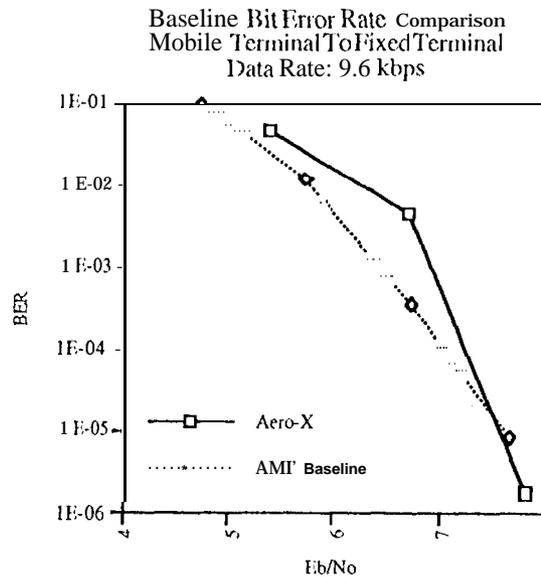
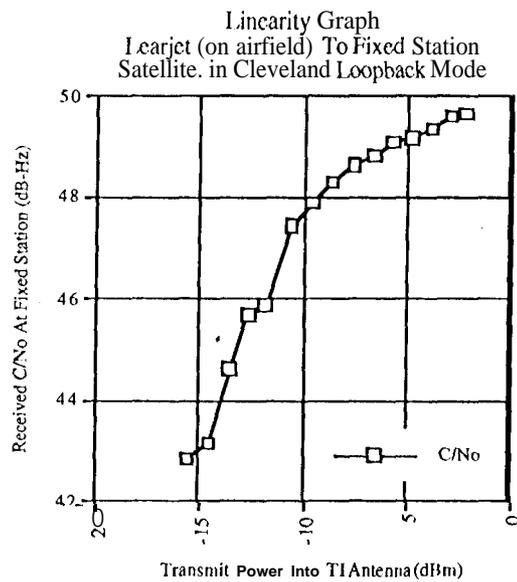


Figure 5 ACTS West Scan Sector Spotbeam Map.

### ***Experiment/Demonstration Results***

The goal of the experimental phase of the project was to checkout the system before " and during flights and to record signal quality for post flight processing and analysis. The system checkout included (th running a linearity check through the satellite and X several bit error rate (BER) tests. Because the weather during the checkouts varied from patchy clouds to heavy downpours the results have to be viewed in this light. Figure 6 shows the linearity of the return link from the Learjet parked on the runway to the fixed station in Cleveland with the satellite configured for Cleveland loopback. The weather consisted of patchy clouds and rain. Under these conditions, the maximum receive C/No at the fixed station was 49.6 dB-Hz. This return link is the critical link because the transmit power is limited by the Texas Instruments antenna, The accompanying BER curve run on the same day with the Learjet parked on the runway is shown in Figure 7. The BER results are within acceptable deviations. During these initial tests, it was noticed that the antenna controller seemed to have problems pointing correctly. Manually pointing the antenna on different occasions produced received C/No's measured at the fixed station between 53.3 and 56.4 dB-Hz. These measurements would result in a link margin of 10 dB or greater for a voice link operating at a data rate of 4.8 kbps.

No BER curves were run while in-flight. The reason is because each BER sample point requires a certain number of errors to be significant. This corresponds to the BER test running for 10 minutes for a  $10^{-3}$  point and up to 40 minutes for  $10^{-6}$  point. The aircraft traveling through the center of a spot beam will go from the 3 dB contour to boresight in 7 minutes and the resultant 3 dB change in received signal level, as can been seen in the baseline BER curves of Figure 7, changes a channel operating at a BER of  $10^{-2}$  to  $10^{-6}$ . A BER run through a such a spot beam could only provide an average BER and would not be indicative of the speech quality during that time. X X



Figures 6 & 7

Later, during the demonstrations, the Texas Instruments antenna was sent back to Dallas for repairs. During the repairs, it was discovered that the antenna pointing circuit was mis-wired. The antenna worked correctly for even offset angles but had difficulty with odd offset angles. Since the antenna was initially only tested at 10° offset intervals, the problem was not detected until late in the project. This explained the inability of the system to maintain a link in-flight if the aircraft executed roll maneuvers. Another antenna pointing problem resulted from faulty aircraft inertial navigation system information. The gyroscope, which sends pitch/roll/yaw information to the antenna controller, provided false readings if the plane maintained a long banking turn. All successful tests were done with the plane in a fixed and steady flight path.

Because the phased array antennas were mounted in the windows, a link could only be established for certain orientations of the plane. It was found that during takeoff and landings, the link would be intermittent. Polarization loss was most likely a factor, especially during steep ascents and descents,

Demonstrations were conducted in at NASA Lewis Research Center in Cleveland, the Dayton Air Show, Washington D. C., Dallas, Los Angeles, Seattle, and Baltimore. Only a few of these demonstrations were actually in-flight demonstrations. Data from the Seattle demonstration is discussed in [4]. It shows that the calculated signal strength and the actual flight data matched to within 0.5 dB. Successful in-flight demos were also held in Washington D.C. and Baltimore, the remaining locations had live demos while the plane was on the airfield.

### ***Future Implications***

The lessons learned from Aero-X are:

- 1) Antennas should be designed to allow continuous coverage during takeoff, cruising, and landing, The antennas should be circularly polarized to eliminate the problem of polarization loss. The antennas should be mounted on the top of the plane to allow a larger look angle. The phased array could be curved to allow the antenna to steer over larger angles.
- 2) The antenna controller would be more robust if pilot signal tracking was part of its algorithm.
- 3) The aircraft transmit antenna needs to support a higher transmit power to allow for better link margins and to allow for a higher data rate to support multiple users.
- 4) The airplane avionics need to be upgraded to higher quality to remove the problem of false readings during extended banking maneuvers.
- 5) In a commercial system, a method to keep a beam steered on the aircraft or beam-to-beam switching similar to cell-to-cell hand-offs in cellular telephone systems needs to be accomplished to allow constant satellite coverage,

## **Broadband Aeronautical Terminal Experiments**

### ***Technology***

The ACTS Broadband Aeronautical Terminal is designed to explore the use of K/Ka-band for high data rate aeronautical satellite communications. Currently available commercial aeronautical satellite communications systems are only capable of achieving data rates on the order of tens of kilobits per second, The broadband terminal, used in conjunction with the ACTS mechanically steerable antenna, can achieve data rates of 768 kilobits per second, while use of an ACTS spot beam antenna with this terminal will allow up to 3 megabits per second. The aeronautical terminal is being utilized to test a variety of applications that require a high data rate communications link.

