NASA GRANT NGR33-011-009

FINAL TECHNICAL REPORT

FEASIBILITY STUDY FOR THE USE OF A YF-12 AIRCRAFT AS A SCIENTIFIC INSTRUMENT PLATFORM FOR OBSERVING THE 1970 SOLAR ECLIPSE

Prepared for

Headquarters
National Aeronautics and Space Administration
Washington, D. C. 20546

Robert D. Mercer

Robert D. Mercer
Principal Investigator

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The Dudley Observatory
100 Fuller Road
Albany, New York 12205

Abstract

This is the Final Technical Report on NASA Grant NGR33-011-009 entitled, "Feasibility Study for the Use of a YF-12 Aircraft as a Scientific Instrument Platform for Observing the 1970 Solar Eclipse". The study was successfully completed in the fall of 1968 with a presentation to the Office of Solar Physics at NASA Headquarters and with the submittal of supporting scientific and technical reports.

That information indicated that a YF-12 or SR-71 type aircraft could be instrumented with several cameras and a ten-inch, f/43.2 telescope feeding spectrographic and photometric systems for measurements of the solar corona and chromosphere. Spatial resolution radially across these regions as low as twenty-five kilometers might be achievable. Total time for observations could be as long as ninety minutes with most of that time spent above ninety percent or more of the atmosphere.

A recommended schedule for aircraft instrumentation and flight check-out was given at the presentation in 1968. Representatives in the office of the Assistant Secretary of the Air Force for Research and Engineering, who controls operations for these aircraft, tentatively approved these plans. No official costs were made available to the Principal Investigator (PI), but such an undertaking was acknowledged to be expensive with estimated costs in the one-to-six million dollar range. As a result of funding constraints on NASA at that time and lack of success by the PI in his efforts to elicit additional financial support from other interested agencies, the results of this feasibility study could not be utilized. However, the study also included a short assessment of feasibility for all solar eclipses through 1981. The solar eclipse of 1977 in the northeastern Pacific Ocean was shown to be equally as useful for YF-12 or SR-71 aircraft observations as the eclipse of 1970.

This Final Technical Report together with its references will review the scientific and engineering findings of the study as presented in late 1968.

Background

In the winter of 1967 Mr. Robert D. Mercer, then an officer in the U.S. Air Force, made an approximate check on the velocity of the lunar umbra as it would travel over the earth during the solar eclipse of 1970., He found the minimum velocity to be about 1300 knots with the shape of the velocity curve approximating the function for the derivative of the arcsin. For almost a two hour period, using the minimum velocity as a midpoint, the speeds would be below 2000 knots and deceleration/acceleration would not exceed 1.0 ft./sec. This velocity/acceleration profile was well within the capability of several new military aircraft then flying. It not only seemed possible to follow an eclipse for a considerably longer time than would otherwise be possible using scientifically outfitted aircraft, such as the NASA Convair 990, but it also appeared feasible for the first time to move within the umbra, particularly along its boundary. This latter capability could permit study of the chromosphere for tens of minutes instead of only ten to twenty seconds. Furthermore, the high altitude capabilities of these fast military vehicles would open up telluric passbands where data had been excluded to previous observers, expecially in the infrared which is badly attenuated by atmospheric water vapor over large spectral regions.

The first aircraft considered for this work was the XB-70A, the test version of a supersonic bomber completing its schedule of flights for the Air Force. However, discussions with Col. J. Cotton, the chief test pilot, revealed significant operational and maintenance constraints that would severely compromise its scientific utility. Col. Cotton suggested that serious consideration be given to using the YF-12A, an aircraft with a very unique altitude and airspeed flight envelope and three of which were then available.

The sum of these ideas was presented verbally to Drs. H. Glaser, J. Gill and Mr. M. Dubin at NASA Headquarters in April of 1967 and followed up with a proposal in writing. NASA and Dr. C. L. Hemenway mutually arranged for Mr. Mercer to pursue the feasibility of this idea at the Dudley Observatory.

Prior to formal implementation of this study Mr. Mercer prevailed on NASA Headquarters to transfer funds to the Flight Mechanics Branch of the Computing and Analysis Division at the Manned Spacecraft Center for the development of a computer program to calculate eclipse locations, their velocities, accelerations, and boundaries versus time and flight altitude. Mr. Mercer derived the required vector equations, defined inputs and outputs, and flow-charted the problem. Mr. R. Piersall performed programing, computer checkout, and documentation. Attachment 1 to this report entitled, "Eclipse Determination, Program D074, Project 1191," is a copy of that documentation.

Technical Progress under the Grant

Formal award of Research Grant NGR 33-011-009 to the Dudley Observatory with Mr. Mercer as Principal Investigator (PI) was effected in August 1967. This work was performed under the technical monitorship of Drs. H. Glaser and G. Oertel in the Solar Physics Office, Code SG, under the Office for Space Science and Applications at NASA Headquarters. The initial collection of information on the YF-12A and its sister ship, the SR-71A, was slowed while the appropriate administrative and security arrangements were worked out by the PI, NASA Headquarters, the U.S. Air Force and their prime contractor on these aircraft, the Advanced Development Projects Group of the Lockheed-California Company.

Once the data on the eclipse track for March 1970 was available, planning began to determine the most useful flight profile for observing the chromosphere, which is more difficult to study than the corona. From these profiles it was possible to compute accurate solar pointing and the range of angles over which a heliostat would have to move to feed a fixed-position, long focal length telescope. Consideration of other, non-eclipse investigations was carried out as a parallel effort under this study so that proposed aircraft modifications could be justified in terms of their fullest scientific utility. Although aircraft structural features were not exactly known at first, some information was available on the contours of the outer skin mold line. This was compared to the required observing angles versus aircraft headings to determine the useable portion of the velocity profile.

When detailed specifications on the aircraft did become available, particularly operational capabilities, it was quickly apparent that the total time in the umbra would increase from sixty to about ninety minutes. In either case, this would require the use of tanker aircraft for aerial refueling. The group assisting the Assistant Secretary of the Air Force for Research and Engineering indicated that such support could be arranged without difficulty. Also, at the suggestion of that office, consideration for using the SR-71A, a strategic reconnaissance version of the aircraft, was added to the study.

Data on the aircraft's instrumentation bays and on-board systems showed that a ten-inch, f/43.2, Schiefspiegel telescope could be accommodated and coupled with spectrographic, photometric and photographic systems. A closed circuit television for remote monitoring and control of these systems could also be included so that an Experiment Systems Operator (ESO) could appropriately position and rotate a slit spectograph on the image of the chromosphere or corona during flight. The ESO could also make use of the autopilot and on-board computer to vary flight path headings in order to vary the position of the vehicle with respect to the umbral-penumbral

Technical Progress under the Grant - Continued

boundary for analysis of the chromosphere in radial slices as narrow as twenty-five kilometers at the sun. This feat would represent not only a five-fold improvement over ground-based resolutions, but also, it would, provide an increase in observation time by more than a factor of one hundred.

Finally, the success of the computer program for computation of eclipse tracks and their related data permitted the study to be enlarged in scope to include all solar eclipses over the expected operational life-time of these aircraft. This effort indicated that the eclipses of March 1970 and October 1977 were the most ideally suited for these aircraft, because the angle of the viewing port in the right-hand chine instrumentation bay would allow the heliostat to feed the full ten-inch aperture of the telescope. While the eclipse of June 1973 would be the best of the twentieth century, it would be too far overhead for good viewing by the long focal length system. However, instruments mounted in the nose compartment would have much greater flexibility in pointing, and, in general, their viewing opportunities would only be a function of the minimum in umbral speeds over the one-and-a-half decades investigated. Eclipses in March 1970, July 1972, October 1977 and February 1979 would be the simplest and least expensive to support in terms of aircraft operations and maintenance. All matters considered, the eclipse in 1977 would be the very best for utilization of this aircraft. The eclipse of 1970 provided an ideal opportunity to begin this work, since it would have been the initial check-out of this new capability, where all modifications to the vehicle could be used again without change. A resume, showing specific details for all of this work is presented as Attachment 2 to this report.

All of these data were presented to NASA Headquarters in late Spring of 1968. The Solar Physics Office suggested that further information on particular scientific experiments be developed, especially through solicitation for expressions of interest from other scientists working in this discipline. This was done by arranging an informal meeting at the Dudley Observatory on 25-26 July, 1968. A full report of those proceedings is given in Attachment 3 to this report. In addition to the government and university groups represented at that meeting, the PI visited others at NASA and Air Force Centers and contacted representatives from the Department of Defense's Advanced Research Projects Agency and the Office of Aerospace Research in an effort to build a broader base in the government's financial support, especially for the aircraft modification costs.

While great interest and enthusiasm was expressed by all, the constraints on funding which existed in government at that time were just too severe. NASA had to drop back in its total commitments, since the Apollo

Technical Progress under the Grant - Continued

Lunar Program had passed through its maximum budget the previous year, and only the major, on-going programs were allocated funds. The anticipated expenditure for the eclipse project was several millions of dollars, based on informal costing information supplied by the Lockheed-California Company. The Solar Physics Office could do little if outside support of sufficient magnitude could not be mustered. Furthermore, that office was well into commitments for Skylab experiments, especially those included in the Apollo Telescope Mount, and felt that priorities could not be modified or resources could not be spread at that crucial time. Hence, the 1970 eclipse opportunity had to be missed.

No additional work nor new developments have taken place from late 1968 to the present.

Conclusions

This study has resulted in the conclusions listed below. They were verbally presented to NASA Headquarters in early Fall of 1968.

1. It is feasible to fly YF-12 or SR-71 types of aircraft in solar eclipses for periods of one hour or more at altitudes from 40,000 to 80,000 feet. Higher altitudes can be achieved and maintained for correspondingly shorter durations of observation time.

2. Information on most of the chromosphere and some of the corona can be collected with greater accuracies and at lower sensitivities than that obtainable from surface sites or any other non-space vehicles by using such aircraft. Use of these instrumented aircraft together with eclipse geometries can provide more valuable and less costly answers to certain solar physics questions than even the use of current-state-of-the-art coronographs in earth orbit.

3. These aircraft can be modified to accept eclipse observing payloads of quite complex design. This includes a long focal length, ten-inch aperture telescopic system to feed spectrographs, photometers and cameras in a chine bay and also more compact photographic instruments, such as fast cameras and spectrographic equipments in the nose compartment.

Conclusions - Continued

4. The aircraft can be operated world-wide and can, therefore, cover any eclipse track if permission for use of airspace or overflight of territory has been granted where required. Difficulty in obtaining such permission can be anticipated from countries with which the U.S. does not have close or cordial relations. Aircraft and instrumentation maintenance and aerial refueling by supporting tankers would be more costly the more remote the eclipse track is from the continental U.S. or its active military bases around the world.

5. Unofficial cost estimates range from approximately $1 million to $6 million. Preparation and participation in an eclipse flight limited to the simplest modifications for installation of scientific equipments in just the nose compartment would require funding at the former figure. This same participation with the fullest complement of scientific instruments possible to completely utilize the aircraft's potential for solar physics studies would be at the latter figure.

6. As further justification for the considerable costs associated with permanent modifications to these aircraft, it must be noted that upward viewing ports can be used to great scientific advantage for such disciplines as stellar astronomy, planetary atmospheres and atmospheric physics as well. A one-meter resolution perpendicular to the direction of flight is certainly possible, and this will permit the lunar occultation measurement of nearby stellar diameters by Fresnel diffraction techniques. Flights at altitudes above most of the earth's atmosphere will permit better spectrophotographic studies of other planetary atmospheres. Finally, these aircraft can be flown along tracks of constant solar elevation or depression angles so that analytical studies can be performed on our own atmosphere.

Recommendations

At the time of this report only one recommendation can be made:

> NASA should review the potential for solar physics and other scientific studies made possible by these aircraft and initiate a program for eclipse flights at the earliest opportunity that sufficient funds become available.

Acknowledgements

This work would not have been possible without the help and advice of the following individuals and, in some cases, their supporting teams.

1. Dr. Donald C. Schmalberger and Dr. Curtis L. Hemenway of the Dudley Observatory and of the State University of New York at Albany.

2. Dr. Harold Glaser, Dr. Goetz K. Oertel, Dr. Jocelyn R. Gill and Mr. Maurice Dubin in the Physics and Astronomy Program Office, Col. John M. Coulter in the DOD and Interagency Affairs Office and Mr. Lawrence J. Bour in the Security Office at NASA Headquarters.

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5. Messers Russell Daniell, Richard DeGrey and David Olsen of the Advanced Development Projects Group of the Lockheed-California Company.

6. Messers Robert R. Piersall and George B. Roush of the Flight Mechanics Applications Branch of the Computing and Analysis Division at the NASA Manned Spacecraft Center.

COMPUTER PROGRAM DOCUMENTATION

ECLIPSE DETERMINATION

Program D074
Project 1191

By

Robert R. Piersall

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas

August 1969

Revised January 1970

92003

MSC PROGRAM NUMBER D074

ECLIPSE DETERMINATION

Prepared by: Robert R. Piersall, Scientific Programmer
Flight Operations Support Section

Approved by: Wallace F. Stewart, Head
Flight Operations Support Section

Approved by: Monte T. Cunningham, Chief
Flight Mechanics Applications Branch

National Aeronautics and Space Administration
Manned Spacecraft Center
Houston, Texas
August 1969

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THIS FORM MUST BE COMPLETED BY TYPEWRITER

COMPUTER PROGRAM ABSTRACT

01 4	01 7 PROGRAM NO	01 14 DATE
MSC	D074	050769

01 23 TITLE OF PROGRAM (61 CHARACTERS MAXIMUM): Eclipse Determination

PARENT PROGRAM: 02 11 CATEGORY / 02 15 SITE / 02 13 PROGRAM NO.

02 26 CATEGORY	02 27 LANGUAGE NO. 1	02 32 LANGUAGE NO 2	02 37 KEY WORDS (6 MAXIMUM SEPARATED BY COMMAS)
D	FORS		Focus, Major Axis, Minor Axis, Cone, Umbra

WHO TO CONTACT ABOUT THE PROGRAM

05 14 CONTACT	05 28 SITE	05 31 ORGN CODE	05 39 PROJECT NO.	05 45 NASA CENTER
Piersall	MSC	ED32	1191	

05 48 STATUS: ☐ A. UNDER DEVELOPMENT ☒ B. OPERATIONAL ☐ C. COMPLETED

05 49 ☐ A. THIS PROGRAM IS NOT FOR SHARING

DATES

05 50 INITIATED	05 54 COMPLETED
0767	

05 58 REVISION CODE: ☐ A. REVISION ☐ B CANCELLATION

TIME AND COST FOR DEVELOPMENT

05 59 MANMONTHS	05 64 MACHINE HOURS	05 69 COMPUTER TYPE	05 74 TOTAL COST (DOLLARS)
6.9	14.50	1108	

ELITE MARGIN / PICA MARGIN

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ABSTRACT

This solar-eclipse program produces data as a function of time on the locus of the umbra-penumbral boundary at any given altitude on or above the surface of the earth, along with the elements of the ellipse describing this interception. Program output is in tabular form and the following quantities are sample outputs: Umbra cone reference ellipse centerline intersection, elements of the intersection ellipse, and the reference ellipse (semimajor and semiminor axis end points) and other related quantities.

MSC Form 860 (Rev Jun 68) PREVIOUS EDITIONS ARE OBSOLETE.

