

Flight Test of ARINC 741 Configuration Low Gain SATCOM System on Boeing 747-400 Aircraft

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ABSTRACT

On May 23, 1989 The Boeing Company conducted a flight test of a SATCOM system similar to the ARINC 741 configuration on a production model 747-400. A flight plan was specifically designed to test the system over a variety of satellite elevations and aircraft attitudes as well as over land and sea. Interface bit errors, signal quality and aircraft position and navigational inputs were all recorded as a function of time. Special aircraft maneuvers were performed to demonstrate the potential for shadowing by the aircraft structures. During the flight test, messages were routed via a Ground Earth Station in Santa Paula, California to Collins Radio in Cedar Rapids, Iowa. These messages were also monitored by ARINC in Annapolis, Maryland through the ACARS ARINC network.

On May 20, 1989, a compass rose test was performed in preparation for a flight test. Both the compass rose test and the flight test indicated that shadowing from the tail is insignificant for the 747-400. However, satellite elevation angles below the aircraft horizon during banking maneuvers were shown to have a significantly deleterious effect on SATCOM communications.

BACKGROUND

Satellite communications will undoubtedly play an important role in future civil aeronautical operations. Presently HF communications (2-30 MHz) provides the communications link when the aircraft is beyond line of sight with VHF. HF provides SSB analog voice communications using ionospheric propagation. The FAA as well as other aviation regulatory bodies recognizes the superior reliability of SATCOM over HF with its propagation vagaries. Used wisely, satellite communications technology will enable more

efficient utilization of the higher traffic density airline routes in both the Pacific and Atlantic Ocean regions.

Cognizant of the potential benefits of this technology, Boeing Commercial Airplane Group has been involved in the development of aeronautical satellite communications systems for over two decades. In more recent times Boeing has been an active participant in the industry regulatory activities associated with satellite communications. It is truly exciting that the introduction of a standard, full time, commercially available satellite communications service is imminent. As an airframe manufacturer, Boeing will be a system integrator, responsible for integrating and testing all the avionics components and finally certifying and delivering complete systems.

On May 20, 1989, in preparation for a flight test, Boeing conducted a compass rose test of the SATCOM system. This test verified that the system wiring was complete and functional as well as verifying that the installed equipment was operational.

On May 23, 1989, Boeing Avionics Engineering conducted a flight test of a SATCOM system similar to the ARINC 741 configuration¹ on a production model 747-400. This flight test was conducted using developmental engineering units as a step in design validation. Due to the nature of the aircraft and the avionics equipment, the test instrumentation was minimal. Hence the recorded performance parameters are not easily related to standard performance measures such as signal to noise ratios or physical quantities such as power. However, some qualitative observations can be made from this flight test data.

TEST DESCRIPTION

A communications link was established between the 747-400 at Paine Field, Washington and the COMSAT earth station at Santa Paula, California. The modulation used was ABPSK (Aviation BPSK) at a rate of 600 bits per second with rate one half Forward Error Correction coding (as described in the ARINC 741 characteristic). The Ground Earth Station (GES) equipment was controlled from a Collins site via a conventional telephone modem link to the Santa Paula station. Collins personnel on the ground in Cedar Rapids were able to view text messages received from the aircraft as well as compose text messages and uplink them to the aircraft. Hence, two way link operation was verified.

The aircraft was instrumented to record a number of forward link performance parameters over time throughout the flight. The data recorded were: aircraft latitude, longitude, heading and attitude (pitch and roll). In addition to these parameters, data provided by the Collins engineering Satellite Data Unit (SDU) were recorded: signal quality and bit errors. The signal quality indication is a relative measure of signal strength. The value is an indication of I^2 plus Q^2 as measured by the demodulator. The bit errors indication received from the SDU reported the number of (channel) bit errors detected in the 6 most recent Signal Units (or 1152 channel bits). The data collected were post processed to evaluate the effects of aircraft attitude and shadowing by aircraft structure on system performance. The aircraft position and attitude data were used to transform the satellite azimuth and elevation into the aircraft coordinate reference frame.

No return link performance parameters were recorded. In fact, very little information as to the performance of the return link was available to the flight test crew. On the forward link there is a p-channel which was monitored continuously. On the return link, the aircraft transmitted only when a text message was composed and sent. There was an acknowledgment on the control panel in the aircraft when a message had been received at the GES.