A detailed description of the Broadband Aeronautical Terminal can be found in a separate article in this journal [1]. The BAT differs from the AMT terminal used in the Aero-X experiments in a number of regards which are delineated in Table 2. The reasons for developing the BAT subsequent to the Aero-X experiments were to develop a system capable of much higher data rate throughputs and more commercially viable. The key technology developed for this experimental terminal is the mechanically steerable aeronautical antenna shown in Figure 8.

| Subsystem               | Aero-X  | BAT  |
|-------------------------|---|--|
| Antenna                 | phased array; window mounted                      | mechanically steerable azimuth and elevation tracking; fuselage mounted allowing coverage of full hemisphere |
| Transmit Amplifier      | integrated into transmit array 1 Watt             | TWTA 120 Watts   |
| RF Converter            | identical   |  |
| IF Converter            | AMT version                                       | AMT version modified to perform Doppler tracking and precompensation up to 30 kHz @ 1 kHz/sec                |
| Modem                   | Differentially coherent PSK; convolutional coding | Coherent BPSK; concatenated convolutional/Reed-Solomon coding  |
| Data Source             | voice, 4,8 kbps                                   | video, voice, data; 768 kbps   |
| Data Acquisition System | modified AMT version                              | modified AMT version   |

Table 2 Comparison/Contrast of Aero-X and BAT Terminals

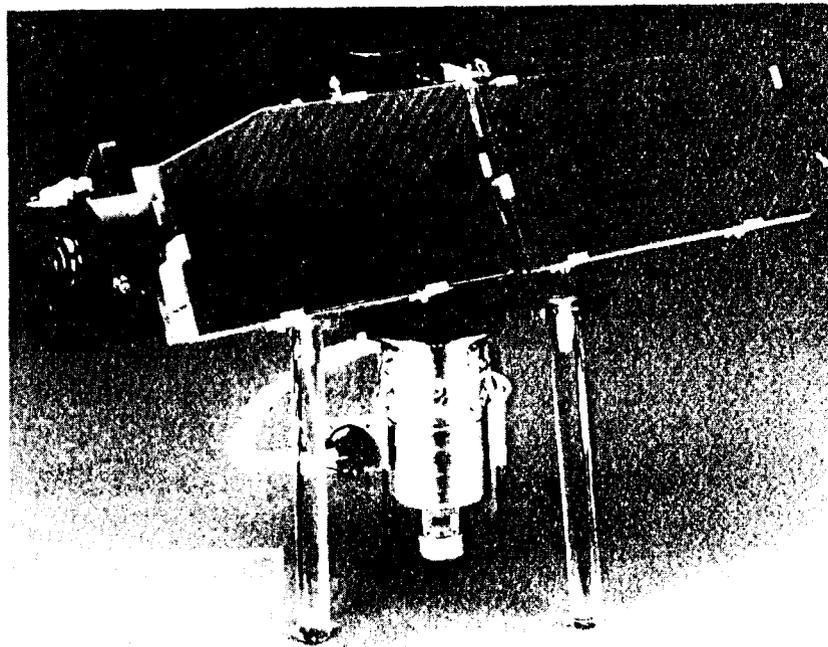


Figure 8 Mechanically Steerable BAT antenna

## ***The Use of ACTS***

Experimentation with the BAT requires ACTS to operate in the baseband processor mode, in which it behaves as a bent-pipe transponder. The ACTS LA/San Diego spot beam will be used to establish the communication link between the fixed terminal at JPL and ACTS. The ACTS one meter diameter mechanically steerable dish antenna will be used to establish the link between ACTS and the aircraft.

The use of the ACTS steerable dish distinguishes this experiment from the previous ACTS land mobile and aeronautical mobile experiments in that the previous utilized an ACTS fixed spot beam to illuminate the mobile terminal. The benefit of using the steerable antenna is that it removes the restriction that the flight path be within geographically fixed spot beam contours, allowing the aircraft to fly anywhere in the Western hemisphere. The drawback of using the ACTS steerable antenna is that it is smaller and thus has lower gain than the spot beam antennas, approximately 10 dB less on transmit and 7 dB less receive. This decrease in satellite antenna gain was in part overcome by designing a higher gain antenna on the aircraft.

Use of the ACTS steerable antenna introduces the additional complication of requiring the antenna to continuously track the aircraft. The ACTS steerable antenna has a 3 dB contour of 280 miles, which coupled with a maximum aircraft ground speed of 700 mph, results in a low dynamic tracking requirement. This tracking is accomplished by multiplexing aircraft positioning information (GPS latitude and longitude) with the data stream transmitted from the aircraft to the fixed terminal located at JPL. At the fixed terminal the positioning information is then demultiplexed and transmitted via the public switched telephone network (PSTN) to the ACTS control station, located in Cleveland Ohio, where the ACTS is then commanded to point the steerable antenna to the aircraft location.

## ***KUIPER AIRBORNE OBSERVATORY LIVE TELEVISION BROADCAST***

### **Background**

The ACTS antenna and BAT were installed on NASA's Kuiper Airborne Observatory (KAO) during the Summer of 1995. The KAO is a C-141 A jet transport aircraft which carries a 0.9-meter reflecting telescope used for infrared astronomy. Four experiments using the ACTS will be carried out from the KAO: 1) Live From the Stratosphere, a multi-media educational program 2) an educational program with the San Francisco Exploratorium, 3) remote control of the telescope and science instrumentation, and 4) telescope-system remote health monitoring and failure diagnosis. Figure 9 shows the KAO and Figure 10 shows the KAO with the antenna and its radome installed.

