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PRECISION SELENODESY AND LUNAR LIBRATION THROUGH VLBI OBSERVATIONS OF ALSEPS

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Summary

Data from 500 observation series, each one representing about 5 hours' continuous observation of a pair of ALSEPs by differential VLBI, have been compiled on magnetic tape. The theoretical models which we use to calculate the rotation of the earth, the orbit of the moon, the libration of the moon, and the basic VLBI observable have been improved substantially: We are now able to fit a four-year span of lunar laser ranging observations with post-fit residuals of 5.5 nsec rms (~ 80 cm in distance), and a 12-day span of VLBI observations with residuals of 15° rms (~ 1 m on the lunar surface). Further work may be required, however, to ensure that uncertainty in the lunar libration model does not degrade the determination of the relative coordinates of the ALSEPs. We are just beginning to analyze the data from long spans of VLBI observations.

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I. OBSERVATIONS AND DATA PROCESSING

Differential very-long-baseline-interferometer (VLBI) observations of Apollo Lunar Surface Experiments Package (ALSEP) S-band radio transmitters continued through 1974[1]. These observations were made at stations of the NASA Spacecraft Tracking and Data Network (STDN), using the STDN "Unified S-Band" (USB) receivers in conjunction with the MIT Differential Doppler Receivers (DDRs) which we continued to maintain. Every observation was directed by an MIT experimenter via telephone connections with the participating stations. A list of all of the observations obtained through October 1974 is appended to this report.

The data from these observations were transmitted from the stations to NASA Goddard Space Flight Center (GSFC) in Greenbelt, Maryland. At Goddard, the data were accumulated and sent at approximately one-month intervals to MIT for analysis. We are indebted to James W. Ryan (Code 920, GSFC) for arranging the data-transmission system. Mr. Ryan, with the important assistance of Mr. H. Wade Stonesifer, has been responsible for all aspects of MIT's liaison with GSFC and the STDN.

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[1]This and subsequent references are listed in Section III.

At MIT the raw VLBI data, together with essential information from the MIT test director's and the station operators' logs, were sorted, collated, and edited, and collected on a number of observation library tapes (see Appendix)*. In the latter form, the observations are ready to be analyzed by MIT's Planetary Ephemeris Program (PEP)[2] in order to determine the selenodetic coordinates of the ALSEP transmitters, etc., as we describe in the following section.

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*Most of our data-processing effort during 1974 was actually devoted to clearing up the enormous backlog of data which had been accumulated during 1973 and early 1974, before this data-analysis grant was received. This job was complicated by the fact that these data had been sent from the tracking stations to MIT on punched paper tape. A thousand rolls of paper tape had to be transcribed onto magnetic tape, and a thousand pages of hand-logged data had to be keypunched. These tasks occupied one full-time data technician, four approximately half-time undergraduates, and four graduate-student research assistants for several months.

II. ANALYSIS

The initial objectives of this grant, namely the determination of the selenodetic coordinates of the five ALSEPs and the determination of parameters influencing the moon's libration, require accurate theoretical-numerical models

(1) of the lunar orbit and the rotation of the earth;

(2) of the libration of the moon; and

(3) of the differential VLBI observable as a function of (1), (2), and other factors.

During 1974 we made significant advances, and/or we were able to use important results of other investigators, in all three of these areas.

II. 1 Lunar Orbit and Rotation of the Earth

The numerically-integrated model of the lunar orbit which we are using was originally incorporated into PEP[2] by M. A. Slade in his thesis research[3]. Our model of the earth's rotation is basically that described in the Explanatory Supplement to the Astronomical Ephemeris[4], and uses the polar motion data published by the Bureau International de l'Heure[5], and the UT.1 data published by the U.S. Naval Observatory[6].* The basic coordinate system

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*Recently, programming changes in PEP were completed by A. Forni at MIT Lincoln Laboratory to use UT.1 data from the B.I.H.[5] instead of those from the U.S.N.O. However, we have not yet used this modification.

(sometimes called the "equator and equinox") to which the earth's rotation (and everything else) is referred in PEP is nominally defined by the mean equator and equinox of 1950.0, and is in practice defined by the PEP planetary ephemeris tape number 311[7]. Since our observable is sensitive to the relative orientations of the earth and moon, and since the orientation of the moon is sensitive, primarily through the very strong perturbations which the sun exerts on the moon's geocentric orbit, to the orientations of the heliocentric orbits of the earth and other planets, it is necessary for us to model accurately all of these systems: the earth, the moon, and the remainder of the solar system.

We have not made any changes to the PEP planetary ephemerides. Thus, these ephemerides serve to define our basic coordinate system. However, we have found it necessary to make adjustments to our earth-rotation model and to our lunar ephemeris in order to eliminate systematic errors which would have degraded the results obtainable from the analysis of the VLBI observations of the ALSEPs. For this purpose, the lunar laser ranging experiment (LURE) team made available to us laser ranging observations made at McDonald Observatory from March 1970 to July 1974. (These data were provided in the form of "normal points"[8].) R. W. King of MIT and Air Force Cambridge Research Laboratory then used

PEP to adjust the two angles which determine the plane of the earth's equator, the six elements of the moon's geocentric orbit, and the mass of the earth-moon system to fit the laser observations. The geocentric coordinates of McDonald Observatory, the selenocentric coordinates of the lunar retroreflectors, and parameters in the lunar libration model were adjusted simultaneously. (We describe the lunar libration model which we used in Section II. 2.) The r.m.s. of the post-fit residuals for these four years of laser observations was 5.5 nsec in delay -- approximately 80 cm in "range" or distance*. We conclude that our models of the rotation of the earth and the <u>orbit</u>** of the moon are now accurate enough that they will probably not degrade the determinations of the relative positions of the ALSEP transmitters at the level of 1-3 m uncertainty, and of the libration of the moon at the level of 0.5 second of selenocentric arc, from VLBI observations.

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*Detailed inspection of these residuals suggests that the most serious defect in our models is now in the representation of variations of UT.1. It is possible that the fit will improve significantly when we begin to use the B.I.H. data for UT.1.