The satellite used in this test was the INMARSAT Pacific Ocean Region satellite, positioned at approximately E 180°. The GES function was performed by experimental equipment installed by Collins at the COMSAT station in Santa Paula, California.

EQUIPMENT CONFIGURATION

Figure 1 shows a block diagram of the SATCOM avionics as configured on the Boeing 747-400 aircraft. This configuration represents the low gain portion of the standard installation offered by Boeing for the 747-400 at the time of this flight test. The low gain SATCOM system design parameters are (from the ARINC 741 characteristic) a receive G/T ≥ -26 dB/K and a minimum transmit EIRP of 13.5 dBW. The low gain antenna is a quadrifilar helix intended to provide omnidirectional azimuth coverage from zenith down to 5° elevation angles. The antenna is housed under an aerodynamically shaped radome which is less than 6 inches high. The design goal is to achieve a minimum of 0 dBic gain for 85% of the coverage volume defined from zenith to 5° elevation angles. The low gain SATCOM system installed on the 747-400 is believed to have had a receive G/T of -24.3 dB/K (assuming a 0 dBi aircraft antenna). The transmit EIRP is believed to have just met the minimum required, 13.5 dBW.

Figure 2 shows the SATCOM provisions as offered by Boeing at the time of this engineering test. The low gain antenna is located on top centerline at body station 650 (see figure 2). Since the low gain antenna is mounted on the top of the upper deck, only the tail fin extends above the horizon as seen by the antenna. Hence the tail fin may block the direct line of sight to the satellite for some aircraft attitudes, and bearings.

COMPASS ROSE TEST

The 747-400 aircraft was positioned on a compass rose at Paine Field Washington (latitude N 47°54.1", longitude W 122°17.1"). The nominal elevation to the satellite at this location is 12.5°. The aircraft was towed in a circle with stops being made at approximately 10 degree increments in order to record the bit error rate and signal quality at each azimuth position. The signal quality and bit error indications were recorded manually from the DLC-800 controller for several seconds at each azimuth position.

Figure 3 shows the data collected during the compass rose test. The radial axis is in units of average signal quality. The angle reference is the bearing to the satellite in the aircraft reference frame. Care was taken to position the aircraft such that the tail was directly in line with the satellite. The nominal elevation was such that line of sight to the satellite was not actually

blocked and no airframe effects were evident in the data recorded.

FLIGHT TEST

Figure 4 shows the flight path chosen for the test. The flight path was designed specifically to test the system over sea and a variety of land terrain. The Pacific Northwest is at the edge of coverage for the Pacific Ocean Region INMARSAT and therefore offers an excellent opportunity to evaluate the system at its performance limits and beyond. Special maneuvers were performed at three locations, Sedar Waypoint, Moses Lake, Washington and Glasgow, Montana in order to test the satellite link at a variety of satellite bearings and elevations in three different basic multipath environments.

Near Glasgow, the aircraft adopted a heading specifically chosen to move the tail into the line of sight to the satellite. The test crew were unable to detect any harmful effects on the link performance due to tail shadowing. Also, the recorded flight data does not reflect any degradation in the link due to tail shadowing.

Figure 5 shows the elevation of the satellite, the signal quality and the bit errors recorded over a period of time spanning about half an hour. This data represents the flight maneuvers conducted over Glasgow Montana (latitude N 48'13", longitude W 106'37"). Glasgow represents the most extreme nominal operating environment included in the test with a nominal elevation to the satellite of $\approx 2.3^\circ$. During the orbiting maneuver, from the aircraft reference frame the satellite dipped to more than 22° below the horizon. During this extreme condition, the receiver indicated a high number of channel bit errors, messages were not received by the aircraft and messages transmitted from the aircraft were not received at the GES. However, during level flight in the vicinity, with a nominal elevation to the satellite of $\approx 4^\circ$ (in the aircraft reference frame) messages were transmitted and received successfully.