1. INTRODUCTION

This solar-eclipse program produces data as a function of time on the locus of the umbral-penumbral boundary at any given altitude on or above the earth. This type of information is not easily derived from the normal sources; that is, from the available canons of eclipses, or from the special-event circulars issued by the Nautical Almanac Office of the U.S. Naval Observatory. The special-event circulars are very accurate, but they are usually issued not more than 2 years preceding the eclipse; therefore, the planning for eclipses more than 2 years in advance or the comparison of detailed ephemerides for several future eclipses is greatly restricted.

Also, the data from either the canons of eclipses or from the special-event circulars require further extensive computation to develop positional information on the umbral-penumbral boundary than the data from this program require. The output data of this eclipse program have been developed for subsequent combination with existing automatic digital plotting routines so that one tabulated listing of data and a variety of mapping and graphing routines can be requested by the user.

The basic formulation was done by Robert D. Mercer, Research Associate at Dudley Observatory, Albany, New York. His work was supported by The National Aeronautics and Space Administration under Research Grant NO-NGR-33-011-009.

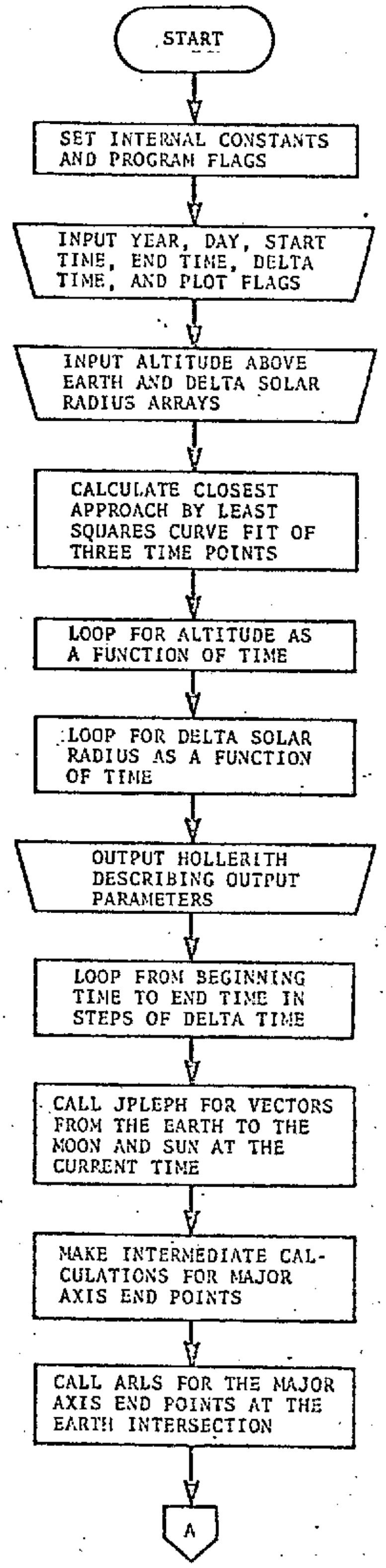
2. PROGRAM DESCRIPTION

2.1 GENERAL DESCRIPTION

The umbral-penumbral boundary positional information is derived by a vector-form computation of the four elements of the umbral cone. The contacts of the four elements with the oblate spheroid on or above the earth form the ends of the major and minor axes of a surface figure that is almost elliptical. The apparent positions of the sun and moon are used for the cone construction, and the corrections for atmospheric refractive bending are included.

The listed output includes the time related positions of an ellipse's focus and center; the ellipse's eccentricity; the lengths and orientation of the semimajor and semiminor axes, and the semilatus rectum; the velocity and azimuth of the ellipse's motion over the surface, and the positions of the umbral cone centerline and the solar north or south pole image points. In addition, it is possible to vary the radius of the solar disk so that image shadow positions of the sublimb, chromosphere, and inner coronal features can be determined. It is also possible to make time variations in the altitude of the surface of observation which is being intersected by the umbral cone during the eclipse pass. Such a variation allows the computation of all of the parameters necessary to develop or to analyze a complete flight profile for the observing aircarft.

The main program flow chart is given in Figure 1.



gure 1. - Main program flow chart.

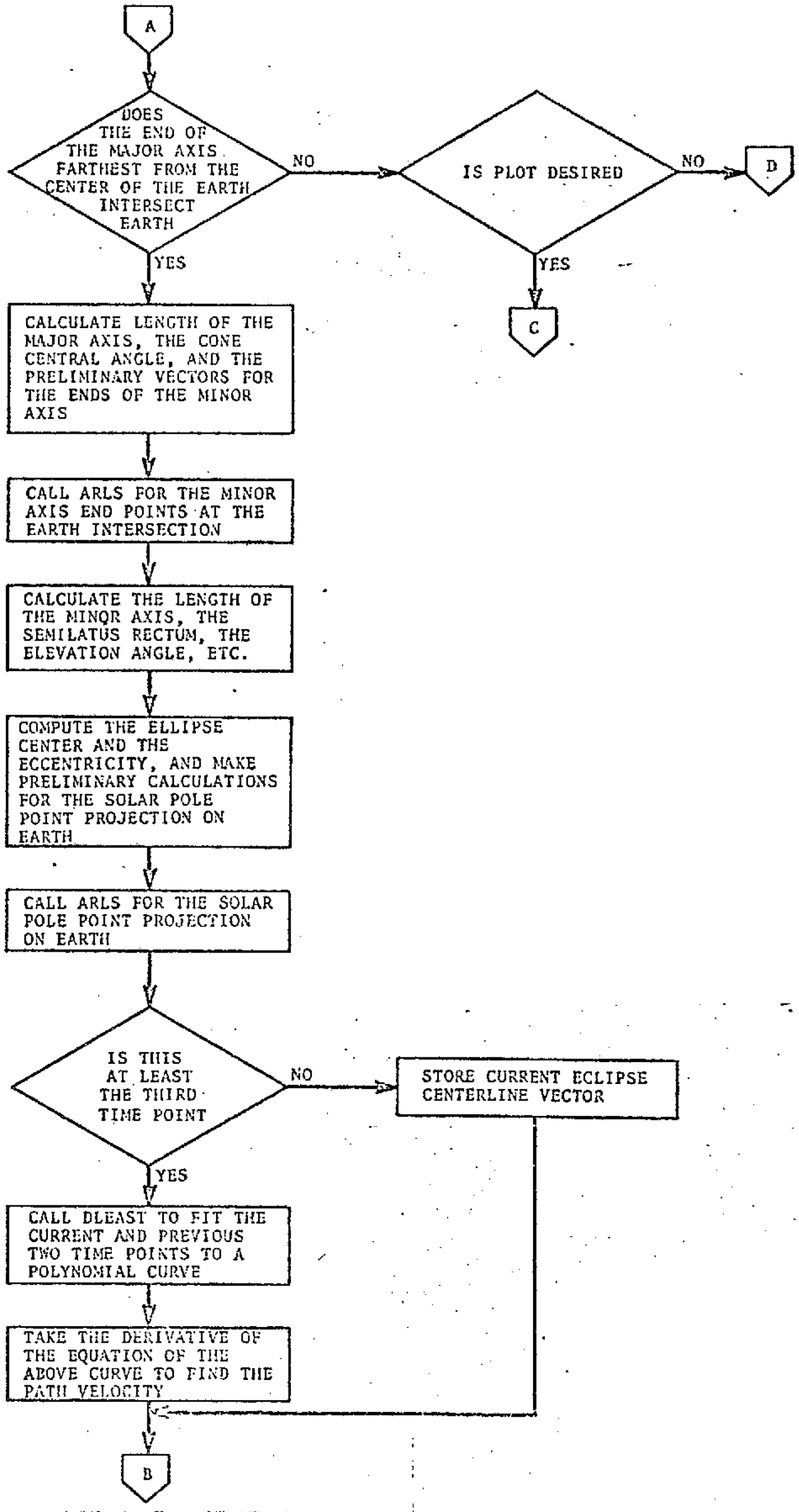


Figure 1. - Main program flow chart - Continued.

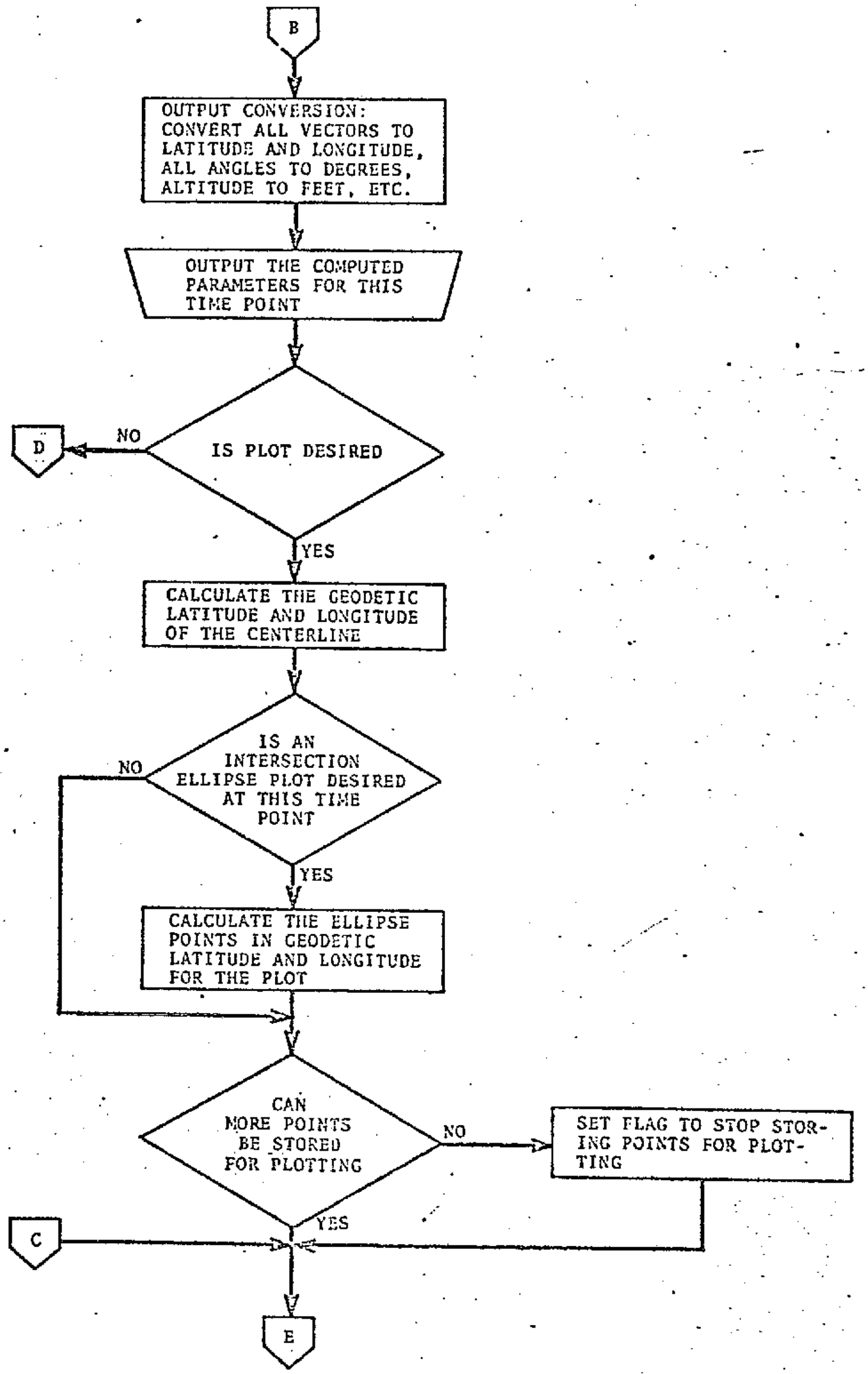


Figure 1. - Main program flow chart - Continued.

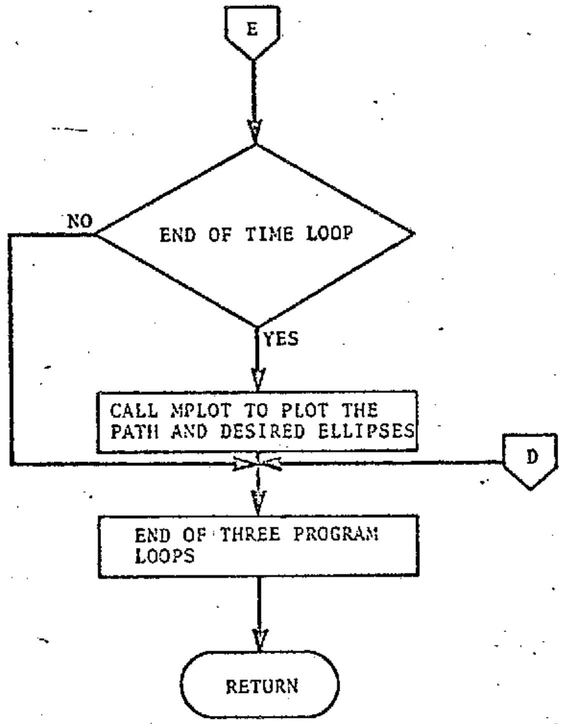


Figure 1. - Main program flow chart - Concluded.

2.2 TECHNICAL DESCRIPTION

Available planetary ephemeris data give the true positions of the sun and moon as a function of time. Since eclipse computations require the apparent rather than true positions of these bodies, the data must be obtained at the time of solar emission and lunar passage of the light forming the eclipse. Because the orbits of the earth about the sun and the moon about the earth are not circular, it is necessary to compute each time correction for a given eclipse.

$$\Delta t_s = \frac{|\overline{R}_{S/E}|}{C} \qquad (1)$$

where

$\overline{R}_{S/E}$ = the position vector of the earth with respect to the sun; in all subsequent computations, it will be the apparent position vector.

C = the speed of light in free space. (See Section 4.2.)

$$\Delta t_m = \frac{|\overline{R}_{M/E}|}{C} \qquad (2)$$

where

$\overline{R}_{M/E}$ = the position vector of the earth with respect to the moon and, in all subsequent computations, the apparent position.

From the planetary ephemeris data, the vectors defining the umbra cone and the associated angles can be obtained as shown in Figure 2.

The vector from the center of the moon to the umbral cone apex can be computed from the following equation.

$$\bar{R}_{M/A} = \frac{R_m \left|\bar{R}_{S/M}\right|}{R_s - R_m} \widehat{R}_{S/M} \tag{3a}$$

The magnitude is obtained from

$$\frac{R_m}{\left|\bar{R}_{M/A}\right|} = \frac{R_s}{\left|\bar{R}_{M/A}\right| + \left|\bar{R}_{S/M}\right|} \tag{3b}$$

and the direction is the same as the unit sun-to-moon vector.

Where

R_m = the spherical radius of the moon as given in section 4.2, Program Constants.

R_s = the spherical radius of the sun as given in section 4.2, Program Constants. (This quantity can be adjusted by input as given in the Users Guide.)