**as opposed to the <u>libration</u>

II. 2 Lunar Libration

Although we intend eventually to integrate the equations of motion for the rotation of the moon directly in PEP, we have not completed the new coding necessary to do this. Instead, R. W. King has adapted PEP to use either the semi-analytic model of the moon's libration developed by D. H. Eckhardt[9] at Air Force Cambridge Research Laboratory, or the numerically-integrated model of W. S. Sinclair and J. G. Williams[10] of the Jet Propulsion Laboratory. In our analysis of lunar laser ranging data to determine the lunar orbit and corrections to the earth's orientation, we used the JPL libration ephemeris tape number LLB-3[11], and we adjusted β, γ, all third-degree harmonic coefficients except S_{33}, and the six initial conditions of the integration*. Further work may be still required to ensure that the lunar libration model does not constitute the greatest source of uncertainty in the determination of the relative coordinates of the ALSEPs.

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*This parameter set, combined with the full set of retroreflector coordinates, is somewhat degenerate. Further discussions with the LURE team are required in order to reach agreement on a reduced parameter set, for example one which has certain coordinates of laser retroreflectors fixed to define the system of selenodetic coordinates.

II. 3 VLBI Observable

Until December 1974, the algorithm which we used in PEP for the theoretical calculation of the doubly-differenced (between ALSEPs, between stations), or differential VLBI observable was basically the same as that which we developed originally for the tracking of the Apollo lunar roving vehicles[12]. An essential feature of this algorithm was the use of concurrently measured values of the two transmitters' frequencies in order to convert the changes of the transmitter-to-receiver propagation time delays over short (~ 1 minute) time intervals, from delay increments to phase increments. The value of frequency used for a particular receive-time interval was the average value of the received frequency over that interval, transformed to the frame of the transmitter to account for the Doppler shift. This procedure involves approximations which become less exact if the transmitter's frequency is rapidly time-varying. The most serious error involved in these approximations is proportional to the first time-derivative of the transmitted frequency and to the length of the time interval used in the calculation, and reflects the simple fact that if the derivative is positive (or negative), then the instantaneous value of the frequency is systematically lower at the beginning of the interval, and higher at the end (or vice versa), than the average value over the interval. We have long been aware of the existence of such effects, but we had miscalculated the size of the error involved in ignoring them. In December we re-did the calculation (hopefully this time correctly), and immediately modified the algorithm in PEP to account for the main effect of the frequency time-derivative. This modification appears now to have eliminated systematic errors which were as large as several tens of degrees of phase in some of our VLBI observations, where the ALSEP transmitters were rapidly drifting in frequency. The remaining errors due to frequency drifts are now believed to be smaller than a few degrees of phase in all but a few rare cases. These cases are easily identified and can be excluded from future analyses of the VLBI observations.

II. 4 Results from Fitting VLBI Observations

At the October 1974 GEOP Conference on Lunar Dynamics and Selenodesy we reported that by adjusting ALSEP coordinates we could obtain satisfactory fits at the 1-meter level* to VLBI observations taken one day at a time, but that a serious discrepancy between observed and computed values of the VLBI observable, equivalent to tens of meters in ALSEP position*, accumulated over a month.

A demonstration of the progress which we have made since October 1974 in improving our theoretical models is provided by Figure 1, which shows postfit residuals from observations spanning 12 days in July 1973, on 8 different interferometer baselines. The earth-rotation, lunar-orbit, lunar-libration, and basic VLBI-observable models used for this fit have been described in Sections II. 1 through II. 3. The r.m.s. of these postfit residuals is 15°, close to the noise level. Systematic error is evident (look at the ACN-MIL points on JD 2441877 and the ACN-GDS points on JD 2441881) at the level of a few meters, whereas previously the level was several <u>tens</u> of meters. It is to be

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*The high-frequency "noise" level of most of the VLBI data is approximately 10-15° of phase, r.m.s. Roughly speaking, a 1-meter ALSEP position error will introduce a slope of ~6°/hour in the residuals [(O-C)'s]. This slope, for a typical 5-hour observation series, would lead to an r.m.s. value of the residuals, exclusive of the "noise", of ~10°. Therefore, a position error of 1 meter or less will not significantly increase the r.m.s. of the residuals. However, the systematic slope of the residuals produced by a 1-meter error is quite obvious to the eye.