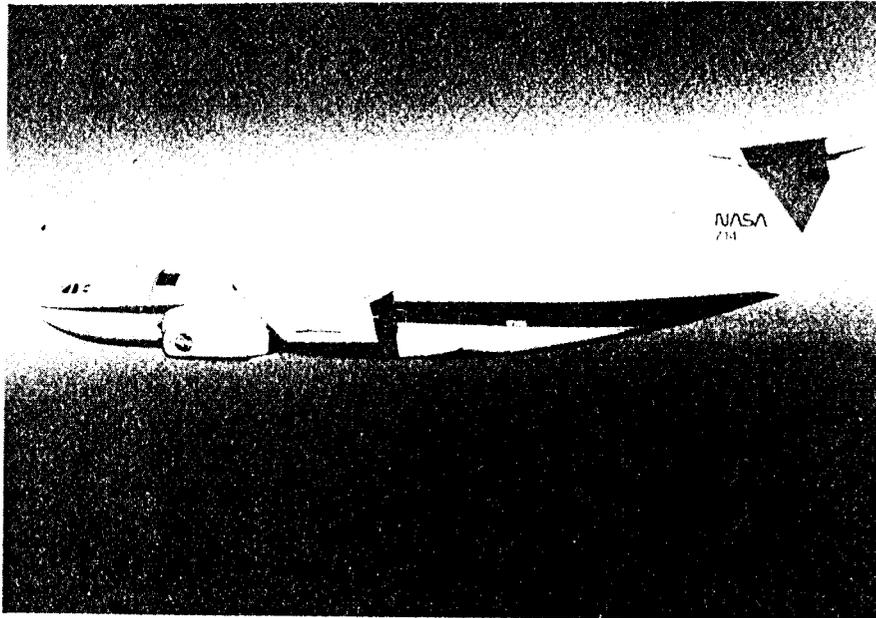


Figure 9 Kuiper Airborne Observatory (KAO) C-141

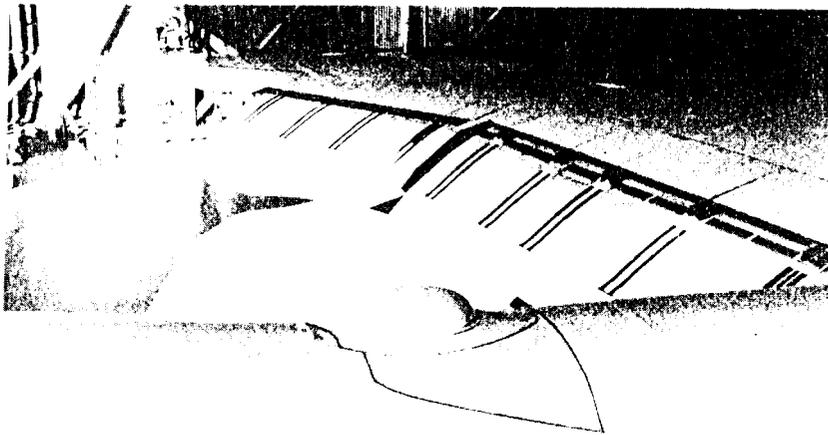


Figure 10 BAT Antenna and Radome Installed on KAO

## Experiment

The configuration for the KAO experiment is shown in Figure 11. As indicated in this figure the aircraft will be transmitting a combination of video, audio, and Internet data via ACTS to the JPL fixed station. The fixed station relays this information via terrestrial T1 line to NASA Ames where worldwide Internet connectivity is established and the audio and video are transmitted via commercial satellite to a Public Broadcasting System which will incorporate them into a live broadcast. Similar data will travel on the return path from the fixed station to the aircraft. The four components of this experiment are discussed below.

