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ASDAR (AIRCRAFT TO SATELLITE DATA RELAY) FLIGHT TEST REPORT

by Edward J. Domino, Robert R. Lovell,
Martin J. Conroy, and David H. Culp
Lewis Research Center
Cleveland, Ohio 44135
August 1977

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16. Abstract

The Aircraft to Satellite Data Relay (ASDAR) is an airborne data collection system that gathers meteorological data from existing aircraft instrumentation and relays it to ground users via a geo-synchronous meteorological satellite. This paper presents a brief description of the system, and the results of the first test flight on a commercial Boeing 747 aircraft. The flight test was successful and verified system performance in the anticipated environment. No problems were encountered and Federal Aviation Administration (FAA) certification was obtained.

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E-9311

SUMMARY

The objective of the Aircraft to Satellite Data Relay (ASDAR) project is to provide a low cost prototype data handling system to transmit meteorological data from wide body jet aircraft to ground users via synchronous meteorological data relay satellites. The ASDAR system was developed by the NASA Lewis Research Center, and managed by the NASA Goddard Space Flight Center for the National Oceanic and Atmospheric Administration. After an extensive in-house test program, the ASDAR package, aboard a Pan American Airways (PAA) B-747 aircraft left New York City on a test flight over the U.S. East Coast and adjacent Atlantic Ocean. During the test flight, extensive interference testing was performed to determine any detrimental affects ASDAR might have on the B-747 electrical and radio frequency systems. No detrimental effects were found.

Some interference from ground based mobile units was experienced by the ASDAR receiver, but these were minimal with no impact on overall system operation. The test flight has been considered a success and the ASDAR system is now considered operational. Pan American Airways, acting under contract to NASA, has received Federal Aviation Administration (FAA) certification on a B-747 and will continue to carry the ASDAR package for a test and evaluation period of one year.

INTRODUCTION

The United States has been deeply involved in the Global Atmospheric Research Program (GARP) and has assumed responsibility for certain activities which are being coordinated by the National Oceanic and Atmospheric Administration (NOAA). One of these activities is the First GARP Global Experiment (FGGE).

A prototype system for providing low cost, fully automated, meteorological observations from aircraft has been developed by the NASA Lewis Research Center located in Cleveland, Ohio. This system will utilize the geostationary satellites expected to be available prior to the FGGE and has been called the Aircraft to Satellite Data Relay (ASDAR) system. The importance of this development to the science of meteorology and, in particular to aeronautical meteorology (where direct benefits such as fuel savings and increased passenger comfort and safety are possible) was noted by the Congress of the World Meteorological Organization (WMO).

On February 4, 1977, the ASDAR system, aboard a Pan American Airways B-747 aircraft left New York City on a flight test over the U.S. east coast and adjacent Atlantic Ocean. All of the components had gone through prior functional and radio frequency interference tests in the laboratory, but this was the first time that actual winds and aircraft position were obtained from the Inertial Navigation System (INS) and Flight Data Acquisition Unit (FDAU) on board. More important, the flights presented a severe test of the ASDAR receiver's capability to receive time-code signals from the U.S. geostationary satellite despite the myriad of other nearby signals over a metropolitan area. Pan American Airways, acting under contract to NASA, received Federal Aviation Administration (FAA) certification on a B-747 and will carry the ASDAR package for a special test and evaluation period of one year. Under this special contract, Pan American Airways will also provide periodic reports of actual conditions under which the system is flown so that NASA engineers can fully analyze the system's performance.

This report presents a brief description of the ASDAR flight system followed by the results of the first flight test of February 4, 1977.

DESCRIPTION

The ASDAR system is illustrated in figure 1. Meteorological data (wind speed, wind direction, and air temperature) along with aircraft position information (latitude, longitude and altitude) is extracted from existing aircraft equipment. The data is processed and transmitted to the SMS/GOES satellites for relay to the National Environmental Satellite Service (NESS) facilities at Wallops Island where it is received and demodulated. The data is then fed to the NESS data recording and dissemination facilities at Marlow Heights, MD.

Figure 2 is a block diagram of the equipment that is installed in the Boeing 747 aircraft. Figures 3, 4, and 5 illustrate the actual aircraft installation.

Downlink signals from the satellite are received by a coplanar, circularly polarized slot antenna which is located on top of the fuselage, above the lounge of the B-747 aircraft. The downlink signal (468.8375 MHz) is separated from the uplink signal (401.835912 MHz) by the diplexer and is fed to the preamplifier which establishes the system noise figure at approximately 2.8 decibels. The preamplifier output is fed to the receiver in the Electronics Unit which is located in the equipment bay area of the aircraft. The demodulated output of the receiver is fed to the Digital Interface Unit (DIU) which extracts coded Greenwich Mean Time from the downlink wavetrain. This time information is used by the microprocessor in the DIU to control data storage and processing. The serial digital data streams from the aircraft Inertial Navigation System (INS) and the aircraft Flight Data Acquisition Unit (FDAU) are also fed to the DIU. Seven parameters are sampled and stored in each sampling period. When eight sets of parameters have been stored, the DIU turns the transmitter on at a preprogrammed time, and all eight sets of stored data are transmitted via the SMS/GOES satellite to the Wallops Command and Data Acquisition station within 37 seconds. In normal operation, the data acquisition and transmission cycle is repeated on a once per hour basis. By setting the appropriate thumb wheel switches under the front panel cover of the Electronics Unit, the data acquisition and transmission cycle can be made to operate at 1, 2, 4, 8, and 16 times per hour. The faster rates are intended for test purposes. A separate power supply provides all the potentials (+28 V dc, 12 V dc, 5 V dc) required by the system from the aircraft 115 volt, 400 Hertz, three phase lines. The system operates automatically without attention by flight or ground personnel except for turn-on or turn-off by means of the flight deck circuit breaker. A photograph of the Electronics Unit and the power supply is shown in figure 6.