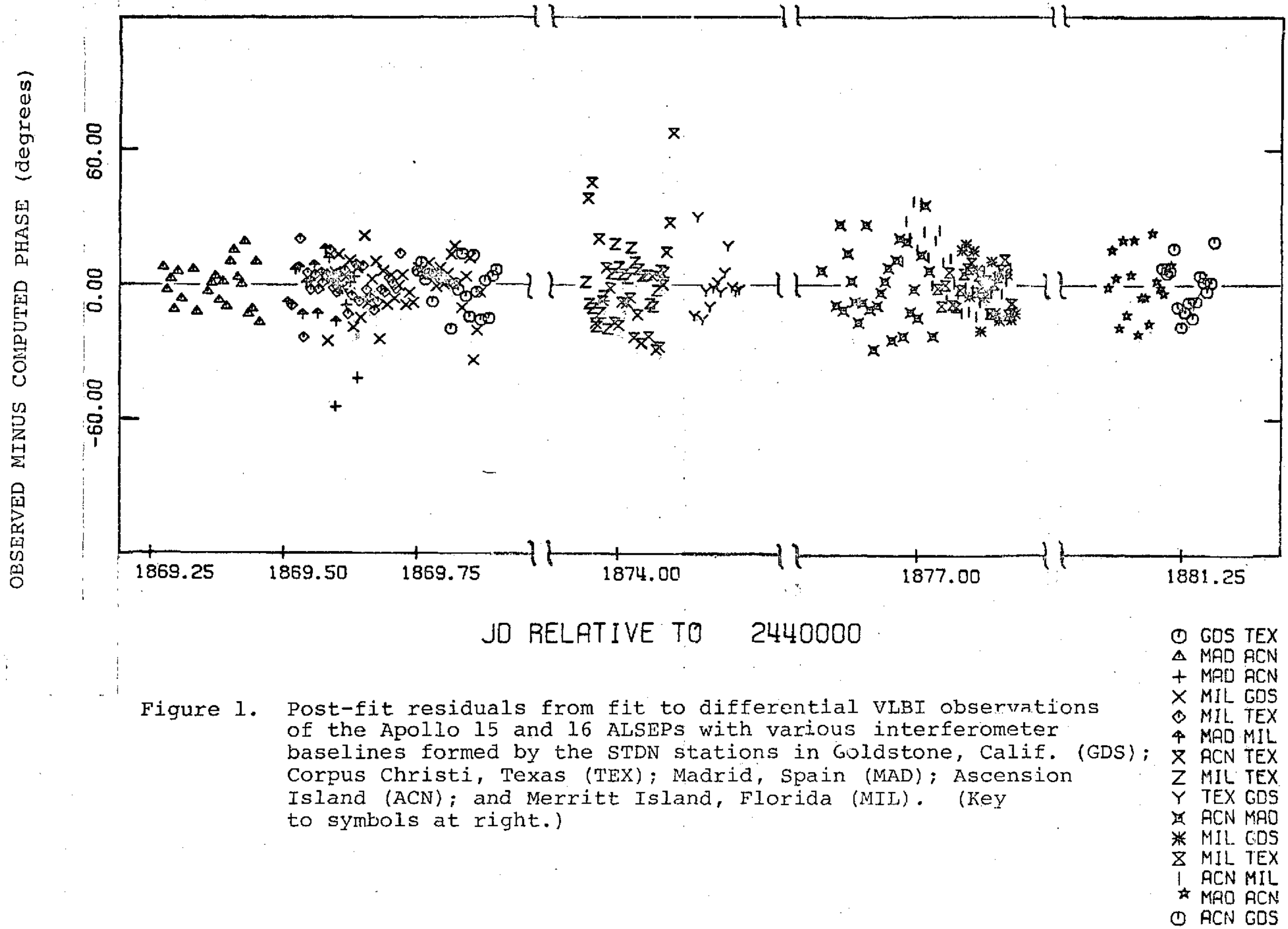

Figure 1. Post-fit residuals from fit to differential VLBI observations of the Apollo 15 and 16 ALSEPs with various interferometer baselines formed by the STDN stations in Goldstone, Calif. (GDS); Corpus Christi, Texas (TEX); Madrid, Spain (MAD); Ascension Island (ACN); and Merritt Island, Florida (MIL). (Key to symbols at right.)

expected, of course, that residuals from fits over time intervals much longer than two weeks will exhibit larger systematic trends, reflecting longer-period errors in the libration model. We are just now beginning to process long spans of VLBI data.

III. References and Notes

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8. Abbot, R. E., P. J. Shelus, J. D. Mulholland and E. C. Silverberg, Laser Observations of the Moon: Identification and Construction of Normal Points for 1969-1971, Astron. J., 78, 784 (1973). [We are indebted to the entire LURE team for making their most up-to-date results available. P. J. Shelus, in particular, provided these in machine-readable form.]

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10. Williams, J. G., D. H. Eckhardt, W. M. Kaula and M. A. Slade, Lunar Physical Librations and Laser Ranging, The Moon, 8, 469 (1973).

11. Sinclair, W. S., JPL, provate communication, 1974.

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APPENDIX

Differential VLBI Observations of ALSEPs, 1972-1974*

The following list shows all of the differential VLBI observations of ALSEP transmitters which have been made with MIT differential Doppler receivers at NASA Spacecraft Tracking and Data Network (STDN) stations, and from which apparently valid data have been obtained. Date is the UTC date of the start of a continuous series of observations, that is, a series within which the differential Doppler counts are uninterrupted at both stations. The times are the UTC start and stop times; if the listed stop time of a series is numerically less than the start time, it is understood that the series stopped on the following UTC day. Stations are: GDS: the 85' "Apollo" station at Goldstone, California; TEX: the 30' station, now closed, at Corpus Christi, Texas; MIL: the original 30' station on Merritt Island, Florida; ETC: the original 30' station at Greenbelt, Maryland; MAD: the 85' station at Madrid, Spain; and ACN: the 30' station on Ascension Island in the South Atlantic Ocean. The first ALSEP listed is the "reference" ALSEP, that is, the one to whose carrier signal the S-band receiver was phase-locked. The second ALSEP is the one to whose carrier signal the DDR was locked. The ALSEPs are designated by their Apollo mission numbers. A number in the Obs. Lib. Tape column identifies

*through 10/25/74

the MIT observation library tape on which the data from a series is written. The absence of any number in this column indicates that the raw data from the observation series has not yet been sorted, roughly edited, and written onto an observation library tape.