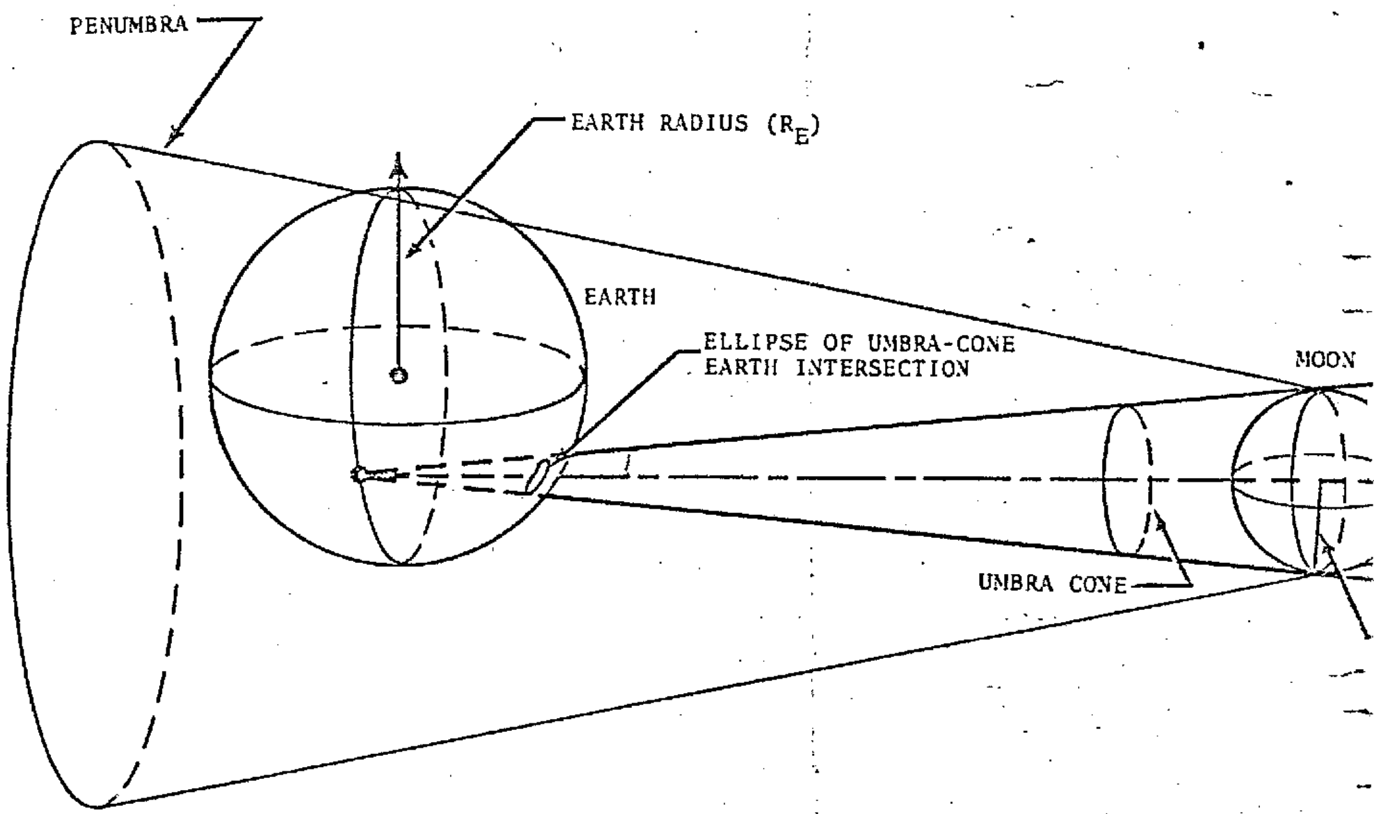


Figure 2. - Compl

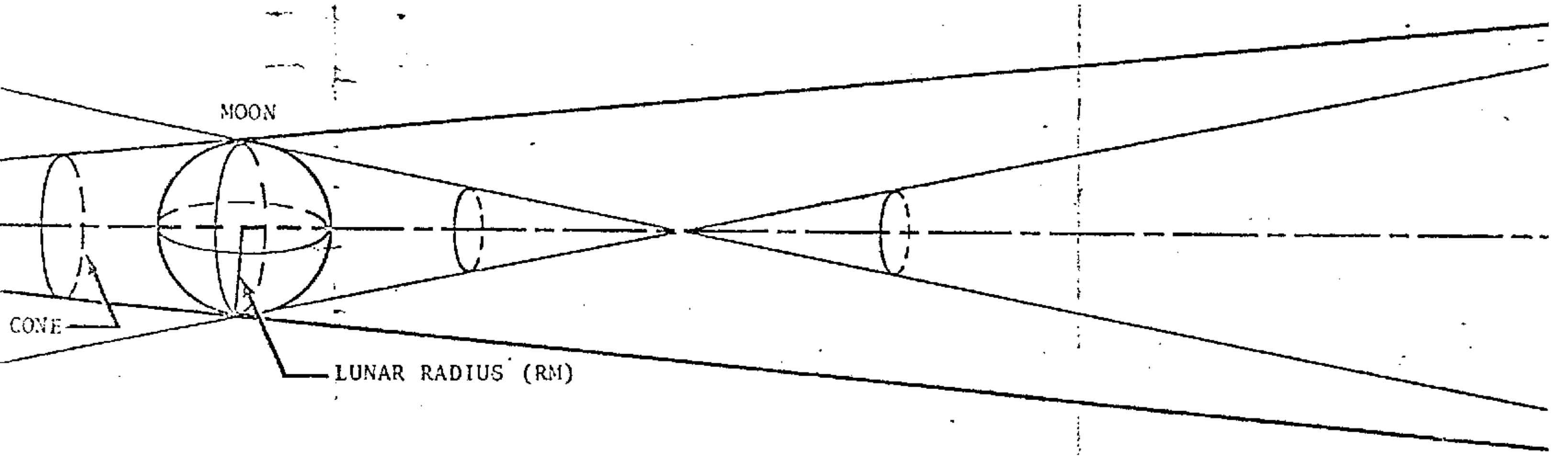
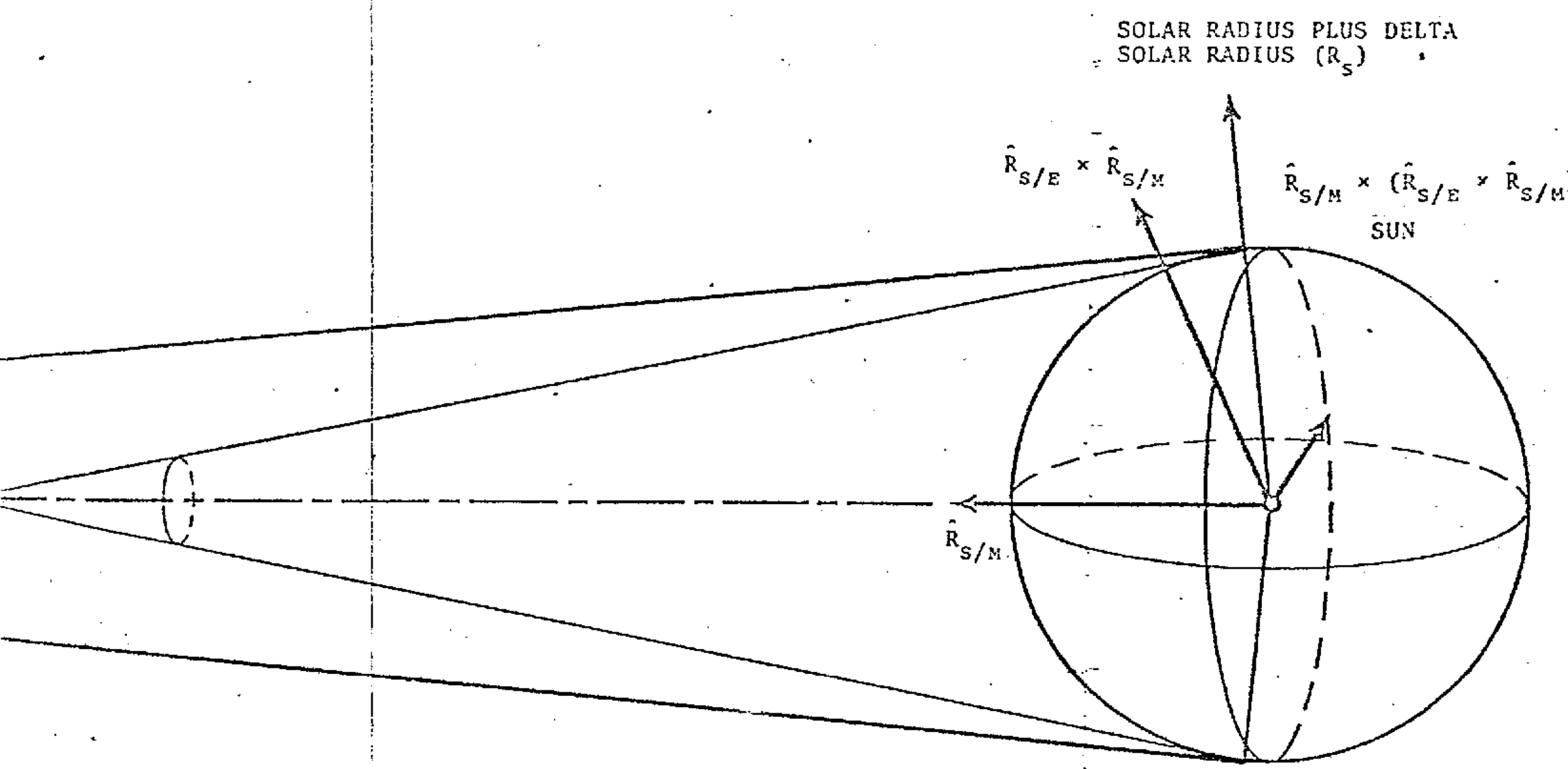


Figure 2. - Complete view of solar elipse using apparent sun and moon.



ing apparent sun and moon.

The perpendicular projection of the moon-to-earth vector onto the moon-to-umbral apex vector can be computed as shown in Figure 3.

$$\overline{R}_{m/Pl} = \left(\overline{R}_{M/E} \cdot \widehat{R_{m/A}}\right)\widehat{R_{m/A}} \tag{4}$$

A vector from the earth-to-umbral apex is computed as the sum of the moon-to-umbral apex vector and the moon-to-earth vector. (See Figure 3.)

$$\overline{R}_{E/A} = \overline{R}_{M/A} - \overline{R}_{M/E} \tag{5}$$

Using the geometry shown in Figure 3, the umbra cone half angle is computed from the radius of the moon and the magnitude of the moon-to-umbral apex vector.

$$\alpha = \sin^{-1}\left(R_m \Big/ \left|\overline{R}_{M/A}\right|\right) \tag{6}$$

Figure 4 shows the ellipse defined by the umbra cone earth intersetcion. This figure shows the major and minor axes of this ellipse and the associated angles.

The vector on the umbra cone which intersects the endpoints of the major axis of the intersection ellipse are computed as

$$\overline{VI} = \overline{R}_{E/A} - \left[\overline{R}_{E/S} + R_s\left(\sin(\alpha)\,\widehat{R_{S/M}} \pm \cos(\alpha)\left[\widehat{\left(\widehat{R_{E/S}} \times \widehat{R_{S/M}}\right) \times \widehat{R_{SM}}}\right]\right)\right] \tag{7}$$