Test Flight Result Summary

The flight test of the ASDAR system occurred on February 4, 1977, from 1:50 pm EST to 6:00 pm EST and was successful. No vibration, shock nor temperature problems were observed with any of the ASDAR components, including the antenna. EMI testing confirmed that the ASDAR did not interfere with any of the aircraft systems. Incorrect outside air temperature readings occurred during the flight, and this anomaly was subsequently traced to an aircraft harness wiring error. The error has been corrected and all aircraft data are now being processed without anomalies. As a result of the flight test, Federal Aviation Administration (FAA) Certification of the installation is assured. Formal transmittal of the FAA Supplemental Type Certificate is expected within 30 days. The aircraft was released for revenue service and the ASDAR is now operating satisfactorily during normal passenger service.

Systems Tests

A flight test program was generated by the LeRC engineers to confirm the ASDAR units meet the environmental and electro/magnetic requirements of the Radio Technical Commission for Aeronautics (RTCA) Documents DO-138 and DO-160, respectively. Chronologically the system tests consisted of the following six operations:

(1) Checkout of ASDAR system No. 103 (EMI Unit).
(2) Ground checkout of system No. 101 (Flight Unit).
(3) Flight operations of Unit No. 101.
(4) EMI operations of Unit No. 103.
(5) Flight checkout of Unit No. 102 (flight backup).
(6) Final installation of Unit No. 101 for revenue flights.

Checkout of System No. 103 (EMI):

ASDAR system No. 103 had been modified by LeRC engineers specifically to provide the capability of manually keying the transmitter in order to facilitate EMI testing on the aircraft. The checkout consisted of applying power to the installed unit by means of the cockpit circuit breaker, manually keying the transmitter, and measuring the RF power output at the Electronics box transmitter port. The unit performed satisfactorily, and was then removed from the aircraft instrumentation rack and stored on the aircraft for subsequent use during the test flight for EMI testing.

Ground Checkout of System No. 101 (Flight Unit):

Upon removal of the EMI test unit, Electronics Unit No. 101 was installed by Pan American technicians under the supervision of LeRC personnel. An in-line wattmeter was temporarily installed at the Electronics box RF output port to permit power measurements during the flight test. A portable electronic teletype terminal to monitor transmitted data was installed in the passenger area, within 12 feet of the aircraft instrumentation racks. Since the aircraft was in the hangar during this portion of the testing, it was not possible to receive the downlink signal from the satellite. To simulate the downlink signal, a signal generator, phase modulated by a minicomputer, and fed to a

9 decibel gain helical antenna was used. The receiver locked to the simulated signal, confirming receiver operation. At approximately 12:00 noon EST, the aircraft was rolled out of the hangar for fueling and engine runup. Outside of the hangar, the receiver acquired the downlink signal from the satellite, the Digital Interface Unit locked to the time code which is multiplexed on the downlink carrier, and transmissions to the satellite commenced.

Flight Operations of Unit No. 101:

At approximately 1:50 pm EST, the B-747 was airborne. During the taxi and ascent, three time and receiver dropouts were noted but these were expected. Similar dropouts had occurred during testing at the LeRC and during test flights in the NASA C-47 aircraft. These dropouts are caused by adjacent and cochannel interference from land mobile stations, which share the downlink frequency band. This type of interference occurs only in highly industrialized areas. Once the cruise altitude of 33,100 feet was reached, no receiver nor time dropouts were noted.

The flight path (fig. 7) was selected to evaluate three major areas: (a) system performance, (b) antenna performance and (c) interference to the downlink from the satellite. An octagonal flight path was chosen to provide a realistic number of antenna view angles to the satellite. The octagon provided a southwest (230°), south (180°), southeast (140°), east (90°), northeast (45°), north (0°), northwest (320°), and west (270°) headings which were considered adequate for preliminary antenna evaluation. Each leg of the octagon had a duration of $7\frac{1}{2}$ minutes. This length was selected to allow two transmissions at the greatest transmission rate on each leg. A path over highly industrialized areas, such as the middle Atlantic coast, was selected to observe receiver and time dropouts.

Data (table 1) taken manually during the flight path consisted of the following information:

(1) Eastern Standard Time
(2) Altitude in feet
(3) Heading in degrees
(4) Angle of attack in degrees
(5) RF power in watts
(6) Signal to noise ratio in decibels
(7) Outside air temperature

In summary, no major problems occurred. Under control of the DIU, in the rapid transmit mode, a block of data was transmitted every $3\frac{3}{4}$ minutes, and the duration of each transmission was 37 seconds. The RF power output, measured at the transmitter port of the Electronics Unit was 80 watts. The carrier to noise ratio was measured at the NESS-CDA station at Wallops Island, and ranged from 8 to 14 decibels, which is adequate for good quality data reduction. Translated carrier frequency measurements were also made by the Wallops Island CDA. The sixth, seventh, and eighth significant figures (thousands, hundreds and tens of Hertz) are given. The carrier frequency remained within the 1.5 kHz channel bandwidth. Two minor discrepancies were noted:

Discrepancy No. 1:

During portions of data runs Nos. 1 and 2 (230^{o} and 180^{o}, respectively), the Wallops Command and Data Acquisition Station reported that their demodulator failed to lock on the ASDAR signal. The dropouts are a function of aircraft heading, and, therefore, appear to be a function of the angle between the antenna and the satellite. However, at this time, range data on the antenna is inadequate to definitely attribute the signal loss to the antenna. Within 15 minutes, the problem disappeared, and no demodulator lock problems were encountered during the remainder of the flight.

Discrepancy No. 2:

The teletype printout obtained during the test flight indicated a constant outside air temperature of +50° C. Unit No. 102 also indicated the same erroneous reading. The aircraft cockpit display indicated an outside air temperature at altitude which varied between -49° and -56° C. A review of the aircraft wiring installation disclosed a wiring error. This error was corrected and on a subsequent revenue flight to London, the outside air temperatures varied between -42° and -57° C as is expected.