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs.Lib. Tape	Series Name	Notes
1972						
10/28	0634-1330	MIL-GDS	12-14	10	302A	
1973						
03/7	1350-2045	MAD-ETC	15-14	11	066G	
03/8	1352-2048	ACN-ETC	15-14	11	067G	
	1130-2048	ACN-MAD	15-14	11	067H	
	1352-2214	ETC-MAD	15-14	11	067I	
	1352-2048	ACN-ETC	15-12	12	067J	
	1130-2048	ACN-MAD	15-12	12	067K	
	1352-2214	ETC-MAD	15-12	12	067L	
03/15	2038-0335	MAD-MIL	15-14	11	074G	
	0146-0330	MAD-ACN	15-14	11	075H	
	0146-0330	MIL-ACN	15-14	11	075I	
	2045-0335	MAD-MIL	15-12	12	075J	
	2045-0335	MAD-ACN	15-12	12	075K	
	2045-0335	MIL-ACN	15-12	12	075L	
03/22	2348-0404	ACN-MAD	15-14	11	081B	
03/24	0215-0545	ACN-MAD	15-14	11	083B	
	0215-0447	ACN-MAD	15-17	13	083A	
03/28	1115-1915	GDS-TEX	15-14	11	087B	
03/30	1135-1415	ACN-MAD	15-14	11	089D	
	1135-1415	ACN-MAD	15-17	13	089B	
04/3	1336-1639	TEX-MAD	15-14	11	093G	
04/4	1454-1627	MAD-TEX	15-14	11	094G	
04/9	1815-2330	ACN-TEX	15-17	13	099A	
	2351-0400	ETC-TEX	15-17	13	099B	
04/12	2115-0059	MAD-ACN	15-14	11	102A	
	2110-0059	MAD-TEX	15-14	11	102B	
04/13	1925-0245	ACN-MAD	15-14	49	103A	
	1635-0245	ACN-MAD	15-16	48	103B	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
04/17	2040-0300	ACN-MAD	15-14	11	107A	
	0228-0520	MAD-TEX	15-14	11	107B	
	0435-1215	TEX-GDS	15-14	11	107C	
04/18	2100-0300	ACN-MAD	15-14	11	108D	
	2100-0300	ACN-MAD	15-17	13	108A	
	0230-0545	MAD-TEX	15-17	13	108B	
	0435-1300	TEX-GDS	15-17	13	108C	
07/2	1450-2035	ACN-TEX	15-14	21	183A	
	1600-2030	TEX-GDS	15-14	21	183B	
	2035-2335	TEX-GDS	15-14	21	183D	
	2335-0305	TEX-GDS	15-14	21	183E	
	2115-2330	GDS-MIL	15-17	22	183C	
07/3	1815-0200	MIL-GDS	15-14	21	184A	
	2015-0200	MIL-TEX	15-14	21	184B	
	1530-2000	TEX-MAD	15-14	21	184C	
	2005-0345	TEX-GDS	15-14	21	184D	
	1815-0200	MIL-GDS	15-17	22	184E	
07/5	1230-1600	MAD-ACN	15-17	22	186A	
	1955-0315	MIL-GDS	15-12	24	186B	
	0000-0500	GDS-TEX	15-16	23	186C	
	1230-1700	MAD-ACN	15-16	25	186D	
	1830-2200	MAD-ACN	15-16	25	186H	
	1645-2200	MAD-MIL	15-16	25	186E	
	1955-0315	MIL-GDS	15-16	25	186F	
	1800-2315	MIL-TEX	15-16	25	186G	
07/6	1410-2140	ACN-MAD	14-15	21	187A	
	1715-0015	ACN-MIL	14-15	21	187B	
	2050-0245	MIL-GDS	14-15	21	187C	
	1410-2140	ACN-MAD	14-12	23	187D	
	1715-0015	ACN-MIL	14-12	23	187E	
	2050-0245	MIL-GDS	14-12	23	187F	
07/9	2145-0245	ACN-TEX	15-16	25	190A	
	2225-0315	MIL-TEX	15-16	25	190B	
	0325-0730	TEX-GDS	15-16	25	190C	
	0245-0545	MIL-GDS	15-17	22	190D	
	2225-0235	ACN-MIL	15-17	22	190E	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
07/10	2100-0115	MAD-MIL	15-14	11	191A	
	0015-0330	MIL-GDS	15-14	11	191B	
	2100-0115	MAD-MIL	15-16	25	191C	
	0015-0600	MIL-GDS	15-16	25	191D	
	0015-0600	TEX-GDS	15-16	25	191E	
07/11	2200-0145	MAD-MIL	15-17	22	192A	
	0200-0600	MIL-TEX	15-17	22	192B	
	0115-0600	MIL-GDS	15-17	22	192C	
	0115-0600	MIL-GDS	15-12	24	192D	
07/12	1845-0050	ACN-MAD	15-16	25	193A	
	2245-0515	ACN-MIL	15-16	25	193B	
	0200-0630	MIL-GDS	15-16	25	193C	
	0000-0430	MIL-TEX	15-16	25	193D	
	0115-0515	ACN-MIL	15-12	24	193E	
	1845-0050	ACN-MAD	15-12	24	193F	
	0150-0630	MIL-GDS	15-12	24	193G	
07/13	1946-0330	ACN-MAD	15-17	22	194A	
	2355-0300	ACN-MIL	15-17	22	194B	
	0240-0553	ACN-GDS	15-17	22	194C	
	1946-0330	ACN-MAD	15-12	24	194D	
	2355-0300	ACN-MIL	15-12	24	194E	
	0240-0600	ACN-GDS	15-12	24	194F	
07/17	0220-0630	MAD-ACN	15-17	22	198A	
	0230-0730	ACN-TEX	15-17	22	198B	
	0415-0730	ACN-GDS	15-17	22	198C	
	0415-1030	TEX-GDS	15-17	22	198D	
	0220-0630	MAD-ACN	15-16	25	198E	
	0415-0730	ACN-GDS	15-16	25	198F	
07/18	0315-0735	TEX-MAD	15-12	24	199A	
	0452-1415	TEX-MAD	15-12	24	199B	
	0500-0735	GDS-MAD	15-17	22	199C	
07/19	0345-0810	MAD-TEX	15-12	24	200A	
	0530-1205	TEX-GDS	15-12	24	200B	
	0530-0810	MAD-GDS	15-16	25	200C	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
07/20	0000-0700	MAD-ACN	15-14	49	201A	
	0620-0930	ACN-GDS	15-14	49	201B	
	0620-0930	ACN-GDS	15-16	48	201C	