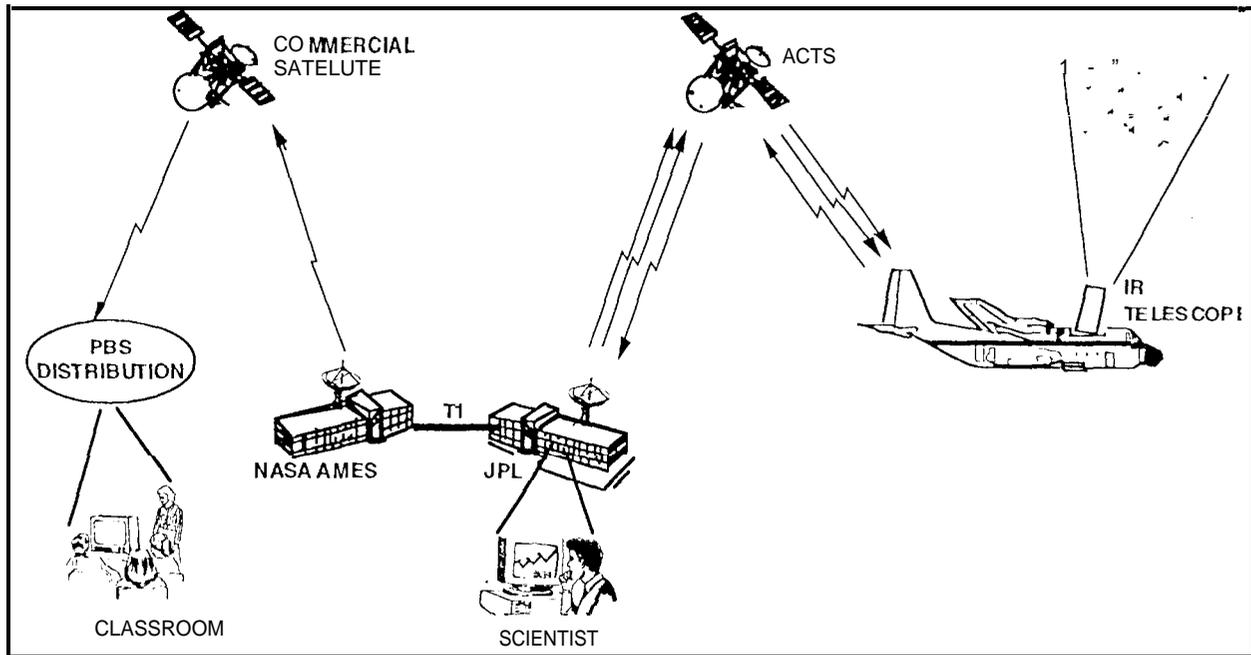


Figure 11 KAO Experiment Configuration

### *Live From the Stratosphere*

*Live From the Stratosphere* is the second of three programs in the Passport to Knowledge series, a multi-media educational project designed to take students on "electronic field trips" in which they participate in scientific research, as it's happening, from their local schools and museums. The first program in the series, *Live From Antarctica*, took place during December '94 and January '95; the third program, *Live From the Hubble Space Telescope*, is planned for the spring of 1996.

The Passport to Knowledge series seeks to integrate various communications media, such as video, print, and on-line materials, into a hands-on, interactive educational experience for teachers and students. Live From the Stratosphere activities will center on two KAO flights planned for October 12 and 13, 1995. During these flights, two-way video, audio, and data will be transmitted via ACTS between the KAO and select "uplink" sites at museums and schools around the U. S. Students and teachers will have the opportunity to interview the crew and scientists during the flights, and will

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participate in on-line activities relating to the astronomy observations carried out from the aircraft. *Live From the Stratosphere* activities will be broadcast live on PBS channels.

More information on this program can be obtained by sending an email message to: **info-lfs@quest.arc.nasa.gov**. To receive regularly updated information online, join the "updates-lfs" list by sending an email message to: **listmanager@quest.arc.nasa.gov**. In the message body, write: **subscribe updates-ifs**. You will be placed on an electronic mailing list to receive information. Information on Live From the Stratosphere can also be received by telephone at: 1-800-626-LIVE.

#### *San Francisco Exploratorium experiment*

During two KAO research flights in September 1995 communication via ACTS will be established with the Exploratorium, a science museum in San Francisco. Two teachers have been chosen to fly aboard the KAO as part of this program; they will perform "CUSeeMe" teleconferencing via Internet with participants at the Exploratorium. To prepare for the experience, students and teachers will be provided with lessons relating to airborne astronomy. During the flights, educational demonstrations relating to astronomy and to the aircraft environment will be conducted,

#### *Remote observing*

During research flights in September, and during the Live From the Stratosphere flights in October, scientists from the University of Chicago's Yerkes Observatory will demonstrate remote control of systems on the aircraft via the ACTS communications link. Planned activities include control of the data acquisition, telescope and tracker systems, transmittal of science and telescope data between the aircraft and the ground, and "CUSeeMe" teleconferencing with audio and video capability,

#### *Real-time Automated Diagnosis System (RAD)*

The RAD is a failure monitoring system that will receive data from three KAO telescope subsystems and use the data to diagnose and report system problems to an operator on the ground. Communication will be over the Internet, via the ACTS link, during normal KAO research flights in August 1995. The purpose of this experiment is to demonstrate the feasibility of using an automated diagnosis system for the airborne telescope, and to demonstrate the possibilities that the RAD may provide for monitoring and diagnosing telescope problems from the ground,

#### **Preliminary Test Flight Results**

To date the Broadband Aeronautical Terminal has been installed on the KAO C-141 aircraft shown in Figure 11. So far six flight tests have occurred and the terminal was found to perform quite well during these tests. The system was able to acquire the satellite signal prior to take-off and remain locked during take-off, cruise, and landing, maintaining a full-duplex compressed video link the entire time. Preliminary