Figure 8 is a reproduction of one data transmission as obtained from the NESS data collection facility. The figure is annotated to describe the method of interpretation.

EMI Operations of Unit No. 103:

Unit No. 103 had been extensively used for ground EMI testing. All ground EMI testing showed the ASDAR system did not interfere with any of the B-747 electrical and communication systems that had been subjected to EMI testing. The only remaining requirements was to perform EMI testing on aircraft equipment that is used during take off and landing operations. The EMI tests during the test flight were on the following systems:

(1) VOR/ILS System - Very high frequency Omni Range/ Instrument Landing System.

(2) Marker System

(3) LRRA - Low Range Radio Altimeter System

No anomalies, visual or aural were observed either during ground or flight testing. Table 2 is a tabulation of all the systems on which EMI testing was performed.

Flight Checkout of Unit No. 102:

ASDAR Unit No. 102 was taken to PAA as a flight backup unit in the event problems were encountered with the flight unit No. 101. Unit No. 102 was installed and tested after the completion of the EMI testing. No anomalies were observed and this unit is now available as a PAA backup.

Final Installation of Unit No. 101 for Revenue Flights:

ASDAR Unit No. 101 was reinstalled at approximately 5:15 pm EST, February 4, 1977. The following switch settings were set on the electronics unit for future revenue flights.

(1) Number of transmissions per hour: 1.
(2) Transmission time (minutes after the hour): 00
(3) Transmission time (seconds after the minute): 00
(4) Address: 155FFC28.

After one transmission to the satellite at 6:00 pm, the flight test was terminated. Table 3 is a listing of the personnel associated with the flight test.

Conclusion

The ASDAR system is now operational with FAA certification assured. All appropriate personnel have signed off on the documentation required to obtain a Supplemental Type Certificate (STC).

No problems were encountered with the Transco interim antenna. Transco had supplied PAA with the required environmental test documentation which was then signed off by the FAA PAA representatives (Quality Assurance, Structural, Aero Dynamics). No failures or anomalies of the antenna were noted during the test flight, and therefore, the antenna has been approved for revenue flights.

The anomaly which manifested itself as an incorrect outside air temperature reading was found to be a wiring error in the aircraft harness. This has subsequently been corrected and is no longer a problem. The ASDAR test flight is a success and the program will continue as scheduled with a one year evaluation period on PAA aircraft NP657 PA.

DATA TABULATION

Flight Sequence	Time (EST)	Altitude (Ft)	Heading	Angle of Attack	S/N Ratio (DB)	O.S. Air Temp (C)	Freq. (Hz)	Remarks
Start & Warm-up	13:17	0	125°	0°	-	-	-	9 min.
R. F. Turn-on	13:20	0	130°	0°	14	-	-	-
Parked	13:37	0	130°	0°	12	-	-	11 min.
Taxi	13:56	0	Var.	0°	14	-	-	19 min.
Take-Off	13:58	0	120°	15°	-	-	-	-
Climbing	13:59	4800	120°	15°	14	-	-	1 min.
"	14:03	12000	150°	5°	-	-	-	4 min.
"	14:07	17600	150°	5°	-	-	-	4 min.
"	14:11	23400	135°	5°	14	-	-	4 min.
"	14:14	27900	150°	5°	13	-	-	3 min.
"	14:18	31500	210°	3°	-	-49°	-	4 min.
"	14:20	33100	230°	2°	13	-51°	-	2 min.
1st Leg Course	14:22	33100	230°	2°	13	-51°	-	No DMOD Lock
" " "	14:26	33100	230°	2°	13	-51°	-	" " "
2nd Leg Course	14:29	33100	180°	2°	10	-51°	-	" " "
" " "	14:33	33100	180°	2°	12	-51°	-	" " "
3rd Leg Course	14:37	33100	120°	2°	13	-50°	-	Lock-up O.K.
" " "	14:41	33100	140°	2°	12	-51°	-	" " "
4th Leg Course	14:44	33100	90°	2°	12	-51°	-	" " "
" " "	14:48	33100	90°	2°	12	-50°	-	" " "
5th Leg Course	14:52	33100	45°	2°	-	-49°	-	" " "
" " "	14:56	33100	45°	2°	10	-51°	590	-
6th Leg Course	14:59	33100	0°	2°	8	-51°	600	-
" " "	15:03	33100	0°	2°	8	-51°	600	-
7th Leg Course	15:07	33100	320°	2°	10	-51°	598	-
" " "	15:11	33100	320°	2°	10	-52°	598	-
8th Leg Course	15:14	33100	270°	2°	12	-51°	609	-
" " "	15:18	33100	270°	2°	12	-51°	615	-
Leg to U. S.	15:22	33100	270°	2°	12	-51°	615	2 min.
Flt.Over Pop'Ars	15:26	33400	270°	2°	12	-52°	615	4 min.
" " " "	15:44	35100	290°	2°	-	-56°	-	18 min.
" " " "	15:48	31200	290°	-2°	-	-49°	-	4 min.
" " " "	15:53	22600	280°	-2°	-	-36°	-	5 min.
Landing @ Dulles	-	-	-	-	-	-	-	
Climbing	16:58	7100	30°	5°	-	8°	-	5 min.
"	17:00	11400	120°	10°	-	-10°	-	2 min.
"	17:03	17400	90°	0°	-	-21°	-	3 min.
Leg to Kennedy	17:15	17100	70°	0°	-	-20°	-	8W Ref'L PWR

Table 1

EMI TESTS FOR ASDAR

1. Inertial Navigation System (INS) #1.
2. Inertial Navigation System (INS) #2.
3. Inertial Navigation System (INS) #3.
4. Central Air Data Computer (CADC) #1.
5. Central Air Data Computer (CADC) #2.
6. Digital Flight Data Recorder.
7. Auto Pilot.
8. Very High Frequency Omni Range/Instrument. Landing System (VOR/ILS).
9. Marker System.
10. Low Range Radio Altimeter (LRRA).
11. Distance Measuring Equipment (DME).
12. VHF Communications (118MHz - 135.75MHz).
13. Selective Calling System (SELCAL).
14. Public Address, Passenger Entertainment, Interphones.
15. Cockpit Voice Recorder
16. HF Communications (2MHz - 28MHz).
17. Automatic Direction Finders (ADF).
18. Weather Radar System.