	0000-0700	MAD-ACN	15-16	48	201D	
07/23	0615-1150	TEX-ACN	12-17	26	204A	
	1425-1850	GDS-TEX	12-17	26	204B	
	0930-1225	ACN-GDS	12-14	21	204C	
07/24	0230-0730	ACN-MAD	12-17	26	205A	
	0820-1400	MAD-GDS	12-17	26	205B	
	0820-1745	TEX-GDS	12-17	26	205C	
	0230-0730	ACN-MAD	12-14	23	205D	
	0820-1400	MAD-GDS	12-14	23	205E	
07/25	0745-0912	MAD-TEX	12-17	26	206A	
	0850-1700	GDS-TEX	12-17	26	206C	
	1000-1515	MAD-GDS	12-14	23	206D	
08/6	2315-0415	GDS-MIL	12-14	23	218A	
	2318-0415	TEX-GDS	12-14	23	218B	
	2315-0415	GDS-MIL	12-17	26	218C	
08/8	0015-0500	MIL-GDS	15-17	22	220A	
	0015-0500	TEX-GDS	15-17	22	220B	
	0015-0500	MIL-GDS	15-16	25	220C	
	0000-0330	MIL-GDS	15-17	22	220D	
	2213-0330	MIL-TEX	15-16	25	220E	
	0000-0330	TEX-GDS	15-16	25	220F	
08/9	1800-2055	MAD-ACN	12-17	26	221A	
	0055-0630	MIL-GDS	12-17	26	221B	
	2330-0500	MIL-TEX	12-15	24	221C	
	0240-0630	MIL-GDS	12-15	24	221F	
	1800-2055	MAD-ACN	12-15	24	221E	
08/14	0105-0600	MIL-ACN	12-15	24	226A	
	0105-0600	MIL-ACN	12-14	23	226B	
08/17	0240-0700	MIL-ACN	12-15	24	229A	
	0240-0700	MIL-ACN	12-14	23	229B	
08/21	0600-1305	MAD-MIL	12-14	23	233A	
	1435-1730	MIL-GDS	12-15	24	233B	
	0600-1100	MAD-MIL	12-17	26	233C	
	1405-1800	GDS-TEX	12-17	26	233D	
	1325-1730	MIL-TEX	12-17	26	233E	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
08/22	0603-1400	MAD-MIL	16-17	47	234A	
	1300-1830	MIL-GDS	16-17	47	234B	
	0603-1400	MAD-MIL	16-15	25	234C	
	1300-1830	MIL-GDS	16-15	25	234D	
	1316-2000	GDS-TEX	16-15	25	234E	
08/23	1440-1620	TEX-GDS	12-17	26	235A	
	1700-2115	TEX-GDS	12-17	26	235B	
08/24	0932-1440	ACN-MIL	12-15	24	236A	
	1300-1945	MIL-GDS	12-15	24	236B	
	0932-1440	ACN-MIL	12-14	23	236C	
	1300-1945	MIL-GDS	12-14	23	236D	
08/27	1502-2200	MIL-GDS	12-14	23	239A	
	1502-2200	MIL-GDS	12-17	26	239B	
	1502-2028	GDS-TEX	12-17	26	239C	
08/28	1508-2300	MIL-GDS	12-14	23	240A	
	1508-2300	MIL-GDS	12-15	24	240B	
	1508-2130	TEX-GDS	12-15	24	240C	
08/29	1600-2230	MIL-GDS	12-14	23	241A	
	1600-2230	MIL-GDS	12-15	24	241B	
	1600-2100	TEX-GDS	12-15	24	241C	
08/30	1633-2130	MIL-GDS	12-17	26	242A	
	1636-2130	MIL-GDS	12-16	34	242B	
	1508-2000	MIL-TEX	12-16	34	242C	
09/3	1830-2400	ACN-MIL	12-15	24	246A	
	1830-2400	ACN-MIL	12-14	23	246B	
09/10	0005-0400	MIL-MAD	15-16	48	253A	
	2352-0400	MIL-MAD	15-14	49	253B	
09/11	2345-0450	MAD-MIL	15-16	48	254A	
	0600-1015	MIL-GDS	15-16	48	254B	
	0605-1200	TEX-GDS	15-16	48	254C	
	2345-0445	MAD-MIL	15-17	46	254D	
	0600-1015	MIL-GDS	15-17	46	254E	
09/13	0015-0530	MAD-MIL	15-17	46	256A	
	0500-1030	MIL-TEX	15-17	46	256B	
	0630-1255	GDS-TEX	15-17	46	256C	
	0015-0530	MAD-MIL	15-14	49	256D	
	0620-1030	MIL-GDS	15-14	49	256E	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
09/14	0125-0550	MAD-ACN	12-15	32	257A	
	0034-0630	MIL-MAD	12-15	32	257B	
	0605-1200	MIL-GDS	12-15	32	257C	
	0125-0550	MAD-ACN	12-14	33	257D	
	0100-0630	MIL-MAD	12-14	33	257E	
	0605-1200	MIL-GDS	12-14	33	257F	
09/15	0115-0700	ACN-MAD	12-16	34	258A	
	0115-0700	ACN-MAD	12-17	31	258B	
09/17	0640-1200	MIL-TEX	12-15	32	260A	
	0858-1330	GDS-TEX	12-15	32	260B	
	0858-1200	MIL-GDS	12-14	33	260C	
09/18	0510-1200	MIL-TEX	12-17	31	261A	
09/19	0540-0930	MIL-TEX	12-17	31	262A	
	0935-1500	MIL-GDS	12-17	31	262B	
	0630-1500	MIL-GDS	12-14	33	262C	
09/20	1126-1340	MIL-GDS	12-15	32	263A	
	1013-1230	MIL-GDS	12-16	34	263B	
	1235-1430	MIL-GDS	12-16	34	263C	
09/24	0930-1530	ACN-MIL	12-15	32	267A	
	0930-1530	ACN-MIL	12-17	31	267B	
09/26	1230-1645	MAD-MIL	12-17	31	269A	
	1352-2200	MIL-TEX	12-17	31	269B	
	1230-1645	MAD-MIL	12-15	32	269C	
09/27	0830-1730	ACN-MAD	12-17	31	270A	
	1350-1900	ACN-MIL	12-17	31	270B	
	0830-1730	ACN-MAD	12-16	34	270C	
	1350-1900	ACN-MIL	12-16	34	270D	
09/28	0916-1800	ACN-MAD	12-16	34	271A	
	1402-2000	ACN-MIL	12-16	34	271B	
	0916-1800	ACN-MAD	12-14	33	271C	
	1402-2000	ACN-MIL	12-14	33	271D	
10/1	1720-2245	ACN-MIL	12-16	34	274A	
	2235-0130	MIL-TEX	12-16	34	274B	
	1720-2245	ACN-MIL	12-15	32	274C	