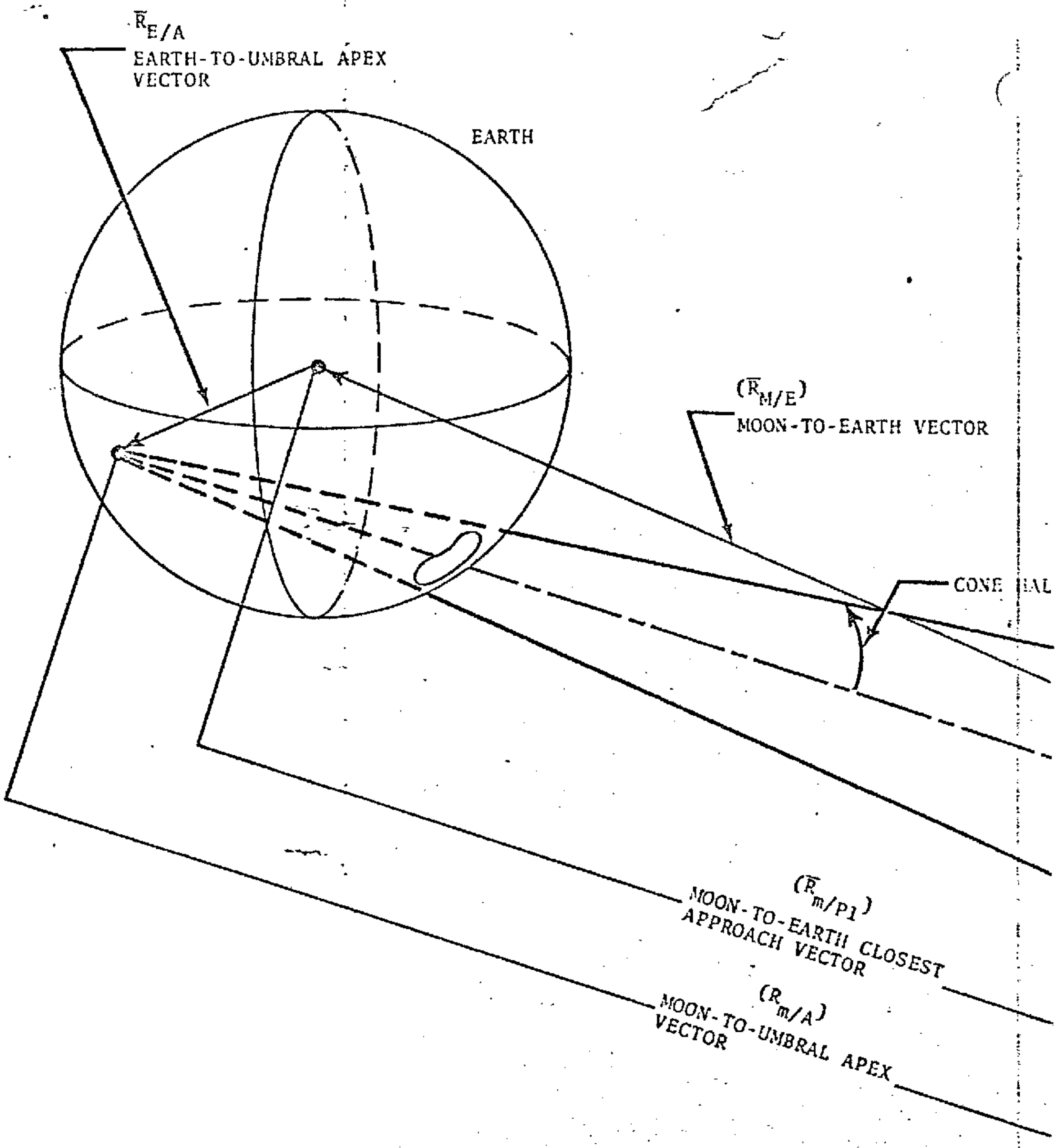


Figure 3. - Umbral con

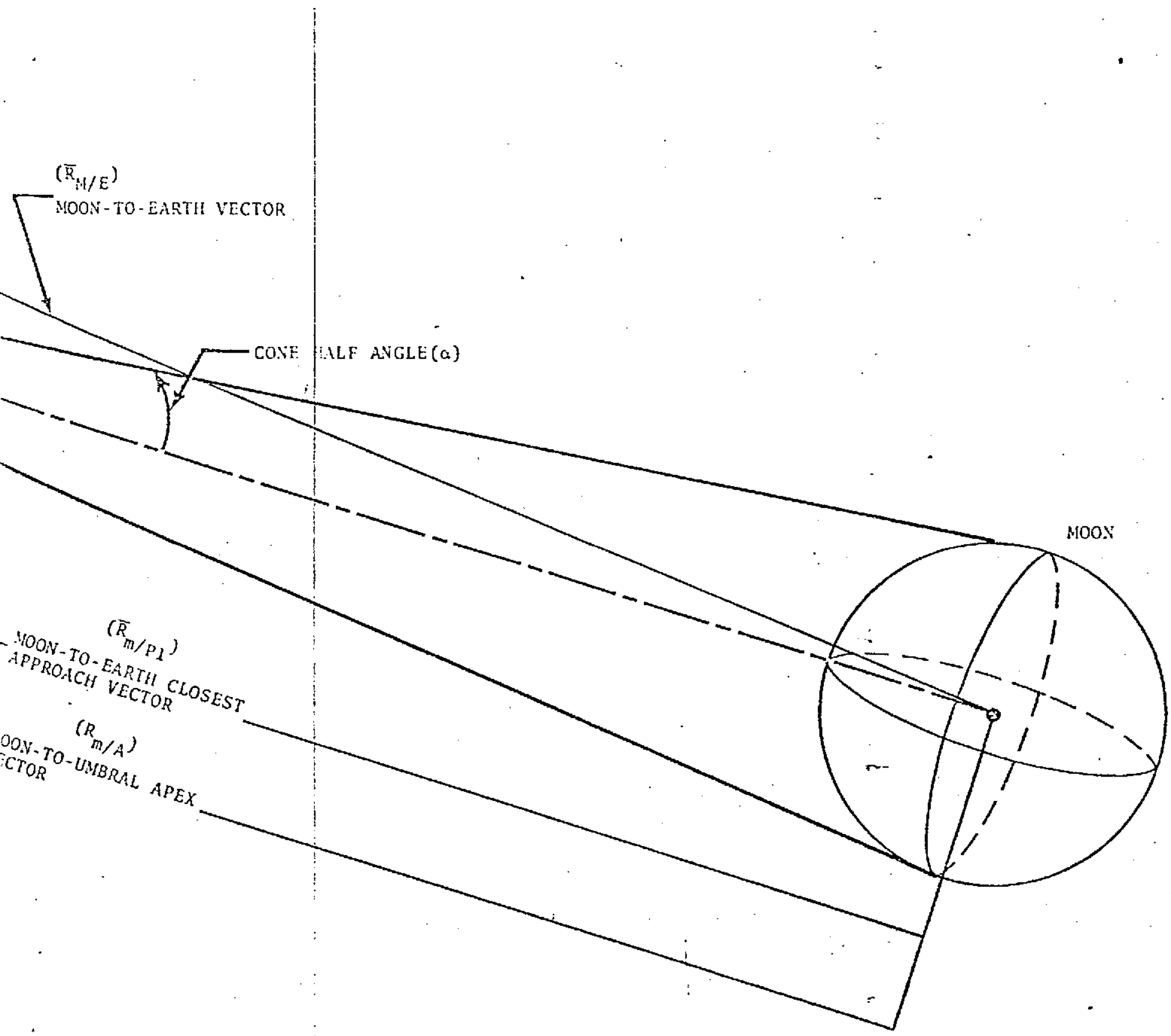


Figure 3. - Umbral cone vectors.

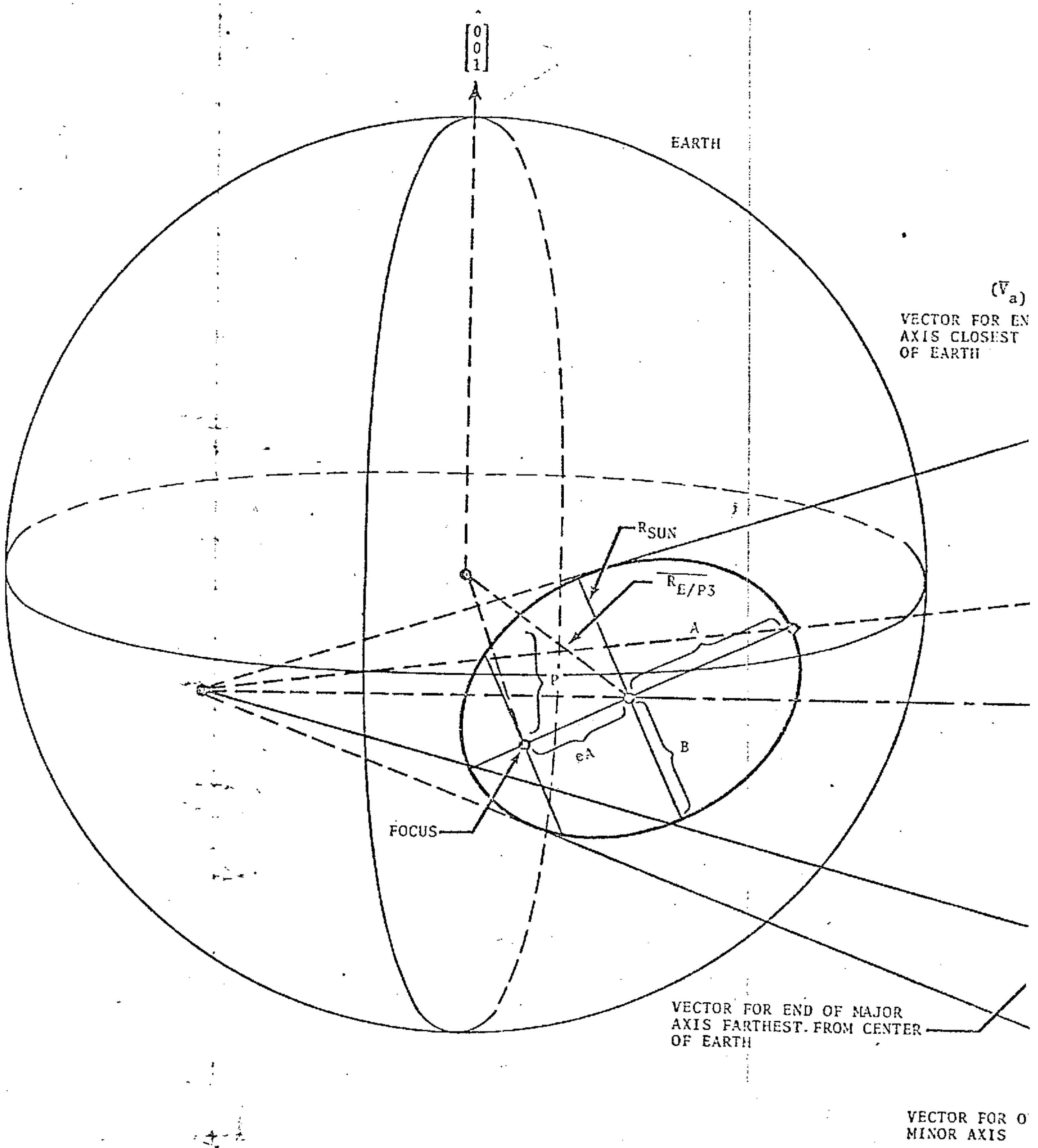
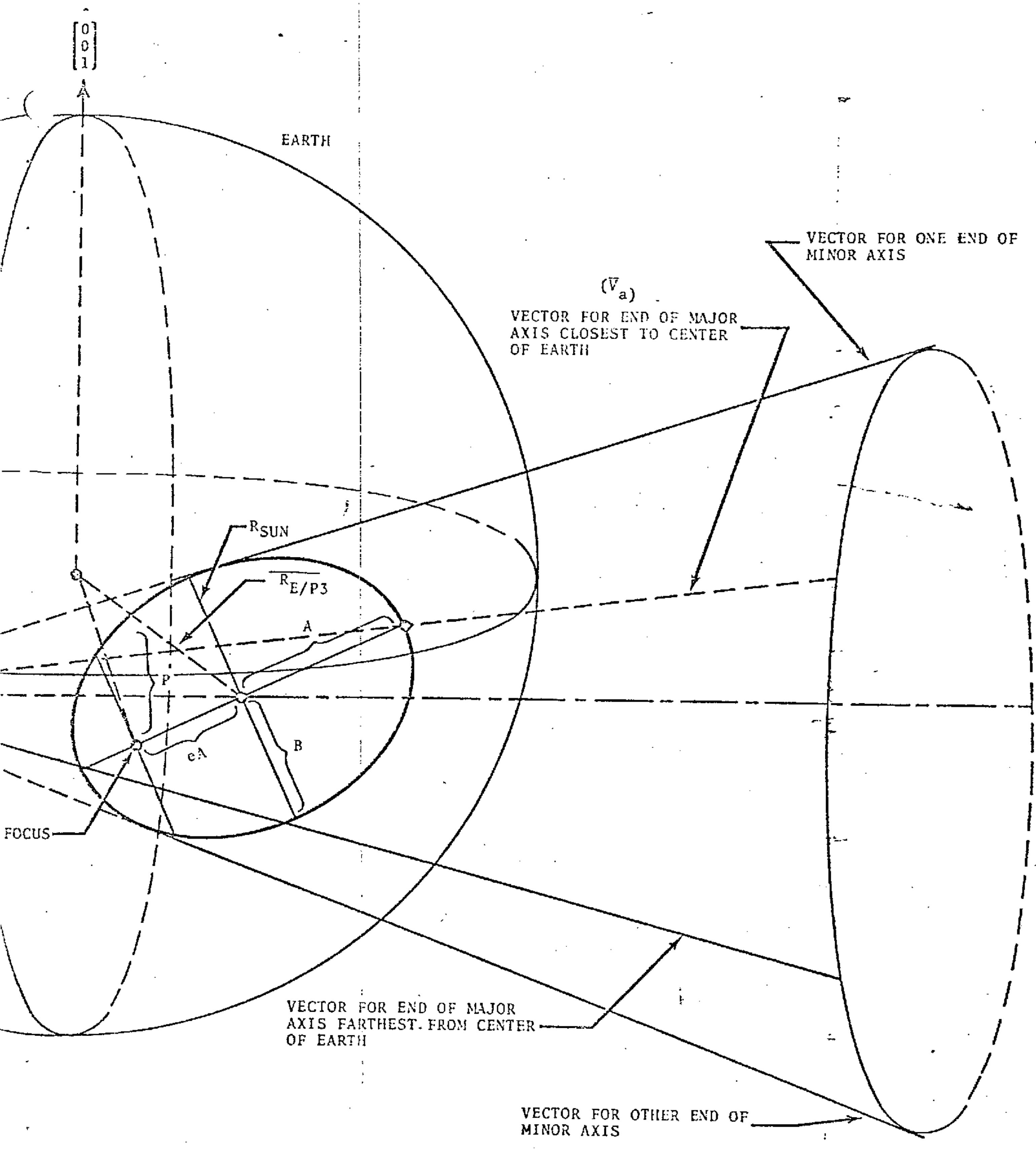


Figure 4. - Vectors for major and minor axis and ellipse of umbral-cone eart



major and minor axis and ellipse of umbral-cone earth intersection.

The positive sign gives the vector closest to the center of the earth.

In order to find the minor axis intersection vectors it is necessary to compute intermediate quantities such as solar elevation and minor axis shift.

The solar elevation above the intersection ellipse is

$$\beta = \cos^{-1}\left[\widehat{\left(\overline{R}_{E/PA} - \overline{R}_{E/PB}\right)} \cdot \widehat{R_{m/A}}\right] \tag{8}$$

where

$\overline{R}_{E/PA}$ = the vector from the center of the earth to the major axis endpoint closest to the center of the earth (computed from line surface intersect with vector $\overline{V}$).

$\overline{R}_{E/PB}$ = the vector from the center of the earth to the major axis endpoint farthest from the center of the earth (computed from line surface intersect with vector $\overline{V}$).

The minor axis shift due to the curviture of the earth is computed from the solar elevation above the surface of the intersection ellipse and the previously computed cone half angle.

$$C1 = \frac{\tan \alpha}{\tan \alpha + \tan \beta} \tag{9}$$

Using the above computation, the vector for the minor axis can be computed.

$$\overline{V2} = R_{E/S} + R_S \sin\alpha\, \widehat{R_{S/M}} + C1\, R_S \cos\alpha\, \widehat{\left(\widehat{R_{E/S}} \times \widehat{R_{S/M}}\right) \times \widehat{R_{S/M}}}$$

$$\pm R_S \left(1 - \sin^2\alpha - C1^2 \cos^2\alpha\right)^{1/2} \widehat{\left(\widehat{R_{E/S}} \times \widehat{R_{S/M}}\right)} \qquad (10)$$

The length of the umbral shadow surface intersect elements: the ellipse semimajor axis, the semiminor axis, and the semi-latus rectum; and the eccentricity now can be computed.

$$A = \frac{R_E}{2} \sin^{-1}\left(\left|\widehat{R_{E/PA}} \times \widehat{R_{E/PB}}\right|\right) \qquad (11)$$

$$B = \frac{R_E}{2} \sin^{-1}\left(\left|\widehat{R_{E/PC}} \times \widehat{R_{E/PD}}\right|\right) \qquad (12)$$

where

$\overline{R}_{E/PC}$ and $\overline{R}_{E/PD}$ are vectors from the center of the earth to the ends of the minor axis computed from $\overline{V2}$ and the line surface intersect routine.

$$P = \frac{B^2}{A} \tag{13}$$

$$e = \left[1 - \left(\frac{B}{A}\right)^2\right]^{1/2} \tag{14}$$

The position of the center of the ellipse is found by summing the earth-centered vector defining the endpoint of the major axis and then unitizing the resultant vector, giving it a magnitude equal to the radius of the earth.

$$\overline{R}_{E/P3} = R_E \left(\widehat{\overline{V}_{E/PA} + \overline{V}_{E/PB}}\right) \tag{15}$$

A unit vector parallel to the ellipse major axis pointing toward the subsolar end is computed as

$$\hat{R}_{SUN} = \left(\widehat{\overline{V}_{E/PA} - \overline{V}_{EPB}}\right) \tag{16}$$

Equation (17) represents the position vector of the intersect ellipse focus with respect to the center of the earth.

$$\overline{R}_{E/P4} = \cos\left(\frac{A\quad e}{R_E}\right) \overline{R}_{E/P3} + R1 \sin\left(\frac{A\quad e}{R_E}\right) \hat{R}_{SUN} \tag{17}$$

A unit vector in the ellipse plane pointing from the focus toward local north is computed as follows.

$$\widehat{R_{LN}} = \widehat{\left(\left(\widehat{R_{E/P4}} \times \widehat{\begin{bmatrix}0\\0\\1\end{bmatrix}}\right) \times \widehat{R_{E/P4}}\right)} \qquad (18)$$

3. USAGE

3.1 INPUT DESCRIPTION

3.1.1 Input Data Forms and Types

The normal type of input to this program is card input. The format and description of the input is given in the Users Guide, section 4.4. If plotting is desired, an input data tape must be requested from the author and mounted on logical unit L.

3.1.2 Data Specifications and Definitions

The required input specifications and definitions are given in section 4.4. The mathematical symbols are given in section 4.1, page 4.1.

3.1.3 Sample Test Data

Figure 5 is a sample test deck for the solar eclipse on March 7, 1970, for output from 16:00 to 19:00 universal time at a delta time of 3 minutes, which includes plot output of the umbral-cone centerline and ellipse at an altitude of zero feet above the ellipsoidal earth.