Table 2

ASDAR CERTIFICATION FLIGHT PERSONNEL LIST

PAA FLIGHT PERSONNEL (7)

Captain/Pilot and FAA/DER . . . . W. A. Brown
1st Officer . . . . W. K. Herndon
Flight Engineer . . . . C. Miller
Flight Engineer . . . . F. D. Cassaniti
Operations Engineer and FAA/DER . . . . R. K. Hart
Training Pilot. . . . . E. Fleming
Technical Controller. . . . . J. Welkerle

PAA ENGINEERING PERSONNEL (8)

Avionics Engineer and FAA/DER . . . . . R. S. Winter
Avionics Engineer . . . . E. A. Cressi
Avionics Engineer . . . . W. W. Austin
Avionics Engineer . . . . N. Madamia
Structures Engineer and FAA/DER . . . . I. Stanton (Miami)
Communications Engineer . . . . E. Ellis
Avionics Mechanic . . . . J. Vandeneedon
Avionics Electronics. . . . . K. Regenhard

NASA - LeRC (9)

Test Director . . . . E. J. Domino
Ass't Test Director . . . . M. J. Conroy
PAA Co-Ordinator. . . . . R. W. Myhre
RF Systems Engineer . . . . R. J. Zakrajsek
DIU Logic Engineer. . . . . B. G. Lindow
Data/Logistics Engineer . . . . D. H. Culp
Power Systems Engineer. . . . . R. J. Krawczyk
Tech-Mechanical . . . . G. E. Belmont
Tech-Electronics. . . . . F. P. Petti

OTHERS (3)

Observer (NASA-GSFC). . . . . F. Stetina
Observer (NOAA) . . . . J. Sparkman
Observer (NOAA) . . . . J. Giraytys

Table 3

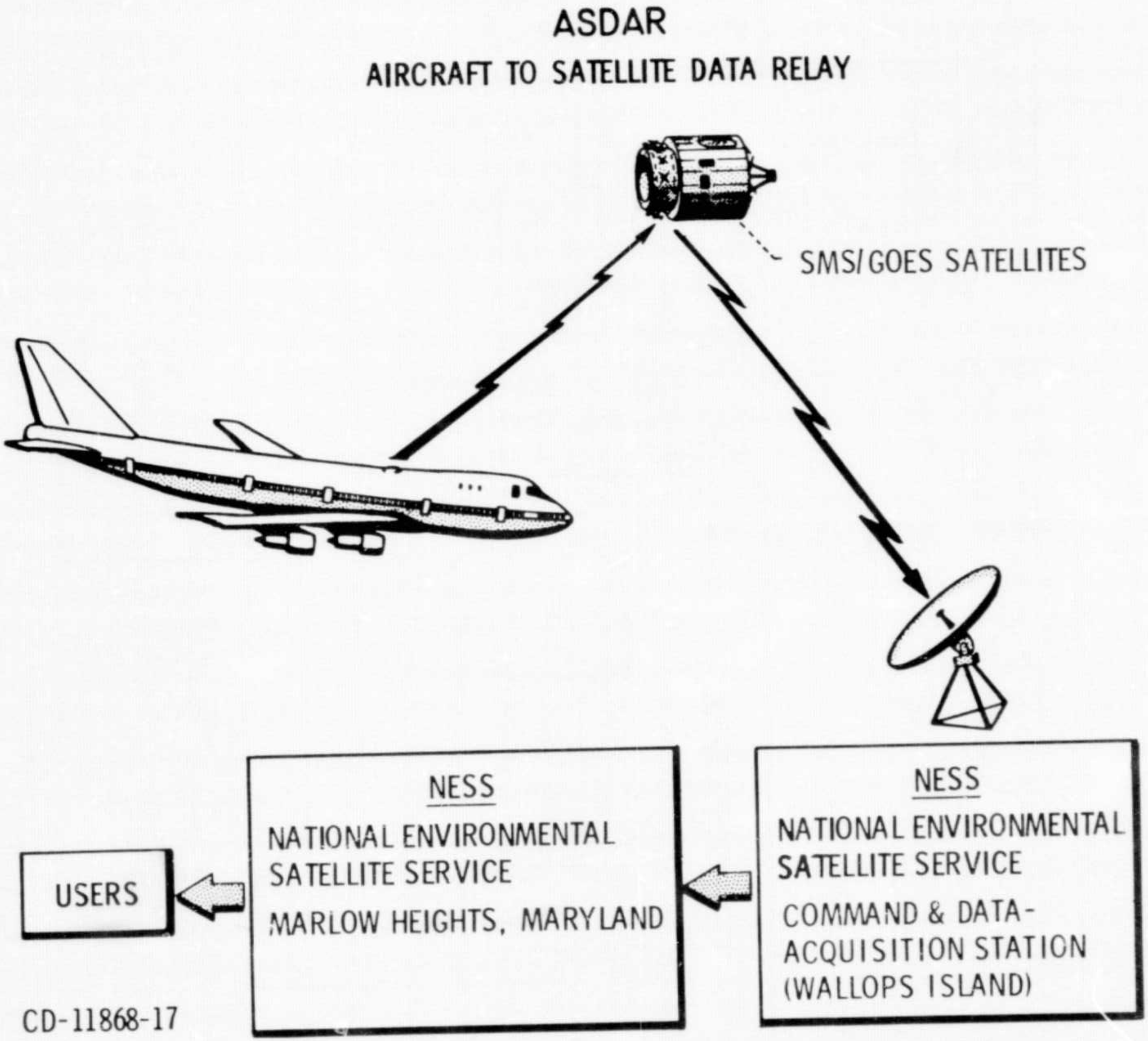
ASDAR
AIRCRAFT TO SATELLITE DATA RELAY
SMS/GOES SATELLITES
USERS
NESS
NATIONAL ENVIRONMENTAL
SATELLITE SERVICE
MARLOW HEIGHTS, MARYLAND
NESS
NATIONAL ENVIRONMENTAL
SATELLITE SERVICE
COMMAND & DATA-
ACQUISITION STATION
(WALLOPS ISLAND)
CD-11868-17

Figure 1.