10/2	1720-2100	MIL-MAD	12-15	32	275A	
	2100-0230	MIL-TEX	12-15	32	275B	
	1720-2100	MIL-MAD	12-16	34	275C	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
10/3	1820-2200	MIL-MAD	12-15	32	276A	
	2010-0300	MIL-TEX	12-15	32	276B	
	1835-2200	MIL-MAD	12-14	33	276C	
10/4	1930-2300	ACN-MAD	12-16	34	277A	
	1930-2300	ACN-MIL	12-16	34	277B	
	0025-0400	MIL-TEX	12-16	34	277C	
	1930-2300	ACN-MAD	12-14	33	277D	
	1930-2300	ACN-MIL	12-14	33	277E	
10/5	1730-2200	ACN-MAD	12-17	31	278A	
	1923-2400	MAD-MIL	12-17	31	278B	
	1730-2200	ACN-MAD	12-14	33	278C	
	1923-2400	MAD-MIL	12-14	33	278D	
10/16	0300-0700	ACN-MIL	12-15	32	289A	
	0300-0700	ACN-MIL	12-14	33	289B	
10/22	0950-1430	ACN-MIL	12-17	31	295A	
	0950-1430	ACN-MIL	12-16	34	295B	
10/25	1140-1600	MAD-MIL	12-15	32	298A	
	1140-1600	MAD-MIL	12-14	33	298B	
11/2	1500-2200	MAD-ACN	12-17	31	306A	
	1905-2230	MAD-MIL	12-17	31	306B	
	1500-2200	MAD-ACN	12-14	33	306C	
	1905-2230	MAD-MIL	12-14	33	306D	
11/5	2320-0600	MIL-GDS	16-17	47	309A	
	2325-0600	MIL-GDS	16-15	48	309B	
11/7	0000-0700	MIL-GDS	16-17	47	311A	
	0000-0700	MIL-GDS	16-15	48	311B	
	2130-0300	MAD-MIL	12-17	31	311C	
	0030-0550	MIL-GDS	12-17	31	311D	
	2130-0300	MAD-MIL	12-14	33	311E	
	0030-0800	MIL-GDS	12-14	33	311F	
11/8	1832-0415	MAD-ACN	12-15	32	312A	
	2150-0500	MAD-MIL	12-15	32	312B	
	0030-0700	MIL-GDS	12-15	32	312C	
	1832-0415	MAD-ACN	12-14	33	312D	
	2150-0500	MAD-MIL	12-14	33	312E	
	0030-0700	MIL-GDS	12-14	33	312F	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
11/9	1934-0500	MAD-ACN	12-16	34	313A	
	2202-0400	MAD-MIL	12-16	34	313B	
	0045-0600	MAD-GDS	12-16	34	313C	
	1945-0500	MAD-ACN	12-15	32	313D	
	2202-0400	MAD-MIL	12-15	32	313E	
	0045-0600	MAD-GDS	12-15	32	313F	
11/27	0500-1830	MAD-MIL	12-15	44	331A	
	1500-1830	MAD-MIL	12-14	42	331B	
11/28	1545-1945	MAD-MIL	12-17	41	332A	
	1545-1940	MAD-MIL	12-16	43	332B	
11/29	1700-2000	MAD-ACN	12-17	41	333A	
	1700-2200	MIL-ACN	12-17	41	333B	
	2155-0115	MIL-GDS	12-17	41	333C	
	1756-2000	MAD-ACN	12-16	43	333D	
	1756-2115	MIL-ACN	12-16	43	333E	
	2155-0115	MIL-GDS	12-16	43	333F	
11/30	1750-2130	MAD-MIL	12-15	44	334A	
	2145-0230	MIL-GDS	12-15	44	334B	
	1745-2130	ACN-MAD	12-14	42	334C	
	1715-2130	MAD-MIL	12-14	42	334D	
	2145-0230	MIL-GDS	12-14	42	334E	
12/1	1645-2100	ACN-MAD	12-15	44	335A	
	1645-2100	ACN-MAD	12-14	42	335B	
12/3	2305-0400	MIL-GDS	15-17	46	337A	
	2305-0400	MIL-GDS	15-16	45	337B	
12/4	1915-0030	MIL-MAD	15-17	46	338A	
	2315-0600	MIL-GDS	15-17	46	338B	
	1915-0030	MIL-MAD	15-16	45	338C	
	2309-0600	MIL-GDS	15-16	45	338D	
12/6	0218-0650	MIL-GDS	15-16	45	340A	
	0218-0650	MIL-GDS	15-16	45	340B	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
12/7	0230-0645	MIL-GDS	12-17	41	340C	
	0230-0645	MIL-GDS	12-14	42	340D	
12/20	1426-1830	MIL-GDS	12-17	41	354A	
	1426-1830	MIL-GDS	12-14	42	354B	
12/21	1330-1915	MIL-GDS	12-15	44	355A	
	1321-1915	MIL-GDS	12-16	43	355B	
1974						
01/9	0345-1515	MAD-MIL	12-17	41	009M	
	0345-1515	MAD-MIL	12-17	41	009N	
	0530-1200	MIL-GDS	12-17	41	009P	
	0530-1200	MIL-GDS	12-17	41	009Q	
01/10	0215-0600	MAD-MIL	15-16	45	010M	
	0455-1100	MIL-GDS	15-16	45	010N	
	0215-0600	MAD-MIL	15-12	44	010P	
	0500-1100	MIL-GDS	15-12	44	010Q	
01/11	0200-0600	MAD-MIL	14-12	42	011M	
	0605-1100	MIL-GDS	14-12	42	011N	
	0200-0600	MAD-MIL	14-12	42	011P	
	0605-1100	MIL-GDS	14-12	42	011Q	
01/28	2215-0230	MIL-GDS	12-16	43	028M	
	2215-0230	MIL-GDS	12-14	42	028N	
01/30	1800-2400	MAD-MIL	12-17	41	030M	
	2112-0400	MIL-GDS	12-17	41	030N	
	1800-2400	MAD-MIL	12-14	42	030P	
	2112-0400	MIL-GDS	12-14	42	030Q	
02/1	1850-2400	MAD-MIL	16-17	47	032M	
	2100-0145	MIL-GDS	16-17	47	032N	
	2100-0145	MIL-GDS	16-15	45	032P	
02/2	1746-2200	MAD-ACN	16-17	47	033M	
	1900-2200	MAD-ACN	16-15	45	033N	
02/15	0515-1000[1]	ACN-MAD	12-17	41	046M	
	0447-1000	ACN-MAD	12-16	43	046N	
02/16	0430-1000	ACN-MAD	15-17	46	047M	
	0425-1000	ACN-MAD	15-16	45	047N	