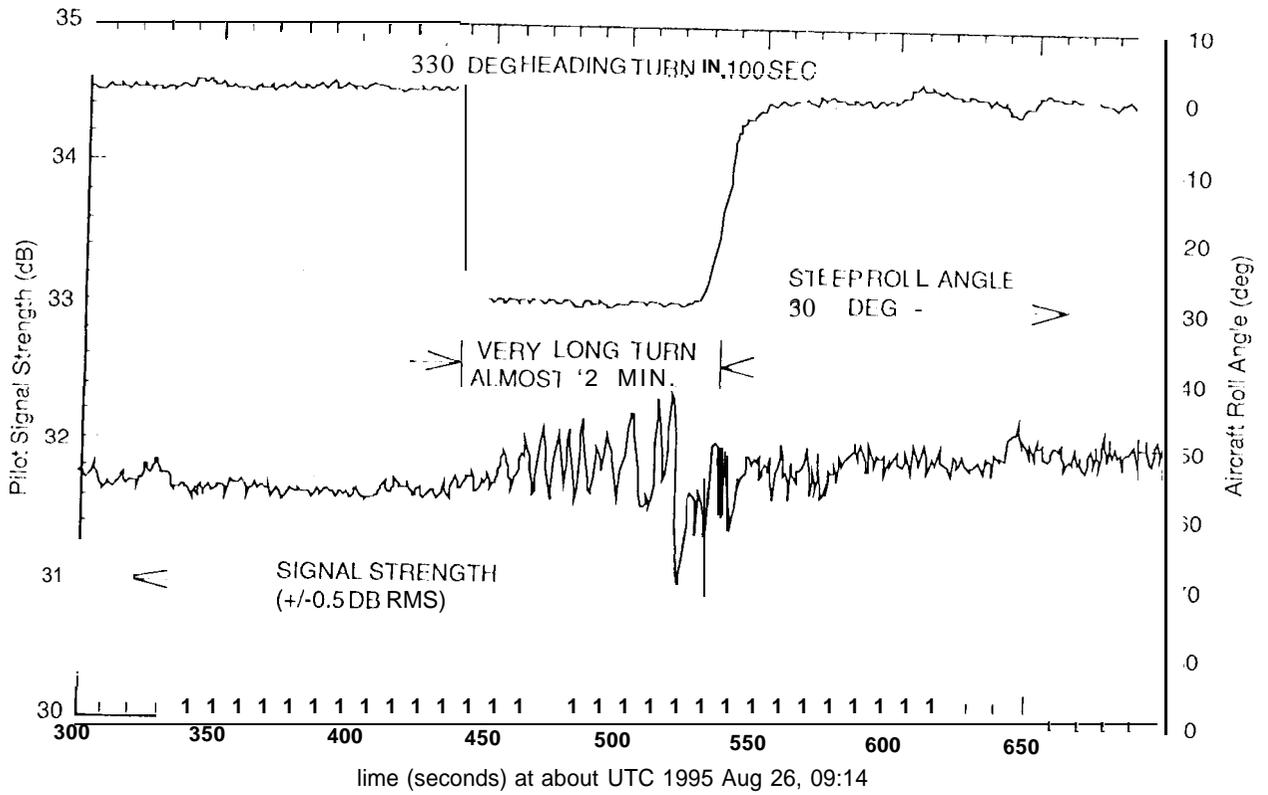


Figure 13 BAT Performance Data for KAO August 26, 1995 Flight



Figure 14 In-flight Video Transmitted from the KAO to JPL Fixed Terminal

## **Future Implications**

The experiments carried out from the KAO using ACTS will serve as proof-of-concept for development of future capabilities for airborne astronomy on the KAO or its planned successor, the Stratospheric Observatory For Infrared Astronomy (SOFIA).

Both the KAO and SOFIA projects are committed to hands-on educational programs which get teachers and students directly involved with science activities. The Live From the Stratosphere and Exploratorium experiments will demonstrate the capabilities for involving larger numbers of participants in research flights, via teleconferencing and Internet activities, than is currently possible due to seating limitations on the aircraft.

Results from the RAD experiment may be used in developing similar capabilities for the KAO or SOFIA. Development of a remote system health monitoring and diagnosis capability may allow a reduction in the number of crew members needed on board the aircraft for research flights, which is a goal for both programs.

Remote observing capabilities would open up new possibilities for scientists involved in airborne astronomy. Scientists could participate in KAO or SOFIA research flights without having to be present on the aircraft. In addition to lowering the number of people on board the aircraft, and lowering travel time and costs for the scientists, this feature would be useful to those scientists who cannot fly due to health reasons. Having immediate access to science data the aircraft may also be helpful for time-critical events, such as the Jupiter comet collisions that occurred in July 1994, or occultation events where world-wide coordination of science results in real-time may be important.

## ***ROCKWELL INTERNATIONAL AERONAUTICAL TRACKING AND HIGH DATA RATE EXPERIMENTS***

### **Background**

Rockwell International is committed to flying an ACTS experiment to characterize the high speed data performance available to/from a turbojet aircraft, and more specifically a small business jet. Additionally, the experiment will also slave the steerable satellite antenna to Global Positioning System (GPS) data uplinked from the aircraft in order that the antenna may track the aircraft course and maintain optimal link performance.

The motivation in undertaking this experiment is several fold:

- The demand for higher data rates to/from aircraft continues to climb, and presently exceeds the technical capability to provide it. Imagery downlinks constitute most of that demand.

- Government users are primarily concerned with sensor downlinks demanding wide digital bandwidth, plus the ability to upload large databases quickly.
- The commercial airline market wants significant "office-in-the-sky" bandwidth into which can be multiplexed many two-way digital signals: voice, fax, data, etc. Only limited use is foreseen for video entertainment.

As a supplier to both markets, Rockwell recognizes the potential for Ka-band service to satisfy these needs, and has undertaken an effort to establish a performance baseline to support further commercialization of Ka-band services.

## Experiment

The configuration for the Rockwell experiment is shown in Figure 15. As indicated in this figure the aircraft will be transmitting a combination of video, audio, and sensor data via ACTS to the JPL fixed station. Similar data will travel on the return path from the fixed station to the aircraft. The configuration details of this experiment are discussed below.

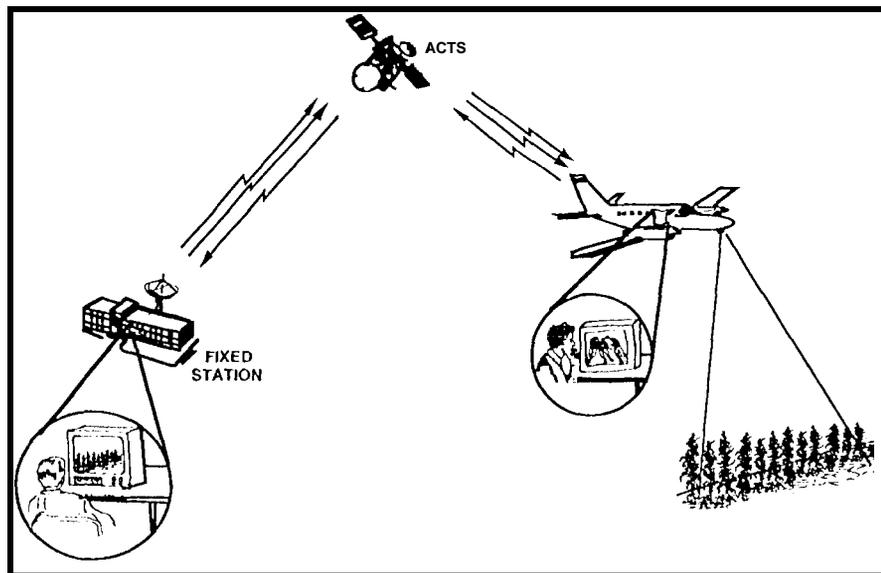


Figure 15 Rockwell Experiment Configuration

### *Experimental Equipment Configuration*

The Rockwell experiment will utilize one of the company's Sabliner jet aircraft, and more specifically the aircraft used for engineering and FAA qualification testing of various avionics. Onto this aircraft will be installed the newly developed ACTS BAT.