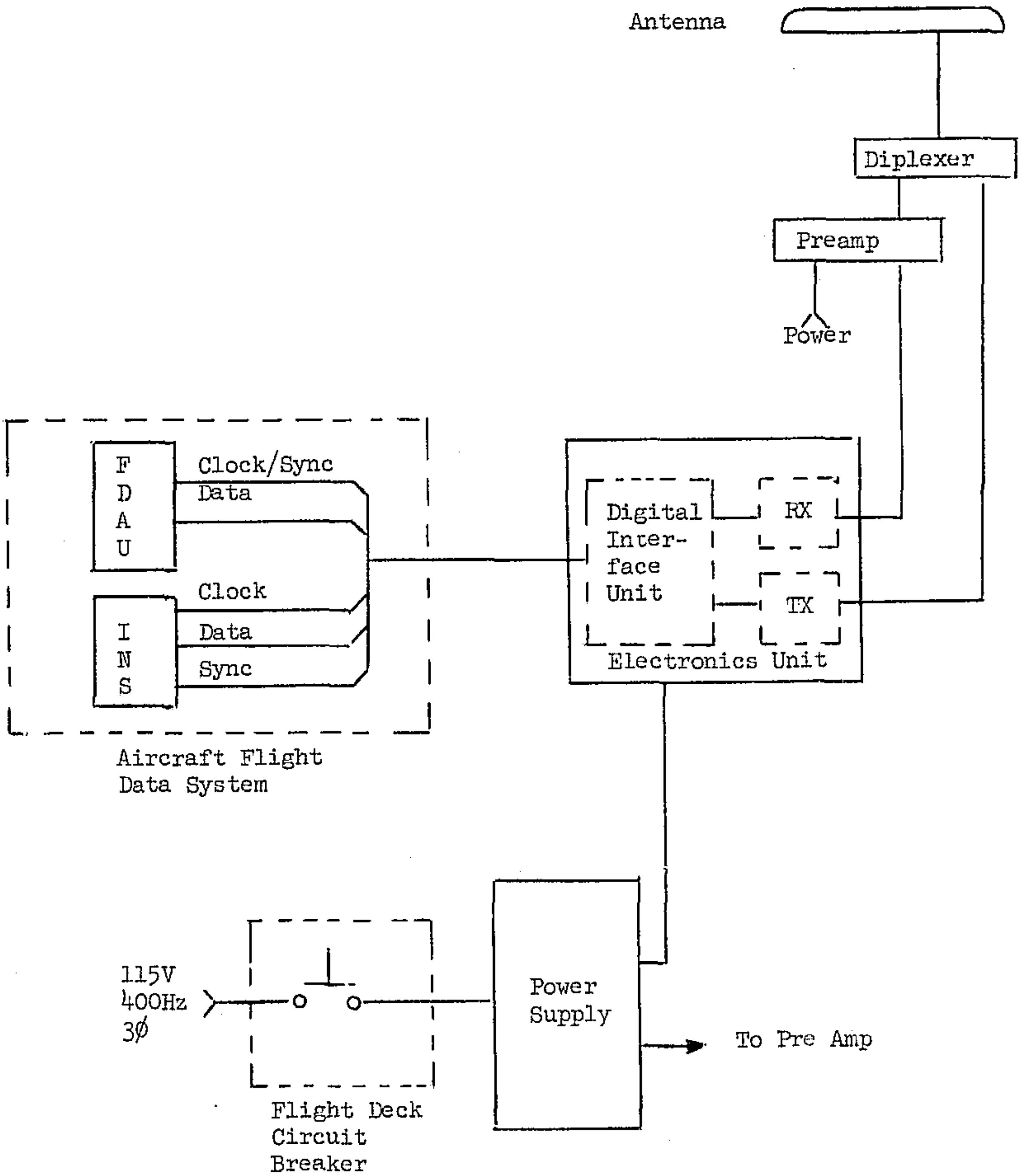

FIGURE 2 BLOCK DIAGRAM

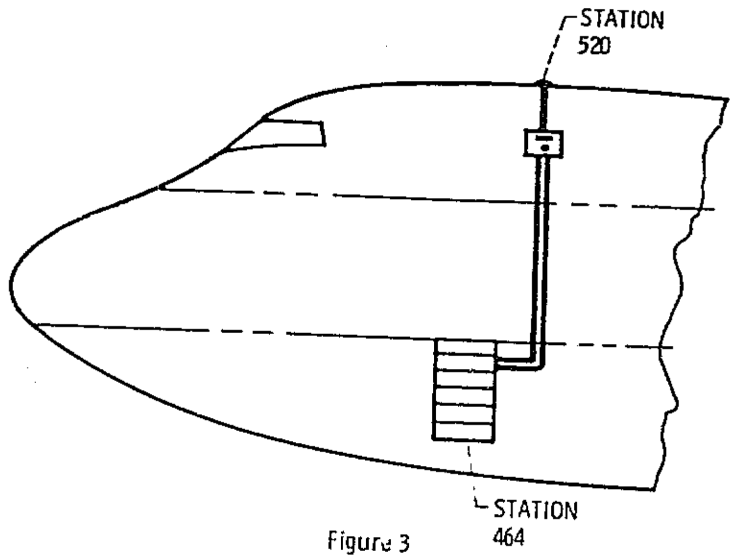

Figure 3

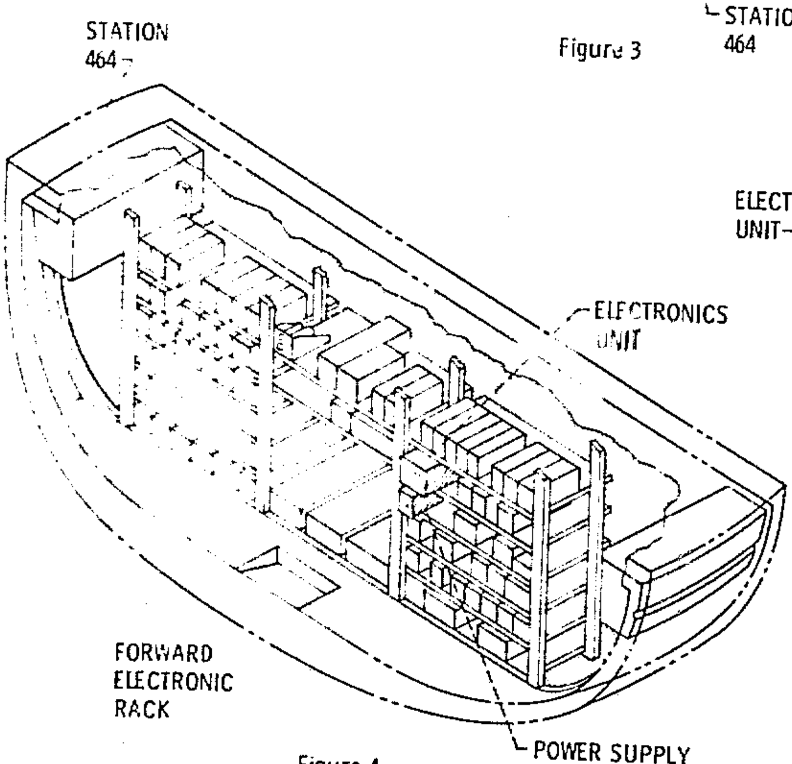

Figure 4

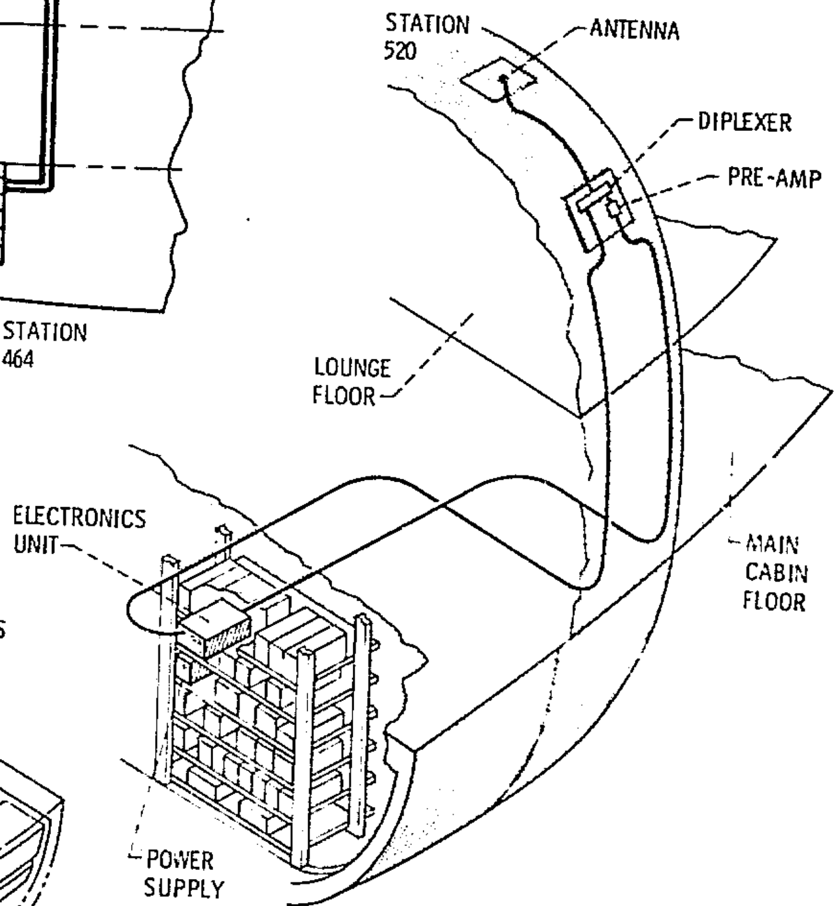

Figure 5

CD-12086-32

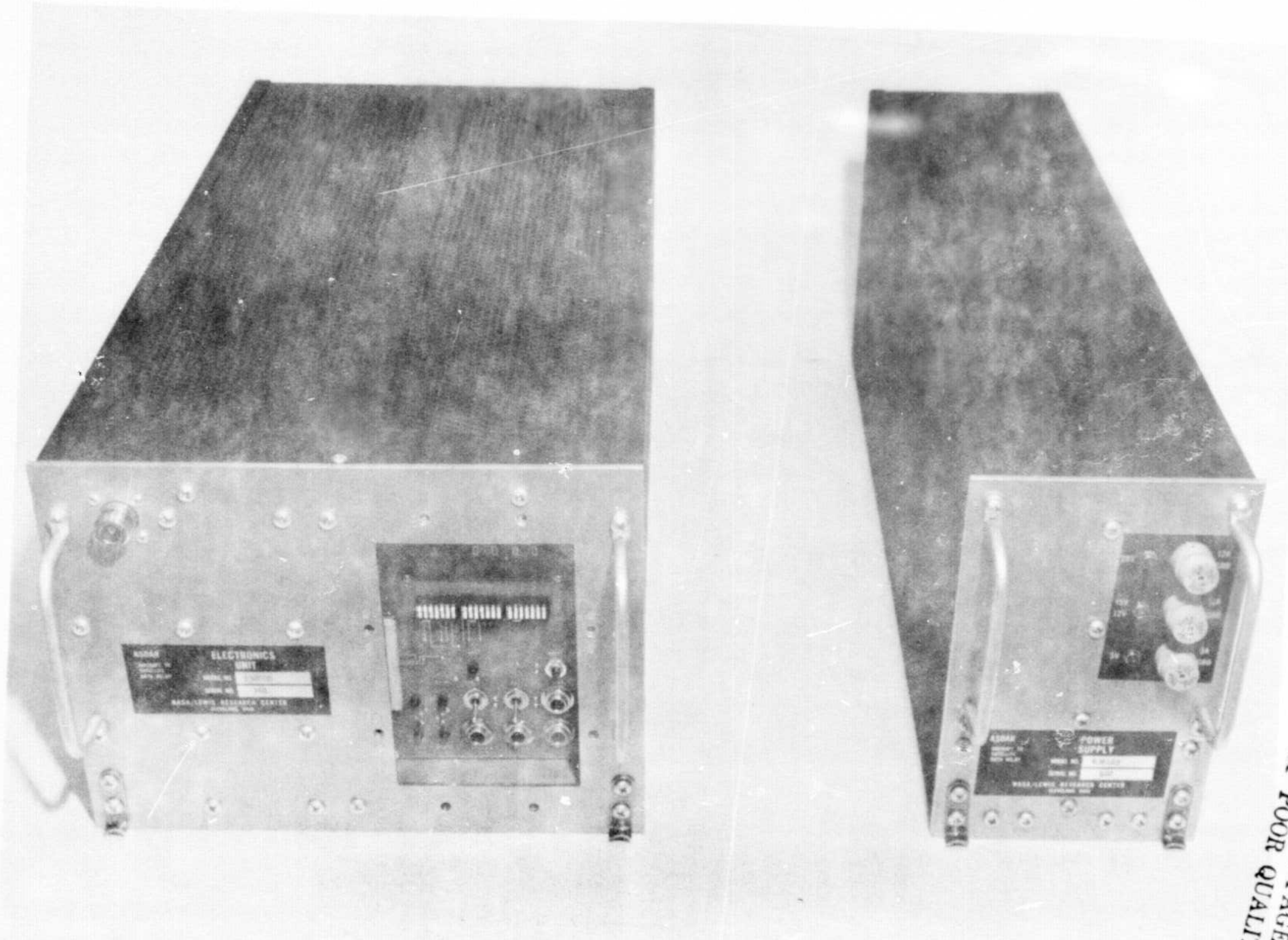
ELECTRONICS
UNIT
NASA/LEWIS RESEARCH CENTER
POWER
SUPPLY
NASA/LEWIS RESEARCH CENTER