[1] Possible offset at MAD

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
02/20	1405-1710	MIL-GDS	12-15	44	051N	
02/21	1015-1700	MAD-ACN	12-17	41	052M	
	1400-1800	ACN-MIL	12-17	41	052N	
	1500-2200	MIL-GDS	12-17	41	052P	
	1135-1700	MAD-ACN	12-16	43	052Q	
	1352-1800	ACN-MIL	12-16	43	052R	
	1454-2200	MIL-GDS	12-16	43	052S	
02/22	1200-1745	ACN-MAD	12-15	44	053M	
	1400-1800	ACN-MIL	12-15	44	053N	
	1509-2200	MIL-GDS	12-15	44	053P	
	1200-1745	ACN-MAD	12-14	42	053Q	
	1400-1800	ACN-MIL	12-14	42	053R	
	1500-2200	MIL-GDS	12-14	42	053S	
02/23	1200-1830	ACN-MAD	12-17	41	054M	
	1200-1830	ACN-MAD	12-14	42	054N	
02/25	1348-2030	ACN-MIL	12-17	41	056M	
	1700-0100	MIL-GDS	12-17	41	056N	
	1348-2030	ACN-MIL	12-16	43	056P	
	1700-0100	MIL-GDS	12-16	43	056Q	
02/26	2317-0200	MIL-GDS	12-15	44	057M	
	2317-0200	MIL-GDS	12-16	43	057N	
02/27	1745-0300	MIL-GDS	12-15	44	058M	
	1745-0300	MIL-GDS	12-14	42	058N	
02/28	1615-2007	ACN-MIL	12-17	41	059M	
	2010-0300	MIL-GDS	12-17	41	059N	
	1615-2100	ACN-MIL	12-14	42	059P	
	1824-0300	MIL-GDS	12-14	42	059Q	
03/4	2235-0300[1]	MIL-GDS	15-17	46	063M	
	2235-0300	MIL-GDS	15-16	45	063N	
03/15	0240-0745	ACN-MAD	12-17	50	074M	
	0240-0910	ACN-MAD	12-14	51	074N	

[1]A5 hi bit rate

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
03/22	1300-1630	MAD-MIL	12-15	52	081M	
	1300-1630	MAD-MIL	12-16	53	081P	
03/26	0955-1425	ACN-MAD	16-17	54	085M	
	1315-1715	MAD-MIL	16-17	54	085N	
	0955-1425	ACN-MAD	16-15	55	085P	
	1315-1715	MAD-MIL	16-15	55	085Q	
03/27	1720-2200	MAD-MIL	15-14	56	086M	
	1110-1630	MAD-ACN	15-16	55	086N	
	1400-2200	MAD-MIL	15-16	55	086P	
04/1	2136-0200	ACN-MAD	16-17	54	091M	
	2040-0200	ACN-MIL	16-17	54	091N	
	2136-0200	ACN-MAD	16-15	55	091P	
	2040-0200	ACN-MIL	16-15	55	091Q	
04/2	2010-0200	MAD-ACN	16-17	54	092M	
	2010-0200	MAD-MIL	16-17	54	092N	
	2010-0200	MAD-ACN	16-15	55	092P	
	2010-0200	MAD-MIL	16-15	55	092Q	
04/9	0000-0630	ACN-MAD	14-12	51	099M	
	0000-0630	ACN-MAD	14-15	56	099N	
	2300-0415	ACN-MAD	12-14	51	099P	
	2315-0415	ACN-MAD	12-17	50	099Q	
04/16	0400-1230	MAD-ACN	17-16	54	106M	
	0400-1230	MAD-ACN	17-15	57	106N	
04/22	1320-1845	MAD-MIL	17-15	57	112M	
	1250-1845	MAD-MIL	17-16	54	112N	
04/23	1445-2330	GDS-MIL	15-12	52	113M	
	1445-2330	GDS-MIL	15-14	56	113N	
04/24	1500-1930	ACN-MAD	17-15	57	114M	
	1455-1904	ACN-MAD	17-16	54	114N	
04/29	1845-2312	ACN-MAD	16-12	53	119M	
	1845-2400	MAD-MIL	16-12	53	119N	
	1845-2312	ACN-MAD	16-17	54	119P	
	1845-2400	MAD-MIL	16-17	54	119Q	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
04/30	1715-2300	ACN-MAD	16-12	53	120M	
	1715-2300	ACN-MAD	16-17	54	120N	
05/1	1955-2400	MAD-MIL	16-15	55	121M	
	1955-2400	MAD-MIL	16-17	54	121N	
05/11	0128-0800	ACN-MAD	14-12	51	131M	
	0128-0800	ACN-MAD	14-15	56	131N	
05/12	0145-0800	ACN-MAD	12-15	52	132M	
	0150-0800	ACN-MAD	12-17	50	132N	
05/13	0126-0700	ACN-MAD	12-14	51	133M	
	0126-0700	ACN-MAD	12-17	50	133N	
05/15	0228-0850	ACN-MAD	16-15	55	135M	
	0228-0850	ACN-MAD	16-17	54	135N	
05/17	1300-1845	GDS-MIL	12-15	52	137M	
	1627-1845	GDS-MIL	12-17	50	137N	
05/20	1155-1600	MAD-ACN	16-17	54	140M	
	1830-2200[1]	MIL-GDS	16-17	54	140N	
	1155-1600	MAD-ACN	16-12	53	140P	
	1830-2200[1]	MIL-GDS	16-12	53	140Q	
05/21	1908-2315	MIL-GDS	15-16	55	141M	
	1908-2315	MIL-GDS	15-14	56	141N	
05/22	1115-1800	MAD-ACN	15-16	55	142M	
	1115-1800	MAD-ACN	15-14	56	142N	
05/27	1240-2000	MAD-ACN	12-14	51	147M	
	1245-2000	MAD-ACN	12-15	52	147N	
05/28	1830-2200	MAD-MIL	12-14	51	148M	
	1830-2200	MAD-MIL	12-16	53	148N	
05/30	2100-0100	MAD-MIL	16-15	55	150M	
	2210-0210	MIL-ACN	16-15	55	150N	
	2100-0100	MAD-MIL	16-17	54	150P	
	2210-0210	MIL-ACN	16-17	54	150Q	