Column 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Card No.
1		1	9	7	0	•	0											1
2		6	6	•	0													2
3		1	6	•	0													3
4		1	9	•	0													4
5		3	•	0														5
8		2	•	0														6
9		6	•	0														7
H							1	9	9	9		0	•	0				8
M	A	R		7	1	9	7	0										9

Figure 5. — Sample test deck for the solar eclipse of March 7, 1970.

3.2 PROGRAM RUN PREPARATIONS

3.2.1 Deck Setup

See Figure 6.

3.2.2 Required Input/Output Devices

Two tapes must be used for normal output. The PCF tape, which contains the source routines, is mounted on logical unit A. The second tape, which is a double-precision sun and moon ephemeris tape, is mounted on logical unit I. For 4060 output, the earth data tape is mounted on logical unit L.

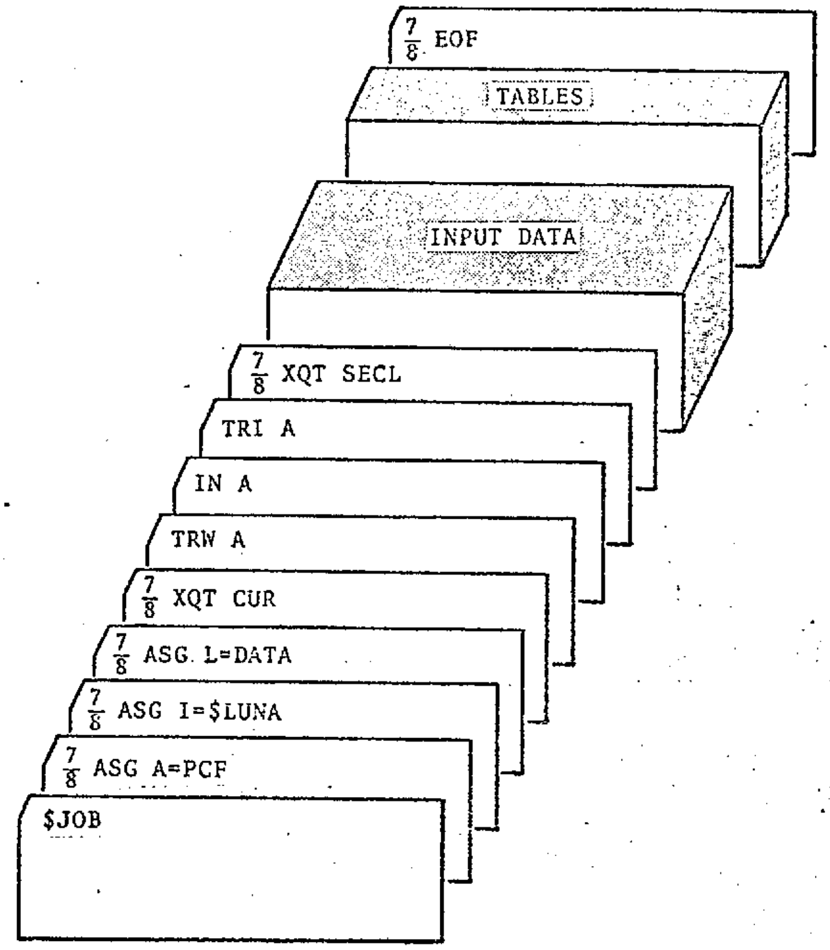


Figure 6. - Sample deck setup.

3.3 OUTPUT DESCRIPTION

The two types of program output include printed output and graphic or plot output. Refer to section 4.6, page 4.77, for sample printed output, and to section 4.7, page 4.86, for sample plot output.

3.4 EXECUTION CHARACTERISTICS

3.4.1 Programming and Analytical Restrictions

The calculations used in this program must be done in double precision whenever possible. The sun and moon ephemeris tape contains 10-place significant figures. Refer to section 4.2, page 4.2, for the program constants.

3.4.2 Storage Requirements

See Table I.

TABLE I. — PROGRAM STORAGE REQUIREMENTS

Name	Storage Required
SECL	
ANG	625_8
ARLS	
ART	

TABLE I. – PROGRAM STORAGE REQUIREMENTS (Concluded)

Name	Storage Required
CROSS	153_8
CROSS 1	143_8
DOT	53_8
DOT 1	52_8
DLEAST	4640_8
FEEDER	40_8
GEDV	107_8
JPLEPH	7301_8
MAMULD	365_8
MAXERR	101_8
MAXMIN	214_8
MAMULD	365_8
MINVOP	651_8
MPLOT	6013_8
PLOTIT	254_8
QUAD	57_8
OUTPUT	954_8
UNVEC	112_8
UNVEC1	110_8
ORTH	163_8

3.4.3 Accuracy Discussion

The program constants, given in section 4.2, are the greatest accuracy factor involved in this program. Revision of the constants may be necessary as better values become available.

4. REFERENCE INFORMATION

4.1 SYMBOL DEFINITIONS

The following is a list of the mathematical symbols with a corresponding definition of each:

C	—	The velocity of light
$\overline{R}_{E/S}$	—	The vector from the center of the earth to the center of the sun
$\overline{R}_{E/M}$	—	The vector from the center of the earth to the center of the moon
RM	—	Mean lunar radius
R_s	—	Mean solar radius plus the current delta solar radius
$\overline{R}_{S/M}$	—	The vector from the center of the sun to the center of the moon
$\overline{R}_{M/A}$	—	The vector from the center of the moon to the umbral-cone apex
$\overline{R}_{E/PA}$	—	The vector from the center of the earth to the major axis end of the umbral-shadow ellipse that is closest to the center of the earth
$\overline{R}_{E/PB}$	—	The vector from the center of the earth to the major axis end of the umbral-shadow ellipse that is farthest from the center of the earth

4.2 PROGRAM CONSTANTS

Program Symbol	Mathematical Symbol or Name	Value
A	a	1.0 er
B	b	0.99664767 er
C	velocity of light	1.69210584×10^5 er/hr
RM	lunar radius	0.272506 er
RS	solar radius	109.125084 er
ENM	n. mi./er	3443.93412
RAD	$180°/\pi$	57.2957795

4.3 SUBROUTINE DOCUMENTATION

In addition to the subroutines documented in the following pages, the subroutines listed below are used, but are not documented.

CROSS — Double precision cross-product routine.
CROSS1 — Single precision cross-product routine.
DOT — Double precision dot-product routine.
DOT1 — Single precision dot-product routine.
UNVEC — Double precision unit-vector routine.
UNVEC1 — Single precision unit-vector routine.

SUBROUTINE ARLS

IDENTIFICATION

Name/Title	—	ARLS (Line ellipse intersection and atmospheric refraction routine)
Author/Date	—	Robert R. Piersall, January 1968
Organization/Installation	—	CAD-MSC
Machine Identification	—	UNIVAC 1108
Source Language	—	FORTRAN V

PURPOSE

Subroutine ARLS computes the vector from the center of the earth to the intersection of an element of an eclipse umbra cone with the ellipsoidal earth, or to the intersection of an input altitude above the earth's surface. The vector is inertially referenced.*

USAGE

- Calling Sequence

```
CALL ARLS(A,B,PB)
```

Arguments:

Parameter Name	In/Out	Dimension	Type	Description
A	In	3	D.P.	Vector from the center of the earth to a point on the desired umbral-cone element

*See reference 1 for the refraction model.

Parameter Name	In/Out	Dimension	Type	Description
B	Out	3	D.P.	Output vector from the center of the earth to the desired intersection
PB	Out	—	Real	Error indicator — If PB=1, a solution exists If PB=0, no solution exists

- Common Array

  COMMON/ECL/T(200),K,A,B,REA(3),RMA(3),BETA,RS1(9),
  H(15,200),I

Name	Description
T(K)	Array containing the current time in hours
K	Array associated with the current data such as time and altitude; i.e., T(K) and H(I,K)
A	Equatorial radius of the earth plus the altitude of the atmosphere
B	Polar radius of the earth plus the altitude of the atmosphere
REA	Vector from the center of the earth to the umbral-cone apex
RMA	Vector from the center of the moon to the umbral-cone apex
BETA	Output angle of refraction

Name	Description
RS1	Vector from the center of the earth to the center of the sun
I	Current outer-loop value for the current value of altitude
H(I,J)	Altitude for the *ith* case at the time point T(K) for surface intersection calculations

- Storage Requirements
  CODE –
  DATA –

METHOD

An intercept is calculated at the edge of the atmosphere. A vector parallel to the desired umbral-cone element solution is rotated toward the center of the earth through the calculated refraction angle. A new intercept is then found from the new vector with either the surface of the earth or with an input altitude above the surface of the earth. The derivation of the ellipse and line intersection is shown in the following discussion.

The equation of an ellipse is

$$X^2 + Y^2 + \frac{A^2}{B^2} Z^2 = A^2 \qquad (1)$$

where A and B are defined by the common array above for the first pass, and on the second pass they are the equatorial and polar radius, respectively, plus the current desired altitude.

The equation of a line is

$$\frac{X - X_1}{X_2 - X_1} = \frac{Y - Y_1}{Y_2 - Y_1} = \frac{Z - Z_1}{Z_2 - Z_1} \qquad (2)$$

where (X_1, Y_1, Z_1) and (X_2, Y_2, Z_2) are the components of the two vectors $\overrightarrow{R_1}$ and $\overrightarrow{R_2}$ which define a line.

The combination of equations (1) and (2) results in an equation for X as follows:

$$X^2 \left[\frac{(Y_2 - Y_1)^2 + \frac{A^2}{B^2} (Z_2 - Z_1)^2 + 1}{(X_2 - X_1)^2} \right]$$

$$+ X \left[\frac{2Y_1 (Y_2 - Y_1) + 2Z_1 (Z_2 - Z_1) \frac{A}{B}}{X_2 - X_1} \right]$$

$$- 2X_1 \left[\frac{(Y_2 - Y_1)^2 + \frac{A^2}{B^2} (Z_2 - Z_1)^2}{(X_2 - X_1)^2} \right]$$

$$+ Y_1^2 + Z_1^2 \frac{A}{B} - X_1 \left[\frac{2Y_1 (Y_2 - Y_1) + 2Z_1 (Z_2 - Z_1) \frac{A}{B}}{X_2 - X_1} \right]$$

$$+ X_1 \left[\frac{(Y_2 - Y_1)^2 + \frac{A^2}{B^2} (Z_2 - Z_1)^2}{(X_2 - X_1)^2} \right] - A^2 = 0 \qquad (3)$$

The solution to this quadratic equation which places X on the correct side of the earth, will give the following solutions for Y and Z .

$$Y = Y_1 + \frac{(Y_2 - Y_1)(X - X_1)}{X_2 - X_1} \quad (4)$$

$$Z = Z_1 + \frac{(Z_2 - Z_1)(X - X_1)}{X_2 - X_1} \quad (5)$$

We now have a position vector with components (X,Y,Z) of the desired intercept of the umbral cone with the ellipsoidal surface on or above the surface of the earth.

RESTRICTIONS

- Analytic
  The calculations used in this program are restricted to double precision.
- Range of Applicability
  Given two points on a line, the desired height of the atmosphere and the desired altitude above the earth, this routine will compute the refracted intercept.

ACCURACY

An effort has been made to provide the maximum amount of accuracy through the use of double-precision calculations. However, care should be taken to input the required information to as many significant figures as are available.

CODING INFORMATION

- Internal Constants

  A = 1.0 — Equatorial radius of the earth

  B = 0.99664767 — Polar radius of the earth

REFERENCES

1. Humphreys, W. J., Ph.D. of Chemical Engineering — Physics of the Air, pp. 455-462.

SUBROUTINE ANG

IDENTIFICATION

Name/Title	—	ANG (Greenwich longitude and geodetic latitude routine)
Author/Date	—	Robert R. Piersall, January 1969
Organization/Installation	—	CAD-MSC
Machine Identification	—	UNIVAC 1108
Source Language	—	FORTRAN V

PURPOSE

Subroutine ANG computes the geodetic latitude and Greenwich referenced longitude from the position vector of the desired point. Figure 7 illustrates the Greenwich longitude, the geodetic latitude, and the resulting unit vector $\hat{R}$ where:

Λ_E = The current longitude of Greenwich

λ_E = The longitude of the desired point with respect to Greenwich

F_G = The geodetic latitude

USAGE

- Calling Sequence

  CALL ANG(A,F,AL)

Arguments:

Parameter Name	In/Out	Dimension	Type	Description
A	In	3	D.P.	Position vector
F	Out	—	D.P.	Geodetic latitude
AL	Out	—	D.P.	Longitude

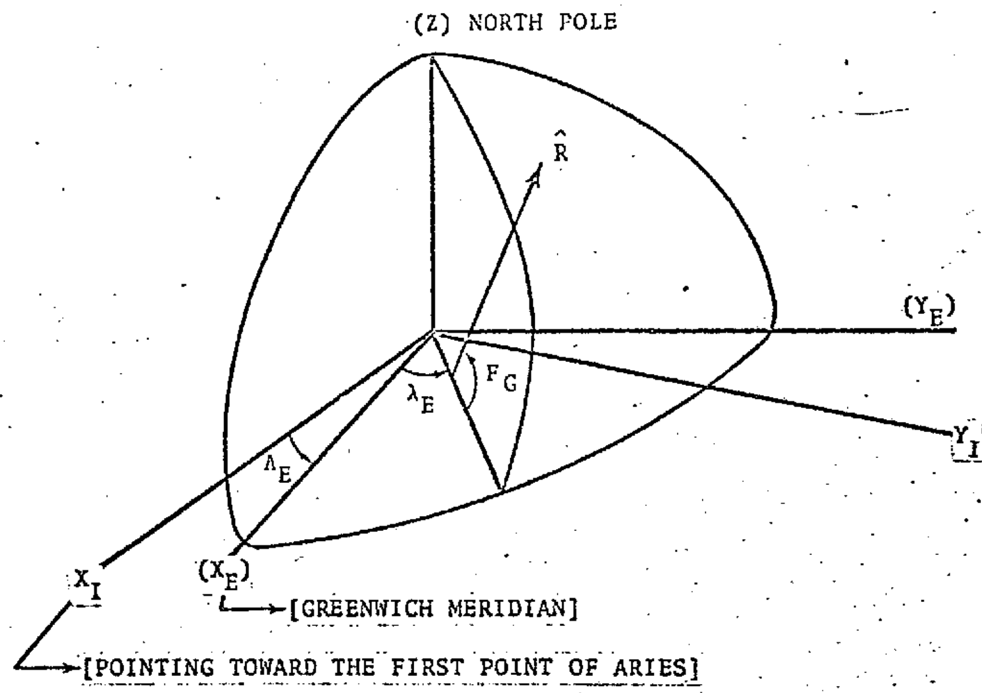


Figure 7. - Position vector coordinate system.