Figure 6 shows the elevation of the satellite, the signal quality and the bit errors recorded over a period of time spanning the flight maneuvers conducted at the Sedar Waypoint (latitude N 45°30.5', longitude W 126°43.0') which is off the west coast of the state of Oregon. This geometry results in multipath from the sea for all azimuth directions. The

nominal elevation to the satellite in an 'earth normal' reference frame at this location is 16.4° . It can be seen from figure 6 that the system continued to operate with a low number of bit errors when the satellite was below the aircraft reference frame horizon (as much as 10°). However, as would be expected, at some very low elevation angles, (greater than 12° below the horizon), the receiver lost lock and a high number of bit errors is indicated.

Figure 7 shows the average signal quality level and bit errors as a function of the elevation of the satellite relative to the aircraft antenna reference frame. This function was produced by averaging the data taken over the time period illustrated in figure 6.

Figure 8 shows data taken during the maneuvers conducted over Moses Lake (latitude N 47°12.7', longitude W 119°18.9') approximately in the center of the state of Washington.. Again it can be seen that the system continued to operate when the satellite was several degrees below 0° elevation relative to the aircraft antenna reference frame.

Figure 9 shows the average signal quality level and bit errors as a function of the elevation of the satellite relative to the aircraft antenna reference frame for the time period illustrated in figure 8.

CONCLUSIONS

This was a successful engineering flight test of an ARINC 741 type low data rate SATCOM system aboard a 747-400. Two way link operation was demonstrated under a variety of operating conditions. In general the SATCOM system performed far better than expected at low satellite elevation angles. There were instances where the communication link failed during banking maneuvers resulting in very low elevation angles and shadowing by aircraft structures. Furthermore, it was found that tail shadowing does not appear to be significant for the 747-400 SATCOM system.

REFERENCE

- 1 ARINC Characteristic 741 "Aviation Satellite Communication System", Aeronautical Radio, Inc.