The aircraft antenna will be mounted on an existing reinforced port of the aircraft approximately over the wing and just slightly off centerline. The antenna was designed by to have minimal protrusion, and hence protrudes through the pressure

hull adapter into the headroom of the cabin only a few inches. Careful analysis was done by Saberliner Inc. to determine the aerodynamic impact of the radome on aircraft safety and performance, and concluded that the top speed of the aircraft may have to be reduced with the antenna mounted, Installation of the antenna was done by Saberliner Inc. in August 1995 and is shown in Figure 16.



Figure 16 Rockwell Saberliner with BAT Antenna and Radome Installed

The equipment configuration installed in the aircraft by Rockwell's Flight Applications Engineering shop includes the basic JPL BAT:

- RF converter and waveguide
- IF converter
- TWT power amplifier (30 watt version planned)
- Modem
- Video Codec (when video is used)
- Antenna control unit
- Data logger
- Test equipment

Navigation data is supplied to the antenna controller from the aircraft bus for antenna pointing, and relayed to the laptop for logging and uplinking. The equipment is mounted in a 19 inch rack pallet, which is fastened to the seat tracks in place of a passenger seat, The aircraft normally seats up to six passengers in its commercial configuration, but the experimental aircraft normally has up to four seats installed and equipment occupying the remaining space, For the ACTS test flights, further seats will be removed, allowing only three passengers plus the two flight crew members.

## *Installation Challenges*

Installation of the ACTS terminal on the small Saberliner aircraft presented a number of engineering challenges, aside from the impact of the radome on flight characteristics. The major issue was the size, weight and power of the JPL mobile terminal. Originally designed for lab and large vehicle rack mount use, the mobile ACTS terminal makes no attempt at compactness or miniaturization, instead favoring rugged construction/packaging and spread out circuitry to allow easy troubleshooting and modification. The initial equipment estimate, including the required pallet and racks, was nearly a 600 pounds and was reason to be concerned about exceeding the maximum gross' takeoff weight of the aircraft. X

After numerous discussions with JPL concerning what equipment and capabilities were required for our experimental objectives and exactly what was inside the various equipment, it was determined that we could eliminate some of the equipment and still accomplish our objectives. Specifically:

- The test equipment (spectrum analyzer, oscilloscope, power meters) could be eliminated since they were primarily used for system setup and confidence. The spectrum analyzer in particular was extremely heavy and was a great weight saving. Rockwell also identified several alternative instruments out of our test equipment inventory that could be used but with far less size and weight.
- The Data Acquisition System is the single largest piece of equipment. It was determined, after careful thought, that since its primary function was to log information of the manually-controlled ACTS terminal, that there might be an alternative to the VME chassis and touchscreen CRT subsystem. Rockwell identified a means to log the most essential data using a laptop computer equipped with the RS-232 port plus plug-in PCMCIA HPIB (receive/transmit power) and A/D interface (pilot level, analog functions) cards. Data from the modem is stored to a high capacity removable hard disk, which has sufficient capacity for the 2,5 hour flight duration of the Saberliner.

Also of concern was the power consumption, due to the relatively small power generation capacity of the twin-engine Saberliner. Approximately 1000 watts of 28 VDC power is available for experimental use (leaving safe reserve for vital aircraft flight systems). AC inverters were already available, since the aircraft is heavily used for instrumented tests, and hence we had to assure that the BAT would operate within the available power budget. Elimination of the test equipment and downsizing of the Data Acquisition System brought us within the power budget as well as the size/weight budget,

## *Flight Test Plan*

The Saberliner is scheduled to fly our test missions in two sessions: August 1995 and December 1995. The tests are deliberately split to allow testing in the humid summer weather and dry winter weather of the Midwestern United States. The broad goals of the testing are to characterize link performance as a function of aircraft motion/antenna Y

pointing as well, ambient weather conditions. This will be done at a variety of data rates. While the precipitation attenuation is a well-known and researched phenomenon on the ground, little detailed data is available on the airborne effects and hence is a primary objective of this experiment,

To characterize the precipitation conditions, data from the onboard Rockwell weather data together with NEXRAD weather radar data will be used to characterize the precipitation and humidity conditions in the path between the aircraft and satellite. The aircraft flight schedule and course will be set to obtain the desired weather conditions. Table 2 shows the planned flight testing.

The final series of tests will utilize a "live" television camera in the cockpit window downlinked to the ground via a video codec, replacing the digital test pattern used for the preceding tests. The complete data set for the flight test series will be analyzed to establish the link performance patterns and variables to guide system and equipment design for the next generation of airborne Ka-band capability.

Table 2 Rockwell Planned Flight Tests

| Weather    | Data Rate (kbps) |     |     |     |     |
|------------|------------------|-----|-----|-----|-----|
|            | 64               | 128 | 256 | 384 | 512 |
| Clear      |                  |     |     |     |     |
| Cloudy     |                  |     |     |     |     |
| Rain       |                  |     |     |     |     |
| Heavy Rain |                  |     |     |     |     |
| Pitch/roll |                  |     |     |     |     |

### Preliminary Test Flight Results

To date the Broadband Aeronautical Terminal has been installed on the Saberliner aircraft shown in Figure 16, To date four flight tests have occurred and the terminal was found to perform quite well during these tests. The system was able to acquire the satellite signal prior to take-off and remain locked during take-off, cruise, and landing, maintaining a full-duplex data link the entire time. During these initial that used a 10 W TWTA and the ACTS steerable antenna in a fixed point mode, full duplex links of 64 kbps were established between the Saberliner flying in the Iowa/Nebraska/South Dakota area and the fixed terminal at JPL. Good signal-to-noise ratios were maintained for a variety of aircraft maneuvers and varying weather conditions, Further Saberliner tests will be conducted in which the satellite antenna is in the tracking mode and with a higher power TWTA in the aircraft to permit higher data rates.