- Common Arrays

COMMON/DATE/IYEAR,DAY,HOUR

Name		Definition
IYEAR	—	Current year
DAY	—	Number of days into the current year
HOUR	—	Hours plus the decimal part into the current day

COMMON/DATE/T(200),K,A,B,REA(3),RMA(3),BETA,RS1(9),
H(15,200),I

Name	Description
T(K)	Array containing the current time in hours
K	Array associated with the current data such as time and altitude; i.e., T(K) and H(I,K)
A	Equatorial radius of the earth plus the altitude of the atmosphere
B	Polar radius of the earth plus the altitude of the atmosphere
REA	Vector from the center of the earth to the umbral-cone apex
RMA	Vector from the center of the moon to the umbral-cone apex
BETA	Output angle of refraction
RS1	Vector from the center of the earth to the center of the sun

Name	Description
I	Current outer-loop value for the current value of altitude
H(I,J)	Altitude for the *ith* case at the time point T(K) for surface intersection calculations

- Storage Requirements

  CODE — 367_8

  DATA — 236_8

METHOD

The longitude and latitude are calculated in the following manner:

$$\lambda = \tan^{-1}\left[\frac{R_Y}{R_X}\right] - \Lambda_E$$

where

Λ_E = the current longitude of Greenwich,

R_X = the X component of the position vector,

R_Y = the Y component, and

λ = output longitude.

$$F_C = \tan^{-1}\left[\frac{R_Z}{\sqrt{R_X^2 + R_Y^2}}\right]$$

where

R_Z = the Z component of the position vector, and

F_C = the geocentric latitude.

The geodetic latitude is

$$F_G = \tan^{-1}\left[\frac{CA}{B \tan (F_C)}\right]$$

where

A = the equatorial radius of the earth plus the current altitude, and

B = the polar radius of the earth plus the current altitude.

$$C(1) = 1$$

$$C(I) = \frac{\frac{(A^2 - B^2)}{A|\vec{R}|} C(I)}{\sqrt{\cos^2(F_C) + C(I)^2 \sin^2 (F_C)}} + B/A$$

where

I = 1 to 3, and

$|\vec{R}|$ = the magnitude of the position vector.

RESTRICTIONS

- Analytic

  The calculations used in this program are restricted to double precision.

- Range of Applicability

  This routine will calculate the geodetic latitude and Greenwich longitude for any position vector on or above the surface of the earth. (See figure 8.)

The reference coordinate system shown in figure 5 is the Besselian inertial, with the $\hat{X}$ and $\hat{Y}$ axis in the mean equatorial plane fixed at the nearest beginning of the Besselian year. The vector $\hat{X}$ is positive toward the vernal equinox, and lies at the intersection of the mean equatorial plane and the earth-sun orbit plane (ecliptic). The $\hat{Z}$ axis is perpendicular to the mean equatorial plane and the positive north, and the $\hat{Y}$ axis completes the right-hand systems. The following is a list defining the terms used in figure 5 with a description of each.

$\vec{R}$ = The vector from the center of the earth to the reference point.

F_C = The angle from the equatorial plane to the position vector.

F_G = The angle from the equatorial plane to a vector which is normal to the surface at the reference point.

λ_I = The longitude referenced to the X-inertial axis.

Λ_E = The longitude of Greenwich referenced to the X-inertial axis.

λ_E = The longitude of the reference point referenced to the Greenwich meridian.

ACCURACY

The program accuracy is limited by the convergence of the geocentric to geodetic latitude and by the numerical constants in the longitude of the Greenwich routine.

CODING INFORMATION

- Internal Constants

  RAD - 57.2957795 — Degrees per radian

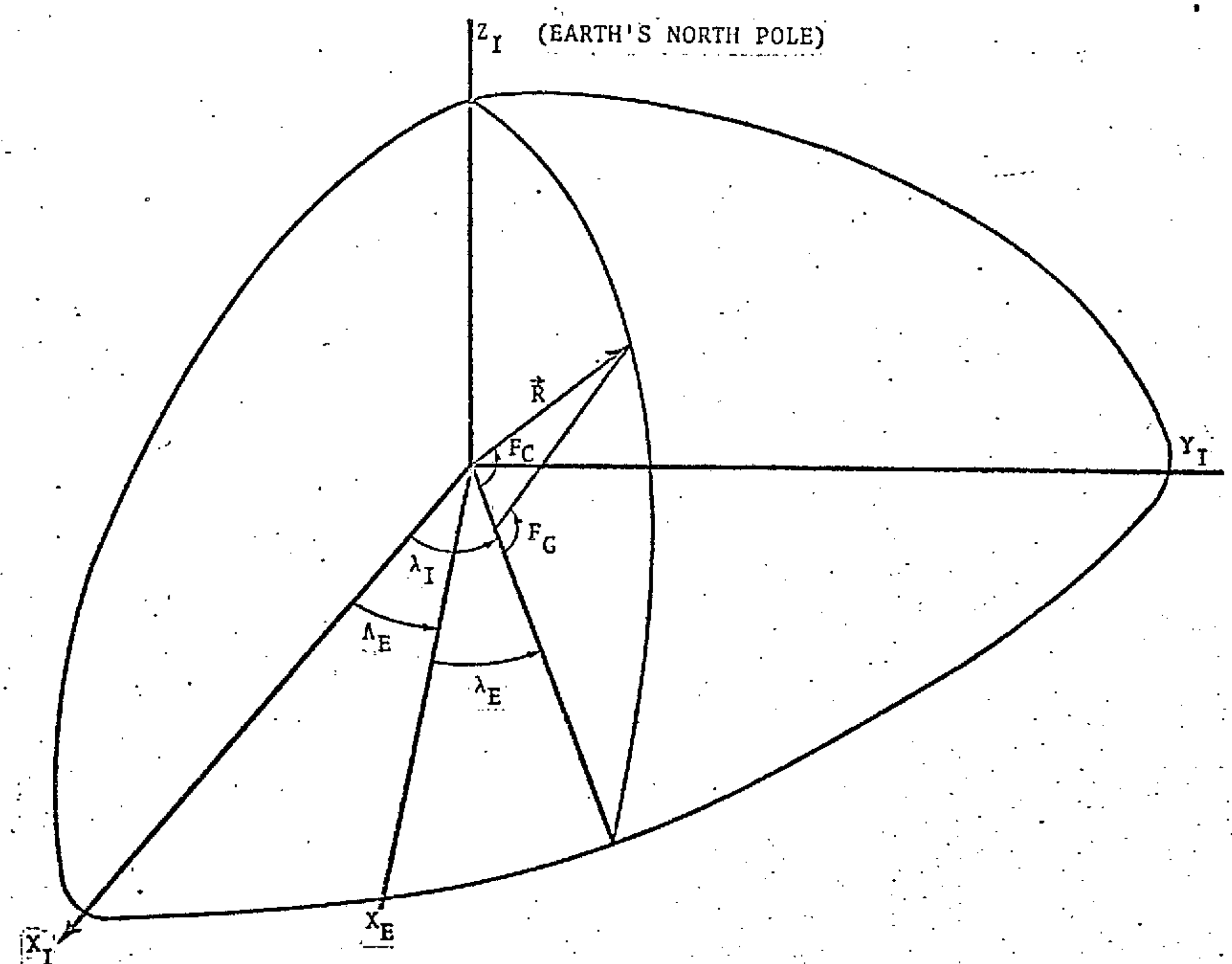


Figure 8. - Vernal equinox intersection of the celestial sphere.

SUBROUTINE GEDV

IDENTIFICATION

Name/Title	—	GEDV (Geodetic vector generation)
Author/Date	—	Robert R. Piersall, July 1968
Organization/Installation	—	CAD-MSC
Machine Identification	—	UNIVAC 1108
Source Language	—	FORTRAN V

PURPOSE

Subroutine GEDV computes and outputs a unit local vertical vector computed from the input geodetic latitude and Greenwich longitude.

USAGE

- Calling Sequence
  CALL GEDV(R,AL,F)

Arguments:

Parameter Name	In/Out	Dimension	Type	Description
R	Out	3	Real	Output local vertical vector
AL	In	—	D.P.	Greenwich referenced longitude
F	In	—	D.P.	Geodetic latitude

- Storage Requirements
  CODE — 61_8
  DATA — 26_8

METHOD

A local vertical vector is generated from the geodetic latitude and the Greenwich longitude by the following equations.

$$X_{LV} = COS\ [AL]\ COS\ [F]$$

$$Y_{LV} = SIN\ [AL]\ COS\ [F]$$

$$Z_{LV} = SIN\ [F]$$

where

AL = Greenwich referenced longitude, and

F = geodetic latitude.

CODING INFORMATION

- Internal Constants

  RAD = 57.2957795 — degrees per radian

SUBROUTINE JPLEPH

IDENTIFICATION

Name/Title	—	JPLEPH (Ephemeris Read Subroutine)
Author/Date	—	Bob McClain, August 1964
Organization/Installation	—	CAD-MSC
Machine Identification	—	UNIVAC 1108
Source Language	—	FORTRAN IV

PURPOSE

Subroutine JPLEPH provides, as a function of time, planetary positional and velocity data and/or a matrix for inertial-to-selenographic coordinate transformations.

USAGE

- Calling Sequence
  CALL JPLEPH(KEPOCH,T,IWANT,RS,RB,PNL,IERROR)
- Arguments
  The parameters, both common and calling arguments, are defined as follows:

Parameter Name	In/Out	Description*
IYEAR	In	Year of base time (integer)
DAY, HOUR, FMIN, SEC	In	Base time parameters (all real) describing elapsed time since 0 hours Jan. 0 of IYEAR (GMT) (elapsed time of calendar year plus 24 hours)

*All output distances are in units of Earth radii (e.r.), and velocities are in Earth radii/hour (1 e.r. = 3963.20006 U.S. statute miles).

Parameter Name	In/Out	Description*
KEPOCH	In	Initially, this integer argument must contain the desired Besselian year for reference epoch. (See Method Section.) On subsequent entries, if the reference epoch and base time remain constant, input KEPOCH = 0 to bypass redundant initiation.
T	In	Time, in hours, relative to base time (real).
IWANT		Integer control switch.
RS (6 cells)	Out	If IWANT = 1 , position only of SUN WRT EARTH. If IWANT = 2 , position only of SUN WRT MOON. If IWANT = 3 , not used. If IWANT = 4 , not used. If IWANT = 5 , not used.
RB (12 cells)	Out	If IWANT = 1 , position and velocity of MOON WRT EARTH. If IWANT = 2 , position and velocity of EARTH WRT MOON.

*All output distances are in units of Earth radii (e.r.), and velocities are in Earth radii/hour (1 e.r. = 3963.20006 U.S. statute miles).

Parameter Name	In/Out	Description*
RB (12 cells)	Out	If IWANT = 3 , position and velocity of MOON WRT EARTH.
		If IWANT = 4 , position and velocity of MOON WRT EARTH.
		If IWANT = 5 , not used.
PNL (9 cells)	Out	If IWANT = 1 , not used.
		If IWANT = 2 , precession, nutation and libration matrix.
		If IWANT = 3 , precession, nutation and libration matrix.
		If IWANT = 4 , not used.
		If IWANT = 5 , precession, nutation and libration matrix.
IERROR	Out	Integer validity indicator. IERROR = 0 if valid data obtained.
		IERROR = 1 if KEPOCH not within limits.
		IERROR = 2 if KEPOCH and IYEAR inconsistent.
		IERROR = 3 if read redundancy (bad tape).

*All output distances are in units of Earth radii (e.r.), and velocities are in Earth radii/hour (1 e.r. = 3963.20006 U.S. statute miles).

Parameter Name	In/Out	Description*
IERROR	Out	IERROR = 4 if wrong data file (probable machine error). IERROR = 5 if time beyond limits for indicated epoch. IERROR = 6 if wrong data record (probable machine error).

- Data In/Out

  The following labeled COMMON block is required for data communication:

  COMMON /INPUT/ IYEAR, DAY, HOUR, FMIN, SEC, FILL(45).

METHOD

The coordinate system for referencing all data is defined by the mean equator and the ecliptic at the nearest beginning of a Besselian year. The beginning of the Besselian year differs from the beginning of the calendar year of the same number by only a fraction of a day. This coordinate frame is geocentric, with the X-axis in the direction of the vernal equinox, the Z-axis along the mean pole, and the Y-axis designed to complete a right-hand coordinate system.

*All output distances are in units of Earth radii (e.r.), and velocities are in Earth radii/hour (1 e.r. = 3963.20006 U.S. statute miles).

The input tape, which was prepared from data provided by the Jet Propulsion Laboratory, is divided into 49 files. Each file contains a year (plus a minimum of 768 hours overlap at each end) of data roughly centered about the epoch of that file.

A mission to be run in the time period from July 1968 through June 1969 should be referenced to the epoch 1969.0, which is the nearest beginning to a Besselian year. A 40-day table of data centered about the initial time will then be read into core and retained for subsequent interpolations. The tape will not be interrogated until the time exceeds the limits of the table in core.

At each entry, a 5*th* order Newtonian interpolation subroutine (NEWT) performs interpolation for only those tables requested.

- Data Tape

  The data tape, MSC No. 0947, or a copy, must be mounted on FORTRAN IV unit number 11 (7040/7094 logical unit number 15). This tape contains 49 files of data arranged in 8-day records of the following format:

  RECORD NO. 1 (four-word file identification record)

  Word 1, NFILE – file number (integer)

  Word 2, JEPOCH – epoch of file (integer)

  Word 3, BTIME – base hour of file (real)

  Word 4, IYR – year of BTIME (integer)

RECORD NOS. 2-56 (278-word data records)

Word 1, NFILE — file number (integer)

Word 2, NREC — data record number (integer, 1 to 55)

Word 3, JEPOCH — epoch of file (integer)

Word 4, HOUR — base hour of record (real)

Word 5, IYEAR — year of HOUR (integer)

Word 6, TABSUN — position and velocity components array of sun with respect to earth in 4-day intervals (real)

$$x1, x2, x3, y1, y2, y3, z1, z2, z3$$
$$\dot{x}1, \dot{x}2, \dot{x}3, \dot{y}1, \dot{y}2, \dot{y}3, \dot{z}1, \dot{z}2, \dot{z}3$$

Word 24, TABLUN — position and velocity components array of moon with respect to earth in 12-hour intervals (real)

$$x1, x2, x3, \cdots, x17$$
$$y1, y2, y3, \cdots, y17$$
$$\vdots \qquad \vdots$$
$$\dot{z}1, \dot{z}2, \dot{z}3, \cdots, \dot{z}17$$

Word 126, PNL — precession-nutation-libration matrix elements array in 12-hour intervals (real)

```
(1,1)1,(1,1)2, (1,1)3,· · ·, (1,1)17
(2,1)1,(2,1)2, (2,1)3,· · ·, (2,1)17
   ·       ·         ·      ·       ·
   ·       ·         ·      ·       ·
   ·       ·         ·      ·       ·

(3,3)1,(3,3)2, (3,3)3,· · ·, (3,3)17
```

RESTRICTIONS

This routine is restricted to the sun-moon-earth system in the interval of time from June 1, 1950 through July 31, 1999. It requires submodules NEWT (for interpolation), FSFBSF (for data file manipulation), VCMSC (for vector manipulation), and .UN11, (an overlay file definition for minimum IOCS).

4.4 MAIN PROGRAM USERS GUIDE

USERS GUIDE FOR THE ECLIPSE PROGRAM

1. INTRODUCTION

This program calculates parameters associated with a user-desired solar eclipse. It also has the capability to plot the centerline and the family of ellipses defined by the intersection of the umbra cone and the ellipsoid representing the earth.

2. PROGRAM DECK SETUP

The required deck setup is shown in figure 6, page 3.3. The PCF and DATA tape numbers may be obtained from the author.