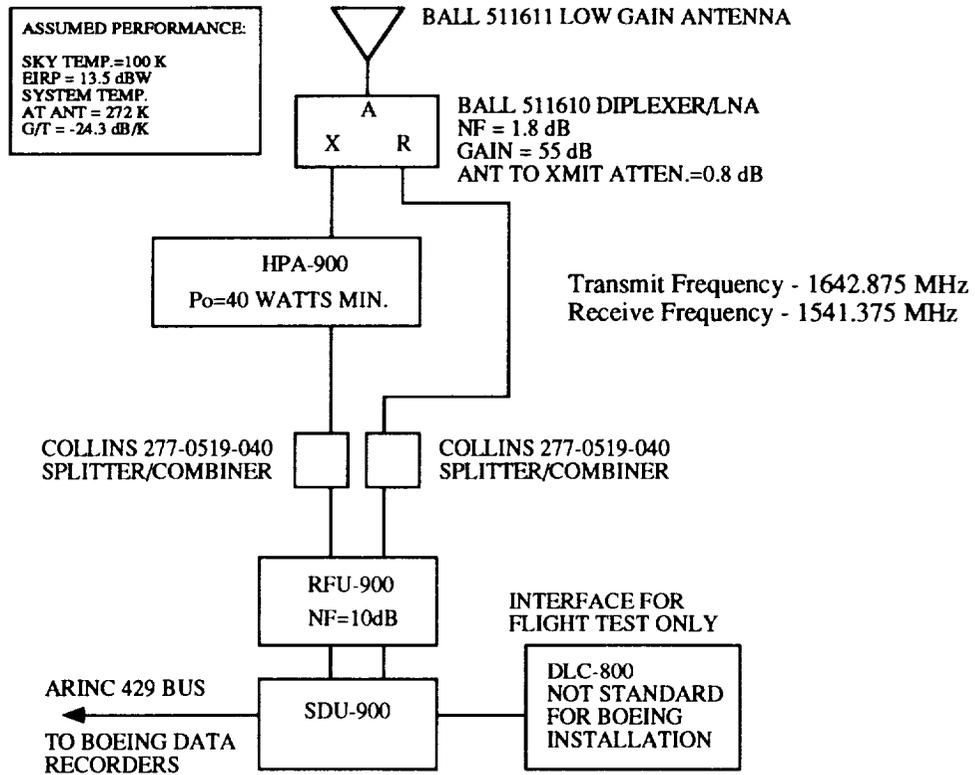


Fig. 1. Block Diagram of Low Gain Aeronautical Earth Station

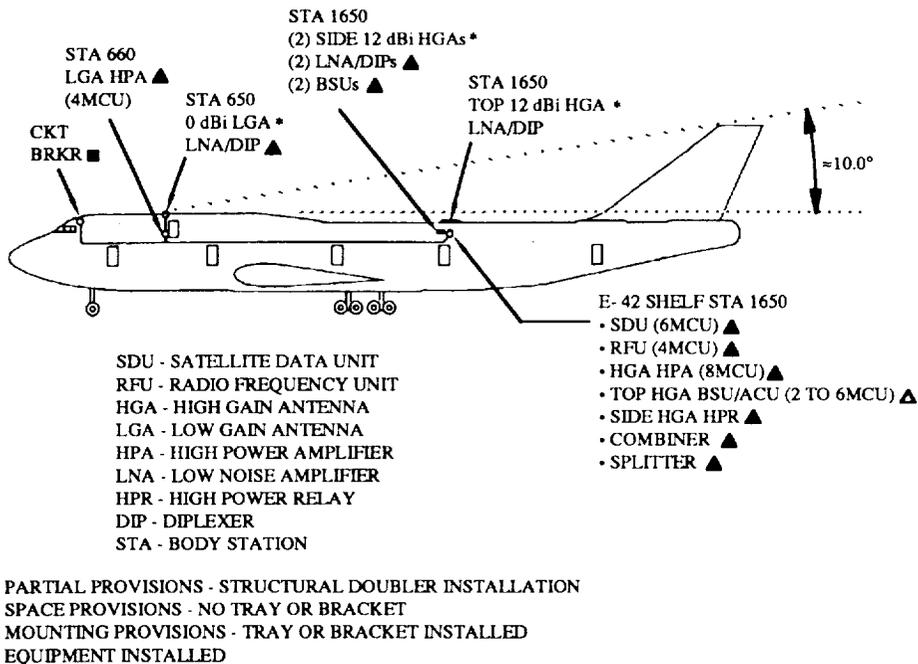


Fig. 2. Standard Boeing SATCOM Installation Provisions as of 9/89.