# **WILDFIRE RESEARCH AND DISASTER ASSESSMENT USING THE ACTS**

## **Background**

The proposed Advanced Communications Technology Satellite (ACTS) Experiment on Wildfire Research and Assessment builds upon 1) NASA Ames experience in wildfire and urban fire assessment, 2) the Ames' aircraft platforms for remote sensor and in situ measurement instruments, 3) Ames' long tradition in satellite communications experiments, and 4) JPL's resources and expertise in the field of mobile and personal satellite communications. A general account of satellite communications provisions for the NASA Ames instrumented earth science aircraft platforms (including the proposed ACTS experiment) is given in [5]. The following discusses a) the background on wildfires, b) justification for wildfire research, c) the need for further investigations of wildfire management and assessment, and d) remote area satellite communications via the ACTS,

## ***Wildfire Research***

Globally, wildfires recur annually over vast areas of savanna. In the Llanos of Orinoco, Venezuela, individual fires have spread over 8,000,000 hectares; and in the Brazilian Cerrado, over 200 million acres burns at an interval of one to four years. These large fires in rural areas destroy many homes, disrupt commerce, and close down airports due to heavy smoke. In the United States, over 130,000 wildland fires occur each year. The consequences of wildfires are devastating: from the generation of greenhouse gases and atmospheric pollution to destruction of homes, ecosystems, and lives.

Globally, 8680 Teragrams (-1 million tons) of dry biomass are burned per year, mostly due to human activity; this produces 3500 Tg Carbon in the form of CO<sub>2</sub> (40% of the total). Since 1980, CO<sub>2</sub> emissions from fossil fuel combustion have leveled off, but the CO<sub>2</sub> atmospheric concentration data measured at Mauna Loa has kept rising - biomass burning is suspected as a possible cause [6].

Fires have been shown to contribute to climate change and to loss of species and biodiversity [7]. Research has shown that fires produce greenhouse gases, tropospheric ozone, and massive amounts of aerosols - all affecting the climate and ecosystem health. Remote sensing and in situ measurements and data analyses of wildfire activity can lead to a better understanding of wildfires in chaparral biomes; hopefully, this will improve assessments of regional impacts, as well as possible global effects on atmospheric trace gases and ozone.

## ***Wildfire Management and Assessment***

Perhaps 2 million years ago man overcame the natural fear common to all primates and other animals and learned to make use of fire. Today, since wildfire frequency and intensity are inversely related, prescribed burning is one of the methods used in fire management; yet each year, in spite of precautions, many wildfires become out-of-control. The disaster assessment and management goal of the

proposed experiment is to serve as a demonstration of satellite communications applied to the needs of a wildfire campaign. We have proposed to work with the Office of Emergency Services (OES), the Federal/State Incident Command Centers (ICCs), the Federal Emergency Management Administration (FEMA), the California Department of Forestry (CDF), and other local resource agencies to demonstrate the utility of rapid movement of data to all agencies involved in disaster management.

Special coordination planning for the proposed experiment will be with the OASIS project initiated by the California Office of Emergency Services, OASIS refers to Operational Area Satellite Information System for mutual aid and coordination between cities and counties within the operational area; VSAT type communications currently provide all interconnection of cooperating emergency service entities to the OASIS, and to each other.

The experience gained from merging remote sensing and mobile satellite communications used in the management and assessment phase of the prescribed burn experiment can lead to their application in real-life wildfire situations. Also, the experience gained from this proposed experiment will, hopefully, contribute to a more effective long-term policy of wildfire management, and to improved coordination procedures in more general emergency situations such as hurricanes, floods, volcano eruptions, and oil spills.

## **Experiment**

The fire research and assessment activity will take place during a prescribed burn at a Southern California chaparral type ecosystem. Measurements will include:

- o Remote Sensing imagery - satellite: Advanced Very High Resolution Radiometer (AVHRR), aircraft: Airborne Infrared Disaster Assessment System (AIRDAS)
- o Aircraft Sun Photometer - radiance, optical depth
- o Sample Analysis - trace gases, smoke particles, ozone
- o Fire Character - flame and soil temperatures, total energy release rate

These measurements will be used to calibrate the remote sensing data, to determine emission factors and combustion efficiencies, and to determine the general relationship between the extent of biomass burning and concentrations of trace gases, smoke particles, and tropospheric ozone. The results for the flaming and smoldering phases of the prescribed burn will be compared,

The image data uplinks from the prescribed burn site will be relayed by the ACTS to researchers and disaster assessment managers at agency sites and to the on-the-scene Emergency Command Center as shown in Figure 17. This "telepresence" can enable experts at the U.S. Forest Service, FEMA, OES, and the California Department of Forestry to direct and/or monitor various phases of the activities at the remote prescribed-fire site.