3. DATA REQUIRED

3.1 GENERAL INPUT DISCUSSION

The general input data must be in the following format. The input array number begins in column 1 with the corresponding values from column 3 to column 33 in either floating-point or exponential form.

Input Array Number	Definition
1	Year of desired eclipse
2	Day of desired eclipse (from January 0)
3	Beginning time for calculations of eclipse parameters (hr)
4	End time for calculation of eclipse parameters (hr)

Input Array Number	Definition
5	Time increment (min)
6	Altitude of atmosphere above the equator (ft) – (Internally set to 400,000 feet, if not input)
7	Altitude of atmosphere above the poles (ft) – (Internally set to 400,000 feet, if not input)
8	Input of 2.0, if plotting is desired
9	Distance of view from earth for plotting (e.r.)

3.2 SPECIFIC INPUT DISCUSSION

3.2.1 Table Input

This program includes the following two table inputs for eclipse parameter calculations:

1. H – Altitude above the surface of the earth (ft)
2. DRS – Altitude above or below the solar radius height (ft)

The following format must be followed for the table inputs.

Columns	Definition for Altitude
1	Must contain an H .
7-8	Contain the largest number of complete (from beginning time to end time) program phases for all values of H . The number must be less than 16 fixed points.

Columns	Definition for Altitude
9-11	Contain the input increment number desired for this altitude, or a number greater than the maximum number of increments if one value is desired for a full phase. (Increment number = 1 to $\frac{\text{(beginning time-end time)}}{\text{time increment}}$ in fixed point.)
12-32	Contain numerical input (floating point or exponential).

Columns	Definition for Delta Radius of Sun
1-3	Must contain DRS.
7-8	Contain the largest number of complete program phases for all values of DRS. (Same restrictions as corresponding input for H .)
9-11	Same restrictions as corresponding input for H .
12-32	Same restrictions as corresponding input for H .

At the end of the table input, a blank card must be inserted.

3.2.2 Date Card Input

The next input card is a Hollerith card with the abbreviation for the month in columns 1 through 3, the day of the month in columns 4 and 5, and the year ending in column 9.

The table inputs and the date card input include all of the required input for this program. As many phases as desired may be stacked by simply referring back to the input array table in section 3.1 of this Users Guide.

4. OUTPUT FORMS AND DEFINITIONS

Quantity	Units	Description
Ellipse center longitude	deg	Greenwich referenced longitude of the center of the ellipse defined by the umbra-cone earth intersection.
Solar pole longitude	deg	Greenwich referenced longitude of the visible solar-pole projection onto the earth.
Delta solar radius	n.mi.	Input change to solar radius.
Focus latitude	deg	Geodetic latitude of the focus of the ellipse defined by the umbra-cone earth intersection.
Semiminor axis	n.mi.	Length of the semiminor axis of the ellipse defined by the umbra-cone earth intersection.
Elevation number atmosphere	deg	Elevation angle as described above, with no atmospheric refraction.
Velocity azimuth	deg	Azimuth of the path velocity vector.

Quantity	Units	Description
Cone axis latitude	deg	Geodetic latitude of the umbra-cone axis as in cone axis longitude
Ellipse center latitude	deg	Geodetic latitude of the ellipse center as in ellipse center longitude.
Solar pole latitude	deg	Geodetic latitude of the solar pole in view.
Cone half angle	deg	The angle from the center of the umbra cone to the edge.
Eccentricity of ellipse	none	Eccentricity of the above defined ellipse.
Semilatus rectum	n.mi.	Semilatus rectum of the ellipse.
Time	hr:min:sec	Current universal time.
Altitude (H)	ft	Altitude above the surface of the ellipsoidal earth.

Quantity	Units	Description
Focus longitude	deg	Longitude of the focus of the ellipse defined by the umbra-cone earth intersection, referenced to the Greenwich meridian.
Semimajor axis	n.mi.	Length of the semimajor axis of the ellipse defined by the umbra-cone earth intersection.
Elevation thru atmosphere	deg	Elevation angle of the eclipse centerline corrected for atmospheric refraction.
Path velocity	knots	Velocity of the umbra-cone path at an altitude (H) above the ellipsoidal earth.
Cone axis longitude	deg	Greenwich referenced longitude of the umbra-cone earth intersection.
Azimuth of sun	deg	Azimuth of the vector from the earth to the sun.
Path width	n.mi.	Width of the umbra-cone path.
Solar pole direction	deg	Angle from the ellipse major axis to the line joining the focus and the solar pole image point.