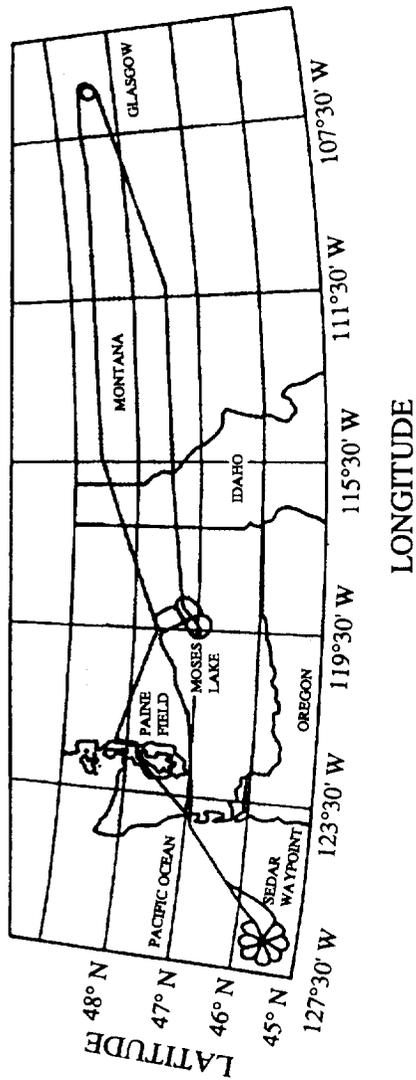


Fig. 4. SATCOM Test Flight Path

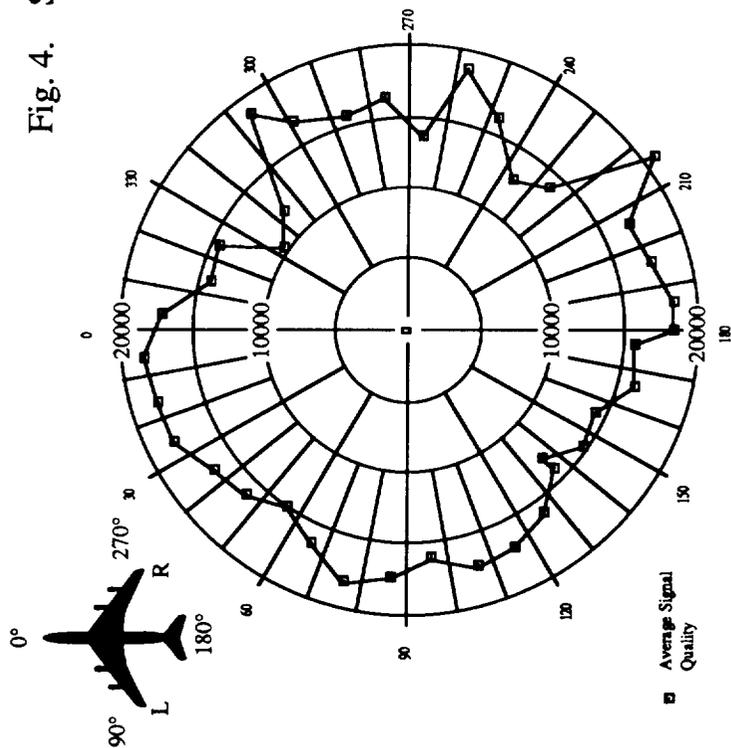


Fig. 3. Signal Quality Data From Compass Rose Test

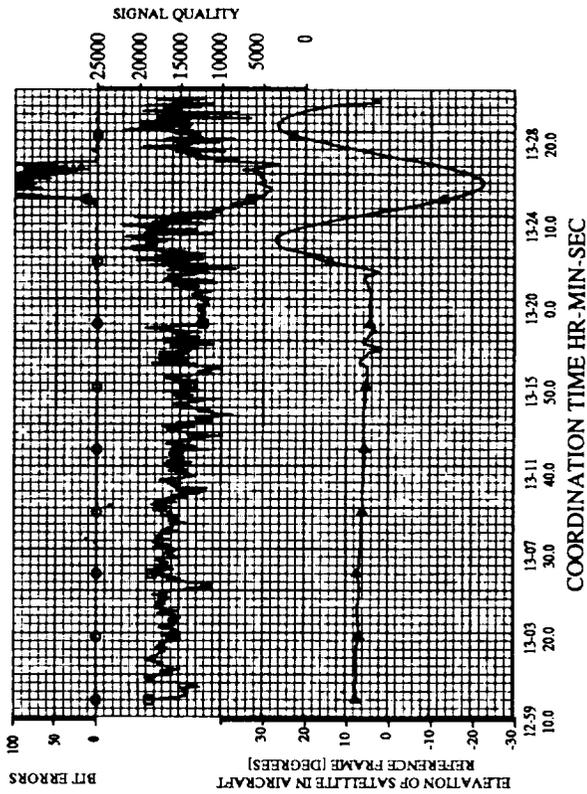


Fig. 5. Flight Test Data For Glasgow Maneuvers

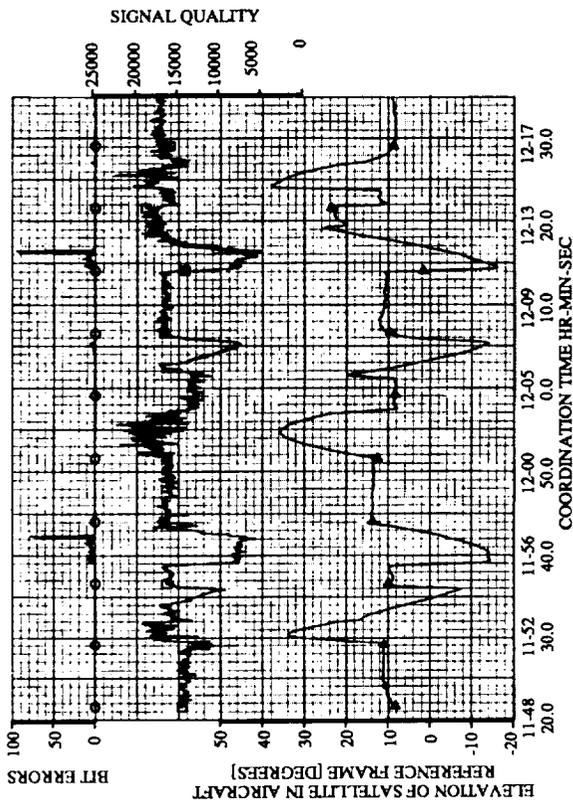