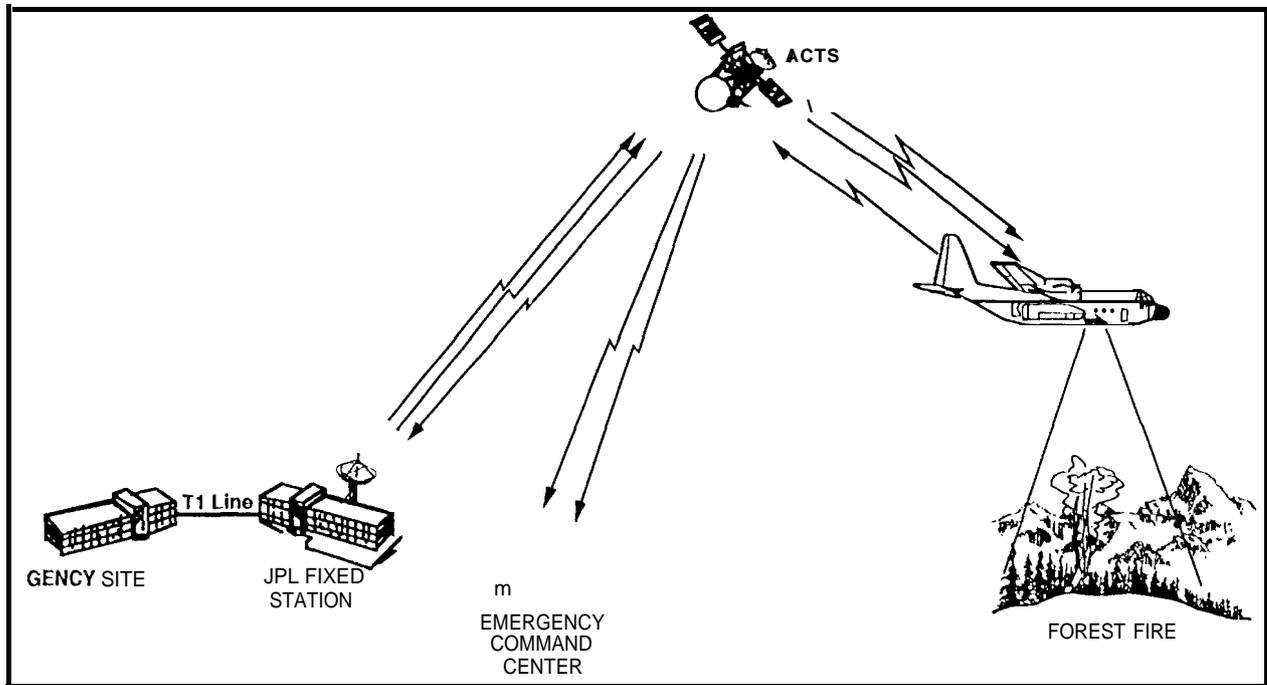


Figure 17 Wildfire Management Experimental Configuration

Image data will be sent in “raw form” to OES, FEMA, and CDF for initial assessment. The image data will also be sent in “processed form”, i.e. overlaid onto ancillary data sets, to more fully inform the manager of the disaster situation. The communications supporting the **fire experiment will contain both commercial and ACTS links**, Commercial aircraft radio, cellular radiotelephony, and GPS position location are anticipated.

User acceptability of path delay effects will be compared for terrestrial and satellite systems. General user acceptability and operational effectiveness to be gained from the real-time communications will be evaluated for the scientific wildfire research activities, for the wildfire disaster management/assessment activities, and for the more general emergency preparedness involving OASIS.

### **Future Experiments**

There are currently plans to fly a number of ACTS aeronautical experiments in the future. These plans include an experiment with Vigyan, Inc. to transmit real-time graphical map information to the cockpit of an aircraft in flight. Additional experiments being discussed involve aeronautical remote sensing applications for fixed wing and rotary wing aircraft, and military aircraft applications,

### **Commercial System Considerations**

A key element of the ACTS program is an effort to work with U.S. industry to keep them apprised of lessons learned from ACTS experimentation, future plans, and solicit feedback and comments. As part of this effort an Aeronautical Mobile SATCOM Focus

Group Meeting was held at JPL in April 1994 and a second gathering was held at the International Mobile Satellite Conference (IMSC) in June 1995. At these meetings were representatives from a wide range of industry concerns including the airlines, communications companies, avionics manufacturers, antenna manufactures, satellite communications companies, and government agencies. After the meetings all indications were that the interchange was beneficial to all involved. For purposes of this paper some of the key points relating to a potential commercial broadband aeronautical satellite communications system are highlighted below.

### ***Potential Demand for a Broadband Aeronautical System***

There is demand for real-time such as sporting events (super bowl), news (state of the union address) and prime time television for example; and 768 kbps provides acceptable video quality because aircraft screens are low resolution in general so the image quality is not of prime importance. The transmission of movies to an aircraft is not practical for a number of reasons (timing of movies, required editing of movies for presentation to a general audience) a real-time broadband aeronautical system that transmitted video to an aircraft would supplement existing on board movie delivery. Additionally, passengers want the "office-in-the-sky", which **will allow them to operate** on the airplane as if they were back in the office with voice, send and receive fax, laptop connectivity, etc. in every seat, Other off-the-wall applications that can not even be dreamt of today will present themselves in the future.

Though there are 7000 commercial airplanes world wide that this system could fly on it should be noted that 40-50% of passengers on an aircraft want to sleep and some percentage of the others want to read and do other things. A commercial broadband aeronautical system will provide services that can be used as a marketing ploy by the airlines to attract customers and hopefully it will also be money making on its own, In addition to commercial applications there will be a large demand for broadband aeronautical services in the military,

### ***Requirements for a Broadband Aeronautical System***

A commercial Broadband Aeronautical System must be international in flavor and the objective should be to provide a high speed "pipe" to the airplane and let the market place determine what goes into the pipe. A commercial system should ensure that the service is available while the airplane is at the gate or still on the ground. Such a system need not include a dedicated satellite system for aircraft, individual transponders on multipurpose satellites could be utilized. In addition, there are too many antennas and too many different types of nonstandard equipment proliferating on the aircraft, emphasis should be placed on standardization of equipment.

### ***Barriers to a Broadband Aeronautical System***

There are barriers that slow the realization of aeronautical SATCOM. These barriers exist in addition to the technological issues. These barriers include: 1 ) standards/coordination meetings and their associated delays which are part of the

implementation/approval process; 2) economic viability for a system that could potentially be very costly; 3) spectrum availability and the requisite allocation, (the required spectrum would be significant for a broadband system); 4) critical weight and space requirements of new equipment.

**The cost issue and the associated** return on investment for any commercial system are of prime importance and can not be overly emphasized. An example of a case where cost concerns were a major driver over technology novelty was in the selection of a mechanically steerable aeronautical antenna for the Sky Radio system rather than a cost prohibitive phased array antenna. In addition to the system cost there are expenses for installation, maintenance, network and operations management (billing, etc.), and replacement cost of equipment (aeronautical equipment has proven to have a high rate of change).

### ***Planned K/Ka-Band Satellite Systems***

Planned commercial satellite systems with which the equipment described in this paper could be utilized include the K/Ka-band systems proposed by Hughes (Spaceway), Teledisic, and Loral (Cyberstar) and potentially others. A total of eleven companies have filed with the FCC to provide commercial satellite services at Ka-band and if the few systems that are ultimately fielded are designed robustly they will be able to provide aeronautical as well as fixed "bandwidth-on-demand" services.

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