[1] Mil gap 1854-1942

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
06/5	0110-0400	ACN-MAD	16-15	55	156M	
	0110-0400	ACN-MAD	16-15	55	156N	
06/7	0005-0600	ACN-MAD	16-15	55	158M	
	0005-0600	ACN-MAD	16-12	53	158N	
06/11	0215-0935	MAD-ACN	12-15	52	162M	
	0215-0935	MAD-ACN	12-14	51	162N	
06/13	0215-1115	ACN-MAD	12-17	50	164M	
	0215-1115	ACN-MAD	12-16	53	164N	
06/17	1300-2000	MIL-GDS	16-17	54	168M	
	1300-2000	MIL-GDS	16-12	53	168N	
06/18	0725-1430	MAD-ACN	16-17	54	169M	
	0725-1430	MAD-ACN	16-12	53	169N	
06/19	0700-1335	MAD-ACN	15-14	56	170M	
	0700-1330	MAD-ACN	15-17	57	170N	
06/20	1830-2230	MIL-GDS	15-14	56	171M	
	1830-2230	MIL-GDS	15-17	57	171N	
06/24	1615-2115	MAD-MIL	15-16	60	175M	
	1615-2115	MAD-MIL	15-14	61	175N	
06/25	1800-2200	MAD-MIL	12-16	62	176M	
	1800-2200	MAD-MIL	12-14	63	176N	
06/28	2000-0200	MIL-ACN	12-17	64	179M	
	2000-0200	MIL-ACN	12-16	62	179N	
07/1	1910-0224	ACN-MAD	12-17	64	182M	
	2224-0224	MAD-MIL	12-17	64	182N	
	1910-0224	ACN-MAD	12-14	63	182P	
	2224-0224	MAD-MIL	12-14	63	182Q	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
07/2	1920-0230	ACN-MAD	12-15	65	183M	
	1920-0230	ACN-MAD	12-14	63	183N	
07/13	0800-1222	ACN-GDS	15-16	60	194M	
	0800-1222	ACN-GDS	15-17	67	194N	
07/14	0837-1258	ACN-GDS	16-15	60	195M	
	0837-1258	ACN-GDS	16-17	66	195N	
07/15	1300-1815	GDS-MIL	16-17	66	196M	
	1300-1815	GDS-MIL	16-15	60	196N	
07/16	1100-1500	ACN-GDS	16-17	66	197M	
	1100-1500	ACN-GDS	16-15	60	197N	
07/17	1310-1700	MIL-MAD	12-14	63	198M	
	1310-1700	MIL-MAD	12-17	64	198N	
07/19	1526-1844	MIL-ACN	12-15	65	200M	
	1526-1844	MIL-ACN	12-14	63	200N	
07/22	1205-2000	ACN-MAD	16-17	66	203M	
	1205-2000	ACN-MAD	16-12	62	203N	
07/23	2100-0200	GDS-MIL	16-12	62	204N	
07/24	1400-2100	MAD-ACN	12-15	65	205M	
	1400-2100	MAD-ACN	12-14	63	205N	
07/25	2115-0300	GDS-MIL	12-15	65	206M	
	2115-0300	GDS-MIL	12-14	63	206N	
07/29	1740-0100	MAD-ACN	16-17	66	210M	
	1740-0100	MAD-ACN	16-15	60	210N	
07/30	1940-0200	MAD-ACN	16-17	66	211M	
	1940-0200	MAD-ACN	16-15	60	211N	
07/31	1830-0300	MAD-ACN	15-14	61	212M	
	1830-0300	MAD-ACN	15-12	65	212N	
08/2	2100-0320	MAD-ACN	15-14	61	214M	
	2100-0320	MAD-ACN	15-12	65	214N	
08/5	0000-0430	ACN-MAD	12-17	64	217M	
	0000-0430	ACN-MAD	12-14	63	217N	
	2200-0300	ACN-MAD	16-15	60	217P	
	2200-0300	ACN-MAD	16-12	62	217Q	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
08/14	0822-1200	MAD-ACN	17-15	67	226M	
	0822-1200	MAD-ACN	17-12	64	226N	
08/15	1330-2100	MIL-GDS	17-15	67	227M	
	1330-2100	MIL-GDS	17-12	64	227N	
08/16	1000-1630	ACN-MAD	15-16	60	228M	
	1000-1630	ACN-MAD	15-14	61	228N	
08/19	1318-1718	ACN-MIL	12-16	62	231N	
	1318-1718	ACN-MIL	12-15	65	231Q	
08/20	1423-1950	ACN-MAD	12-14	63	232M	
	1423-1950	MAD-MIL	12-14	63	232N	
	1423-1950	ACN-MAD	12-17	64	232P	
	1423-1950	MAD-MIL	12-17	64	232Q	
09/6	0330-0800	ACN-MAD	16-17	66	249M	
	0330-0900	ACN-MAD	16-12	62	249N	
09/7	0300-0845	ACN-MAD	15-14	61	250M	
	0300-0845	ACN-MAD	15-12	65	250N	
09/9	0130-1050	ACN-MAD	12-17	64	252M	
	0130-1050	ACN-MAD	12-14	63	252N	
09/10	0400-0955	ACN-MAD	12-17	62	253M	
	0400-0955	ACN-MAD	12-17	64	253N	
09/16	1235-1730	MAD-MIL	12-16	62	259M	
	1235-1730	MAD-MIL	12-15	65	259N	
09/19	1520-2100	ACN-MIL	15-17	67	262M	
	1520-2100	ACN-MIL	15-14	61	262N	
09/23	1900-0100	ACN-MIL	12-14	63	266M	
	1900-0100	ACN-MIL	12-17	64	266N	
09/27	2215-0230	ACN-MAD	15-16	60	270M	
	2215-0230	MIL-MAD	15-16	60	270N	
	2215-0230	ACN-MAD	15-17	67	270P	
	2215-0230	MIL-MAD	15-17	67	270Q	
09/30	2300-0300	ACN-MAD	15-16	60	273M	
	2300-0300	MIL-MAD	15-16	60	273N	
	2300-0300	ACN-MAD	15-17	67	273P	
	2300-0300	MIL-MAD	15-17	67	273Q	

Date (mm/dd)	Times (hhmm)	Stations	ALSEPS	Obs. Lib. Tape	Series Name	Notes
10/1	2148-0609	ACN-MAD	15-16		274M	
	2148-0609	ACN-MAD	15-17		274N	
10/7	0545-1000	ACN-GDS	15-12		280M	
	0545-1000	ACN-GDS	15-14		280N	
10/8	0645-1100	GDS-ACN	12-14		281M	
	0645-1100	GDS-ACN	12-17		281N	
	1322-1700	GDS-MIL	12-14			
	1322-1700	GDS-MIL	12-17			
10/14	1300-1700	ACN-MIL	15-14		287M	
	1300-1700	ACN-MIL	15-12		287N	
10/18	1710-2115	ACN-MIL	16-15		291M	
	1710-2115	ACN-MIL	16-17		291N	
10/24			12-14		297M	
			12-14		297N	
			12-17		297P	
			12-17		297Q	
10/25	2057-2355	MAD-MIL	15-16		298M	
	2000-2355	MAD-MIL	15-17		298N	