Figure 6

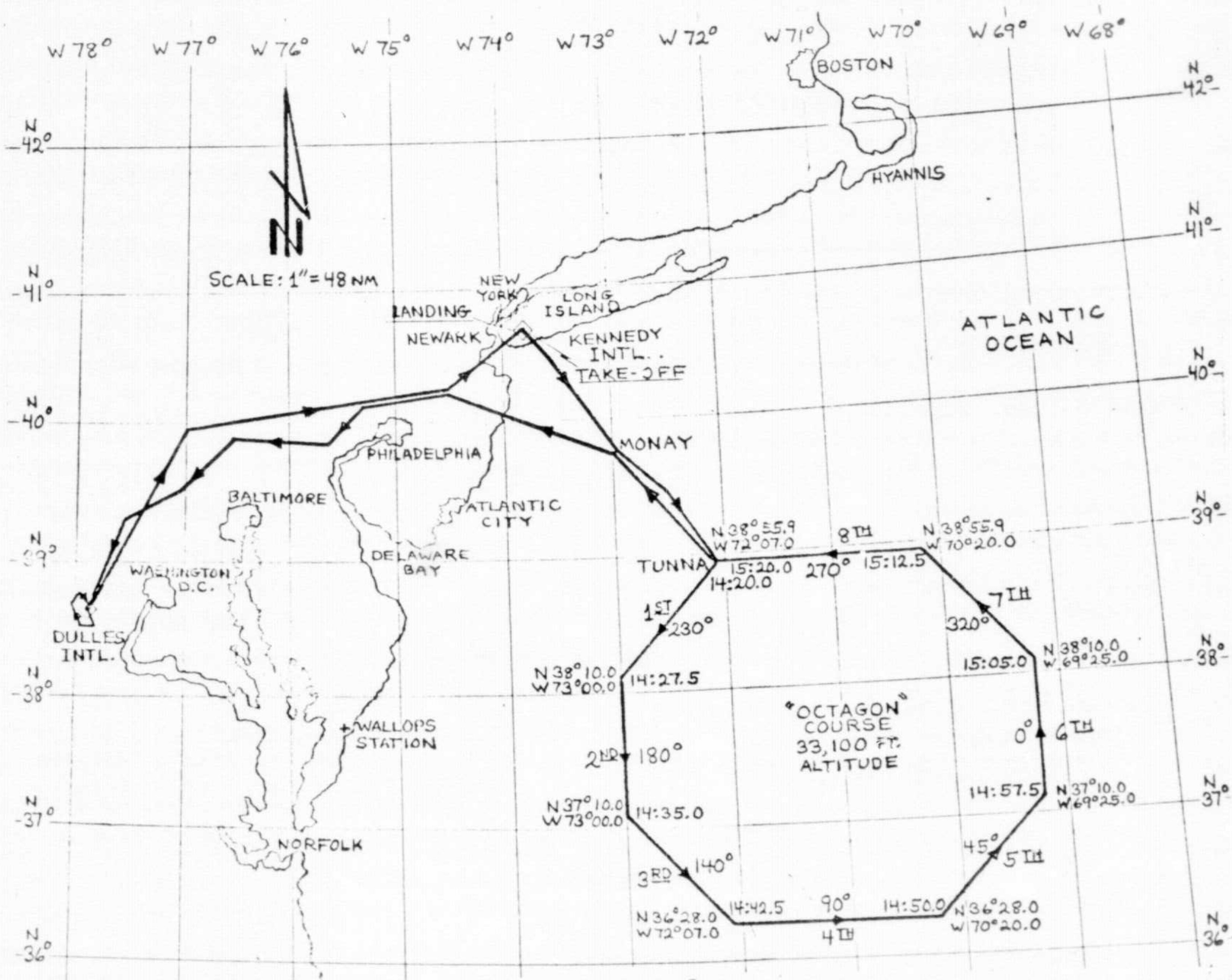
W 78°
W 77°
W 76°
W 75°
W 74°
W 73°
W 72°
W 71°
W 70°
W 69°
W 68°
N 42°
N 41°
N 40°
N 39°
N 38°
N 37°
N 36°
BOSTON
HYANNIS
SCALE: 1" = 48 NM
NEW YORK
LONG ISLAND
LANDING
NEWARK
KENNEDY INTL.
TAKE-OFF
ATLANTIC OCEAN
MONAY
PHILADELPHIA
BALTIMORE
ATLANTIC CITY
DELAWARE BAY
WASHINGTON D.C.
DULLES INTL.
WALLOPS STATION
NORFOLK
TUNNA
N 38°55.9
W 72°07.0
14:20.0
15:20.0
8TH
270°
15:12.5
N 38°55.9
W 70°20.0
1ST
230°
7TH
320°
N 38°10.0
W 73°00.0
14:27.5
N 38°10.0
W 69°25.0
15:05.0
"OCTAGON" COURSE
33,100 FT. ALTITUDE
2ND
180°
0°
6TH
N 37°10.0
W 73°00.0
14:35.0
N 37°10.0
W 69°25.0
14:57.5
3RD
140°
45°
5TH
N 36°28.0
W 72°07.0
14:42.5
90°
4TH
14:50.0
N 36°28.0
W 70°20.0