Fig. 8. Flight Test Data For Moses Lake Maneuvers

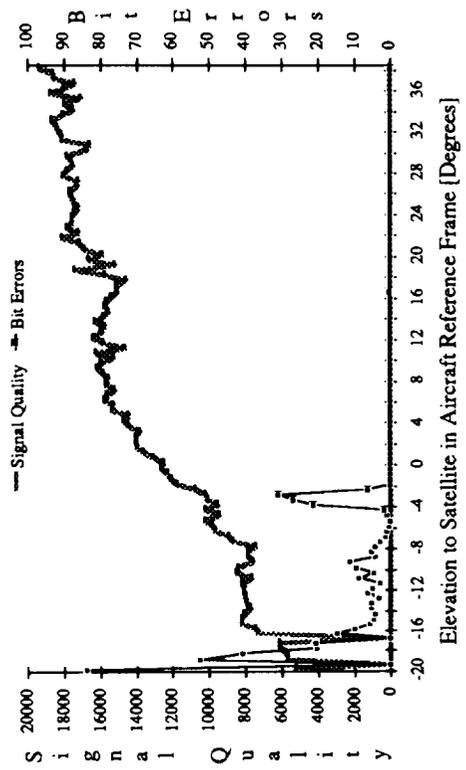


Fig. 9. Flight Test Data For Moses Lake Maneuvers

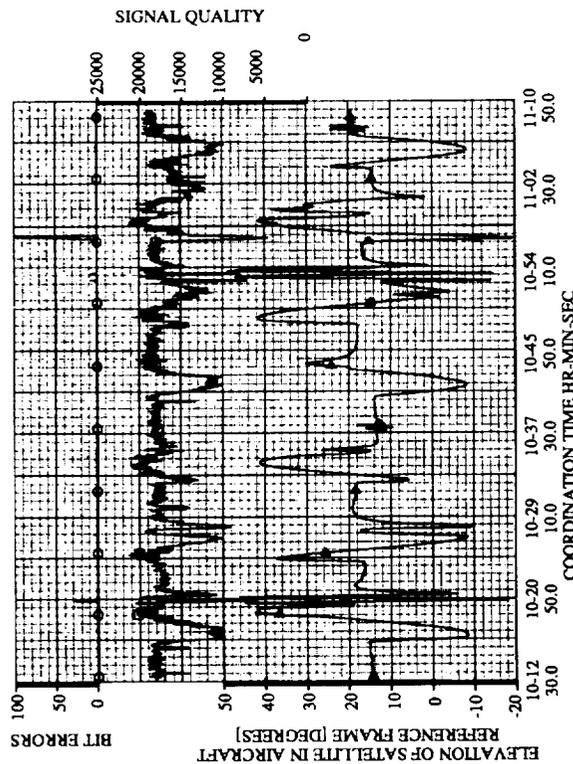


Fig. 6. Flight Test Data For Sedar Waypoint Maneuvers

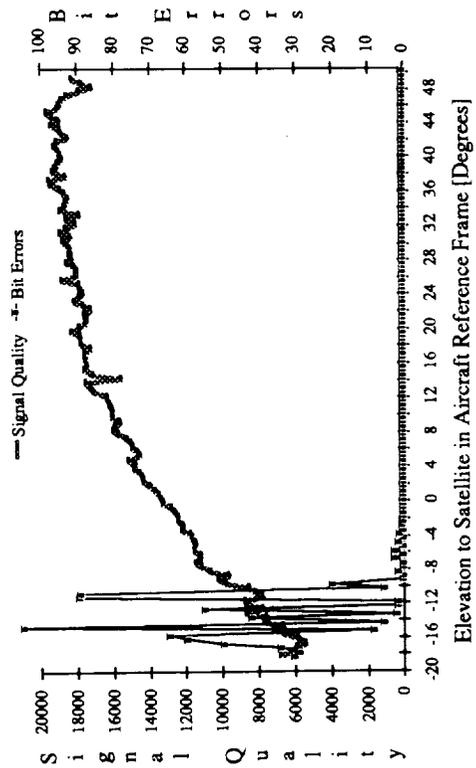


Fig. 7. Flight Test Data For Sedar Waypoint Maneuvers