Figure 7

DATA PRINTOUT

OBTAINED FROM

NESS DCS

SUITLAND, MARYLAND

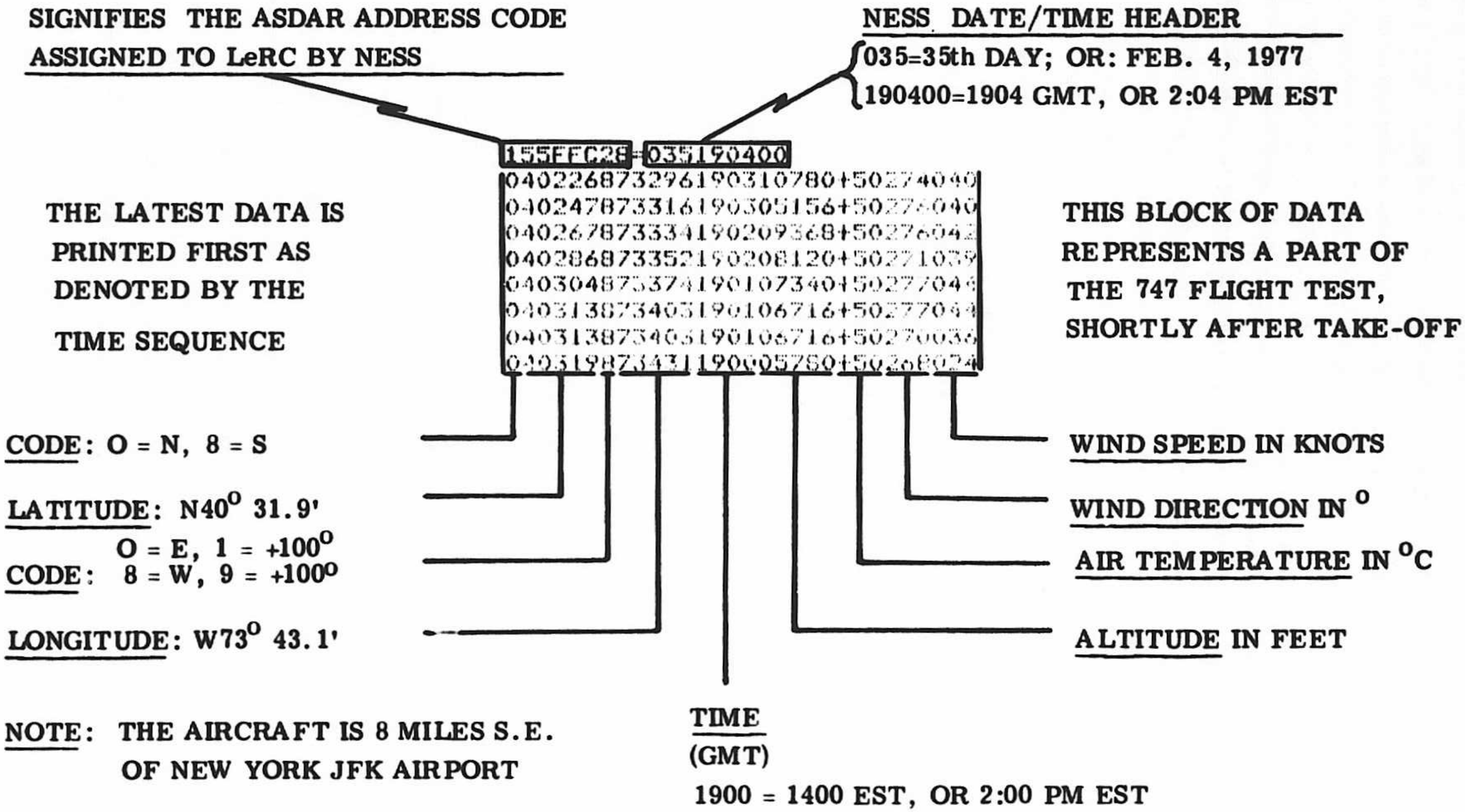

FIGURE 8