4.5 PROGRAM AND SUBROUTINE LISTINGS

```
      IMPLICIT DOUBLE PRECISION (A-H.O-Z)
      REAL DAY.DUM.F.P5.P8.X
      DIMENSION RMI(12).RSI(9).H(15.200).DRS(15.200).T(200).
     1 RSM(3).RHA(3).RMP(3).REA(3).C(100).VD(3).VC(3).V(50).
     2 VEP3(3).VSUN(3).VEP4(3).VTN(3).VSHP(3).VE(3).VEP5(3).
     3 VAZSP(3).VSPOR(3).VLNV(3).DVEP2(3).VAZV(3)
     4 .RES(4).RCM(4).IT(10.10).DUM(50).ALD(100).ALO(20).ALC(25)
     5 .F(200).X(3.600)
      COMMON/EPL/ICP.X
      COMMON/DATE/IYEAR.DAY.HOUR
      COMMON/ECL/T.K.XYZ.ZYX.REA.RMA.BETAIP.RS1.H.I
      DATA/H1/0/H2/0/H3/0/H4/0/H5/0/HG/0/
      DATA(DUM(I).I=1.12)/5HADJUS.5HTED  .5HPOLE  .6HNORTH .6HPOLE  .
     1 6H      .6H      .6H      .6HSOUTH .6HPOLE  .6HNEITHE.6HR POLE /
      DATA DUM(48)/6H      /DUM(49)/6HORS   / DUM(50)/6HH     /
 37   RE=1.0000
      FER=2.092574147007
      F(76)= 1.0191152
      F(77)= 1.0156938
      VL=1.69210504D5
      RH=0.2725030D0
      RS=109.12500400
      ENH=3443.9341200
 781  READ(5.1782)I.DUM(14)
      IF(I) 1789.1789.
      IF((I/10)-((I+9)/10))1783. .
      I=I/10
 783  F(I+70)=DUM(14)
      GO TO 1781
 7C   FORMAT(I2.E20.4)
 789  CONTINUE
      IYEAR=(F(71)+1.E-4)
      DAY= F(72)
      TB = F(73)
      TE = F(74)
      DELT=F(75)/60.0
      XYZ =F(76)
      ICP=1
      ICPC=ICP+34
      ZYX =F(77)
      IPLOT=(F(78)+1.E-4)
      HOUR =0.0
      FMIN=0.0
      NOP=0
      KK=1
```

```
      KL=1
      SEC = 0.0
      KP = IYEAR
      IF( DAY .GE. 181.0 )  KP = KP+1
      KMAX=(TE-TB)/DELT+1
      IMAX=1
      JMAX=1
      DO 35 II=1.3
      DO 35 JJ=1.50
      H(II.JJ)=0.
   35 DRS(II.JJ)=0.
      LLLL=0
 1790 MJ=1
      JM= KMAX
      READ(5.1791)DUM(45).I.J.DUM(20)
 1791 FORMAT(A6.I2.I3.F12.0)
      IF( J .GE. KMAX) GO TO 1792
      JM=J
      MJ=J
 1792 IF(DUM(45)-DUM(50)) 1795.1793.1795
 1793 C(I)=DUM(20)
      DO 1794 II=MJ.JM
 1794 H(I.II)= C(I)/FER
      IMAX=1
      GO TO 1790
 1795 IF(DUM(45)-DUM(49))1798.1796.1798
 1796 DO 1797 II=MJ.JM
 1797 DRS(I.II)=DUM(20)
      JMAX=1
      GO TO 1790
 1798 CONTINUE
C  KP BESSELIAN YEAR
      CALL JPLEPH(KP.TB.1.RS1.RM1.C.II)
      KP=0
      M7=1
      IF(II .GT. 0)  WRITE(6.999) M7.II
      TAUS= SQRT(DOT(RS1.RS1))/VL
      TAUM =DOT(RM1.RM1)
      TAUM=SQRT(TAUM)/VL
      RAD= 57.2957795
      S=0.700
      ALPHS=0.0
      ALPHAP=0.0
      ELP = 0.001
      DO 9 II=1.100
```

```
    9  C(II)=0.
       II=1
       T(1)= TB
       T(2)= (TB +TE)/2.0D0
       T(3)= TE
  901  NO=20
       II=II+1
       MN=1
       DO 902 LI=1,3
       T(LI+3)= T(LI)-TAUM
       T(LI+6)= T(LI)-TAUS
       CALL JPLEPH(KP,T(LI+3),1,RS1,C(MN),ALD,IN)
       MN=MN+3
       IF(IN.GT.0) GO TO 999
       CALL JPLEPH(KP,T(LI+6),1,C(NO),RM1,ALD,IN)
       NO=NO+3
       IF(IN  .GT. 0) GO TO 998
  902  CONTINUE
       DO 904 LI=1,3
       C(LI+30)=C(LI)-C(LI+19)
       C(LI+33)=C(LI+3)-C(LI+22)
  904  C(LI+36)=C(LI+6)-C(LI+25)
       CALL UNVEC(C,C)
       CALL UNVEC(C(4),C(4))
       CALL UNVEC(C(7),C(7))
       CALL UNVEC(C(31),C(31))
       CALL UNVEC(C(34),C(34))
       CALL UNVEC(C(37),C(37))
       CALL CROSS(C,C(31),C(31))
       CALL CROSS(C(4),C(34),C(34))
       CALL CROSS(C(7),C(37),C(37))
       C(30)=SQRT(DOT(C(31),C(31)))
       C(31)=SQRT(DOT(C(34),C(34)))
       C(32)=SQRT(DOT(C(37),C(37)))
       CALL DLEAST(T,C(30),3,3,ALO,KI1,ALC,0,0,ALD,14,C(10))
       T1=-ALC(2)/(2.0*ALC(3))
       IF(II .GE. 3)  GO TO 906
       T(1)= T1-10.0D0/6.0D0
       T(2)= T1
       T(3)= T1+10.0D0/6.0D0
       GO TO 901
  906  IF(II .GT. 3) GO TO 909
       T(1)=T1-1.0D0/60.0D0
       T(2)=T1
       T(3)= T1+1.0D0/60.0D0
```

```
      GO TO 901
  998 WRITE(6.911) IN
  911 FORMAT(///.34X.27HJPLEPH TERMINATION ERROR IS .I3)
      READ(99)  FAKE
  908 CONTINUE
C
C  INSERT NO OP    1
      READ(5.402) DUM(20).DUM(21).DUM(22)
  402 FORMAT(A3.A2.A4)
C
      DO 4 I =1. IMAX
      DO 4 J =1. JMAX
      NOP=0
C
      WRITE(6.230)
      WRITE(6.240)
  240 FORMAT(////////////)
      WRITE(6.403)(DUM(II) . II=20.22)
  403 FORMAT(44X.27H DATA FOR SOLAR ECLIPSE ON  .A3.1X.A2.2H. .A4///)
      ENM= 3443.93412
      J11=RS*ENM
      C(2)=RM*ENM
      C(3)=RE*ENM
      WRITE(6.404) J11.C(2).C(3)
  404 FORMAT(  9X.35H PHYSICAL VALUES :  SOLAR RADIUS = I6    .3H NM
     1  .10X. 15HLUNAR RADIUS = .F7.2 .3H NM .10X. 15HEARTH RADIUS = .
     2 F8.2.3H NM //)
C
C   INSERT TIME CALCULATIONS
C
      M=1
      N=1
      EZI =5.0E-06
      T(99)=TB
  419 IT(M.N)= DAY+T(99)/24.0 +EZI
      M=M+1
      IT(M.N)= T(99)+EZI
      TB1=IT(M.N)
      AMIN = (T(99)- TB1)*60.0
      M=M+1
      IT(M.N) = AMIN +EZI
      AMIN1 = IT(M.N)
      M=M+1
      IT(M.N) =(AMIN-AMIN1)*60.0 +EZI
      N=N+1
```

```
      M=1
      IF(N-3)416.417.418
  416 T(99)=TE
      GO TO 419
  417 T(99)=T1
      GO TO 419
  418 WRITE(6.405)((IT(M.N).M=1.4).N=1.3)
  405 FORMAT(9X.27HKEY TIMES :  RUN STARTS AT  .I3.I4.I3.I3 .
     1 4X.13HRUN ENDS AT  .I3.I4.I3.I3          .3X.27HCLOSEST UMBRAL APP
     2ROACH AT  .I3.I4.I3.I3 //)
      WRITE(6.406)
  406 FORMAT(5X.4HTIME./13H (HR MIN SEC).//4X.8HALTITUDE.7X.10HFOCUS LO
     1NG.4X.14HSEMIMAJOR AXIS.3X. 14HELEV THRU ATMS.3X.13HPATH VELOCITY
     2 .3X.14HCONE AXIS LONG.3X.14HELPS CNTR LONG3X.14HSOLR POLE LONG )
      WRITE(6.407)
  407 FORMAT(5X.6H(FEET).8X.9H(DEGREES).6X.12H(NAUT MILES).6X.9H(DEGREE
     1S).9X.7H(KNOTS).8X.9H(DEGREES).8X.9H(DEGREES).8X.9H(DEGREES) /)
      WRITE(6.408)
  408 FORMAT(15H DELT SOLAR RAD.4X. 9HFOCUS LAT.5X.14HSEMIMINOR AXIS.3X
     1 .13HELEV NO ATMOS.4X.14HVELOCITY AZMTH.2X.13HCONE AXIS LAT.
     2 4X.13HELPS CNTR LAT.4X.14HSOLAR POLE LAT )
      WRITE(6.409)
  409 FORMAT(14H  (NAUT MILES).5X.9H(DEGREES).6X.12H(NAUT MILES).6X.
     1 9H(DEGREES).8X.9H(DEGREES).7X.9H(DEGREES).8X.9H(DEGREES).8X.9H(DE
     2GREES) / )
      WRITE(6.410)
  410 FORMAT(15H CONE HALF ANGL.3X.12HECCENTRICITY.3X.14HSEMILATUS RECT
     1.3X.14HAZIMUTH OF SUN.5X.10HPATH WIDTH.4X.13HADJUSTED POLE.5X.
     2 12HPOLE IN VIEW.4X.14HSOLAR POLE DIR)
      WRITE(6.411)
  411 FORMAT(12H   (DEGREES).7X.10HOF ELLIPSE.5X.12H(NAUT MILES).6X.
     1 9H(DEGREES).7X.12H(NAUT MILES).5X. 9HSTATEMENT.8X.9HSTATEMENT.8X.
     2 9H(DEGREES) // )
      WRITE(6.230)
C  INSERT  NO OP 2
C
      DO 4 K =1. KMAX
C
      M1=0
      M2=0
      M3=0
      M4=0
      M5=0
      M6=0
C  INSERT  NO OP  3
```

```
      R1 = RE +  H(I.K)
      R2 = RS + DRS(J.K)
      T(K) = TB +(K-1)*DELT
      TM  *T(K)-TAUM
      TS      * T(K)-TAUS
      CALL JPLEPH(KP.TM  .1.C.RM1.C.II)
     M7=6
      IF(II .GT. 0)  WRITE(6.999) M7.II
      CALL JPLEPH(KP.TS    .1.RS1.C.C.II)
     M7=7
      IF(II .GT. 0)  WRITE(6.999) M7.II
  999 FORMAT(12H ERR IN JPL.  3H II .I2.3HM7= .I2)
      DO 1191 II=1.3
      RES(II) = RS1(II)
      REM(II) = RM1(II)
 1191 RSM(II)=RM1(II)-RS1(II)
      CALL UNVEC(RSM.C(10))
      DO 2 II=1.3
    2 RMA(II)= RM/(R2-RM)*RSM(II)
      CALL UNVEC(RMA.C(49))
      C(52)=DOT(RM1.C(49))
      CALL CROSS(RS1.RSM.C(1))
      CALL UNVEC(C.C(69))
      CALL CROSS(C(1).RSM.C(1))
      CALL UNVEC(C(1).C(1))
      DO 3 II=1.3
      RMP(II) *C(52)*C(II+48)
      REA(II)= RM1(II)+RMA(II)
      C(4)=SQRT(DOT(RMA.RMA))
      C(4) = ASIN(RM/C(4))
      ALPHA=C(4)
      C(II+4)= RS1(II)+R2*SIN(C(4))*C(II+9)+R2*COS(C(4))*C(II)
    3 C(II+7)= C(II+4)-2.0*R2*COS(C(4))*C(II)
      CALL ARLS(C(5).V(4).PB)
      CALL ARLS(C(8).V(7).PB)
      IF(ABS(PB)-ELP) . .30
      IF(IPLOT) 4.4.607
   30 CONTINUE
C  COME BACK WITH V(E/P2).V(E/P4).V(E/PB)  FROM ECLIPS
      CALL ARLS(RM1.V.PB)
      CALL  UNVEC(V(4).C(20))
      CALL  UNVEC(V(7).C(23))
      CALL CROSS(C(23).C(20).C(23))
      A=R1/2.0*ASIN(SQRT(DOT(C(23).C(23))))
      DO 6 II = 1.3
```

```
  6  C(25+II) = V(6+II)-V(3+II)
     CALL UNVEC(C(26).C(26))
     CALL UNVEC(V(1).C(29))
     BETA=ACOS(DOT(C(26).C(49)))
C  CORRECTION NEEDED FOR REFRACTION
     C1=TAN(ALPHA)/(TAN(ALPHA)+TAN(BETA))
     CALL CROSS(RS1.RSM.C(1))
     CALL CROSS(C(1).RSM.C(4))
     CALL UNVEC(C(4).C(4))
     CALL UNVEC(C(1).C(1))
     CALL UNVEC(RSM.C(10))
     DO 7 II =1.3
     C(II+6)= SQRT(1.0-C1**2*COS(ALPHA)**2-SIN(ALPHA)**2)*R2*C(II)
     VC(II)=RS1(II)+R2*SIN(ALPHA)*C(II+9)+C1*R2*COS(ALPHA)*C(II+3)
    1 +C(II+6)
     C(II+77)=REA(II)
  7  VD(II)=VC(II)-2.0*C(II+6)
     CALL ARLS(VC.V(10).P8)
     CALL ARLS(VD.V(13).P8)
 PC PD   V(EIPC)   V(E/PD)
     CALL UNVEC(V(10).C(70))
     CALL UNVEC(V(13).C(73))
     CALL CROSS(C(70).C(73).C)
     B=R1/2.0*ASIN(SQRT(DOT(C(1).C(1))))
     ECC= SQRT(ABS(1.0-(B/A)**2))
     SHLTRC =B*B/A
     DO 77 II=1.3
     VEP3(II)=V(3+II) +V(6+II)
 77  VSUN(II) =V(3+II) -V(6+II)
     CALL UNVEC(VEP3.VEP3)
     CALL UNVEC(VSUN.VSUN)
     DO 8 II = 1.3
     VEP3(II)=VEP3(II)*R1
  8  VEP4(II)= COS(A*ECC/RE)*VEP3(II) +R1*SIN(A*ECC/RE)*VSUN(II)
     VTN(1)=0.
     VTN(2)=0.
     VTN(3) = 1.0
     CALL CROSS(VEP4.VTN.C(1))
     CALL CROSS(C(1).VEP4.C(1))
     CALL UNVEC(C(1).C(1))
     CALL CROSS(VSUN.C(1).C(4))
     CALL UNVEC(C(4).C(4))
     C(60)=DOT(VEP4.C(4))
     IF(C(60)) 31.31.23
 31  M1=1
```

```
   23 CONTINUE
      AZM=ACOS(DOT(VSUN,C))
      AZ=QUAD(AZM,M1)
C
C     VSNP   GIVEN VECTOR  PARALLEL TO   UNS NORTH POLE
      C(1)=23./RAD +27./(60.*RAD)*(8.26 -46.84*S-.004*S**2+.0018*S**3
    1 )/3600.*RAD
      C(2)= ATAN(TAN(74./RAD+(22.+84.*S)/(60.*RAD))/COS(C(1) ))
      C(3)= 7.0/RAD + 0.25*S/RAD
      VSNP(1)=RS*SIN(C(2))*SIN(C(3))
      VSNP(2)=RS*(-COS(C(1))*COS(C(2))*SIN(C(3))-SIN(C(1))*COS(C(3)))
     VSNP(3)=-RS*(SIN(C(1))*COS(C(2))*SIN(C(3))-COS(C(1))*COS(C(3)) )
C
      CALL UNVEC(RSM,C)
      C2= DOT(C,VSNP)
      IF(ABS(C2)-RS*SIN(ALPHA) )13,13,24
   13 M2=1
   24 CONTINUE
      IF(C2 .LE. 0.) GO TO 14
      DO 11 II=1,3
   11 VSNP(II)=-VSNP(II)
      M3 =1
   14 CALL UNVEC(RSM,C(1))
      CALL UNVEC(VSNP,C(4))
      CALL CROSS(C(1),C(4),C(1))
      C(1)=SQRT(DOT(C(1),C(1)))
      C(2)=SQRT(DOT(VSNP,VSNP))
      DO 12 II=1,3
    2 C(II+3) =RSM(II)-VSNP(II)
      C(3)=SQRT(DOT(C(4),C(4)))
      C3=C(1)*C(2)/C(3)
      C4=RM/C(3)
      ALPHAP=ASIN(C3*SQRT(1.0-C4**2)-C4*SQRT(1.0-C3**2))
      DO 21 II=1,3
      C(II+77)= REA(II)
      REA(II)=SIN(ALPHA)/SIN(ALPHAP)*RMA(II)+RM1(II)
   21 VE(II)=RS1(II)+VSNP(II)
C
   17 CALL ARLS(VE,VEP5,P5)
C  COMEBACKWITH P(5)
      IF(M4) . .16
      IF(P5)16,15,16
   15 DO 25 II = 1,3
      REA(II)=C(II+77)
   25 VE(II)=RS1(II)+VSNP(II)
```

```
      M4=1
      GO TO 17
C
 16   CONTINUE
      CALL CROSS(VEP4.VEP5.C)
      CALL CROSS(C.VEP4.C)
      CALL UNVEC(C.VSPOR)
      CALL UNVEC(VSPOR.C)
      CALL UNVEC(VSUN.C(4))
      CALL CROSS(C(1).C(4).C(4))
      CALL UNVEC(C(4).VAZSP)
      CALL UNVEC(VEP4.VEP4)
      C(60)= DOT(VAZSP.VEP4)
      IF(C(60)) 33.33.18
 33   M5=1
 18   CONTINUE
      AZN=ACOS(DOT(VSPOR.VSUN))
      AZP = QUAD(AZN.M5)
C   CONST TABLE FOR VEP2
C     DVEP2=0.
C   USE CURVE FIT  TO COMPUTE FOLLOWING
C     VEL =R1/RE(D(VEP2)/DT))
C  ASSUME MAX OF 10 DATA POINTS
      ALD(KL)=T(K)
      ALD(KL+10)=V(1)
      ALD(KL+20)=V(2)
      ALD(KL+30)=V(3)
      IF(KK-3)200.210.210
  9   KL=2
      CALL DLEAST(ALD.ALD(11).3.3.ALD.KII.ALC.0.0.C.14.C(10))
      DVEP2(1)=ALC(3)*2.0*T(K) + ALC(2)
      CALL DLEAST(ALD.ALD(21).3.3.ALD.KII.ALC.0.0.C.14.C(10))
      DVEP2(2)=ALC(3)*2.0*T(K) + ALC(2)
      CALL DLEAST(ALD.ALD(31).3.3.ALD.KII.ALC.0.0.C.14.C(10))
      DVEP2(3)=ALC(3)*2.0*T(K) + ALC(2)
      C(98)= DVEP2(1)+V(2)*0.262516142
      C(99)= DVEP2(2)-V(1)*0.262516142
      C(100)= DVEP2(3)
      C(100)= SQRT(DOT(C(98).C(98)))*ENM
      DO 221 II=1.3
      ALD(II)=ALD(II+1)
      ALD(II+10)=ALD(II+11)
      ALD(II+20)=ALD(II+21)
 221  ALD(II+30)=ALD(II+31)
      CALL CROSS(V    .VTN.C(1))
```

```
      CALL CROSS(C.V.VLNV)
      CALL UNVEC(VLNV.VLNV)
      CALL UNVEC(DVEP2.DVEP2)
      CALL CROSS(DVEP2.VLNV.VAZV)
      CALL UNVEC(VAZV.VAZV)
      C(1)= DOT(VAZV.V)
      IF(C(1)) 34.34.19
   34 M6=1
   19 CONTINUE
      AZO=ACOS(DOT(DVEP2.VLNV))
      AZV =QUAD(AZO.M6)
      GAMMA= AZV-AZ
      D= 2.0*SQRT((A*SIN(GAMMA))**2+(B*COS(GAMMA))**2)
C
C    CONVERSION OF OUTPUT NEXT
C    OUTPUT
      GO TO 203
  200 D=0.0
      AZV=0.0
  203 KL=KL+1
      KK=KK+1
      NOP=NOP+1
      IF(NOP-9)270.280.280
  280 NOP=0
      WRITE(6.230)
  230 FORMAT(1H1)
  270 CONTINUE
C
      M=1
      N=1
      IT(M.N)=T(K)+EZI
      TB1=IT(M.N)
      AMIN=(T(K)-TB1)*60.0
      M=M+1
      IT(M.N)= AMIN+EZI*100.0
      AMIN1 =IT(M.N)
      M=M+1
      IT(M.N)=(AMIN-AMIN1)*60.0+EZI
      A=A*ENM
      B=B*ENM
      DRS(I.K)=DRS(I.K)*ENM
      SMLTRC=SMLTRC*ENM
      D=D*ENM
      CALL ANG(VEP4.FP4.ALP4)
      CALL ANG(VEP3.FP3.ALP3)
```

```
      CALL ANG(VEPS.FPS.ALP5)
      CALL ANG(V.FP2.ALP2)
      BETAAP=BETAIP*57.2957795
      IF(M4)561.561.562
562   M8=1
      GO TO 563
561   M8=6
563   IF(M2) . .564
      IF(M3) . .566
563   N8=4
      GO TO 567
564   N8=11
      GO TO 567
566   N8=9
567   N9=N8+1
      M9=M8+2
      ALPHA=ALPHA*RAD
      BETA=BETA*RAD
      AZV=AZV*RAD
      AZ=AZ*RAD
      AZP=AZP*RAD
      MN1=1
      J12= H(I.K)*2.09257413007 +0.5
      F(2)=ALP4
      F(3)=A
      F(4)=BETAAP+BETA
      F(5)=C(100)
      F(6)=ALP2
      F(7)=ALP3
      F(8)=ALP5
      J13= DRS(J.K)*ENM
      F(10)=FP4
      F(11)=B
      F(12)=BETA
      F(13)=AZV
      F(14)=FP2
      F(15)=FP3
      F(16)=FP5
      F(17)=ALPHA
      F(18)=ECC
      F(19)=SHLTRC
      F(20)=AZ
      F(22)= AZP
      F(21)=D
      WRITE(6,412) (IT(M.1).M=1.3).J12.(F(I1).I1=2.8).J13.(F(I1).I1=10.
```

```
    1 21).(DUM(M).M=M8.M9).(DUM(N).N=N8.N9).F(22)
412   FORMAT( 3I3./.I11.9X. F8.3.6X.F10.5.3X.E14.7.7X.F10.3.8X.F8.3
    1 .9X.F8.3.9X.F8.3./.I11.8X.F9.3. 6X.F10.5.3X.E14.7.7X.F10.5.9X.
    2 F7.3.10X.F7.3.10X.F7.3./.E13.8.2X.E14.8.5X.F10.5.7X.F10.5. 7X.
    3 F10.5.5X.3A5.3X.2A6.5X.F10.5//)
      IF(IPLOT-1) 4.887.
      CALL GEDV(X(1.ICP).ALP2.FP2)
      ICP=ICP+1
      IF(ICPC-ICP) . .885
      CALL GEDV(X(1.ICP).ALP5.FP5)
      DO 805 II=1.3
      C(II)= V(II+3)-VEP3(II)
      C(II+3)= V(II+9)-VEP3(II)
805   X(II.ICP+1)=0.0
      ICP=ICP+2
      CALL UNVEC(C.C)
      CALL UNVEC(C(4).C(4))
      CALL ANG(V(4).C(8).C(9))
      CALL GEDV(X(1.ICP).C(9).C(8))
      ICP=ICP+1
      CALL ANG(V(7).C(8).C(9))
      CALL GEDV(X(1.ICP).C(9).C(8))
      X(1.ICP+1)=0.0
      X(2.ICP+1)=0.0
      X(3.ICP+1)=0.0
      ICP=ICP+2
      CALL ANG(V(10).C(8).C(9))
      CALL GEDV(X(1.ICP).C(9).C(8))
      ICP=ICP+1
      CALL ANG(V(13).C(8).C(9))
      CALL GEDV(X(1.ICP).C(9).C(8))
      X(1.ICP+1)=0.0
      X(2.ICP+1)=0.0
      X(3.ICP+1)=0.0
      ICP=ICP+2
      C8=0.0D0
      DO910 II=1.10
      C8=C8+9.0D0/RAD
      C(9)=(A*B/SQRT(B*B*COS(C8)**2+A*A*SIN(C8)**2))/ENM
      DO 807 IPL=1.3
      C(IPL+10)=(C(IPL)*COS(C8)+C(IPL+3)*SIN(C8))*C(9)+VEP3(IPL)
      C(IPL+13)= C(IPL+10)-2.0*(C(IPL+3)*SIN(C8)*C(9))
      C(IPL+16)=-C(IPL+13)+2.0*VEP3(IPL)
807   C(IPL+19)=-C(IPL+10)+2.0*VEP3(IPL)
      IPL=ICP+II
```

```
      CALL ANG(C(11).C(8).C(9))
      CALL GEDV(X(1.IPL).C(9).C(8))
      IPL=ICP+21-II
      CALL ANG(C(17).C(8).C(9))
      CALL GEDV(X(1.IPL).C(9).C(8))
      IPL=ICP+20+II
      CALL ANG(C(20).C(8).C(9))
      CALL GEDV(X(1.IPL).C(9).C(8))
      IPL=ICP+41-II
      CALL ANG(C(14).C(8).C(9))
      CALL GEDV(X(1.IPL).C(9).C(8))
 810  CONTINUE
      DO 812 II=1.3
      X(II.ICP+41)=X(II.ICP+1)
 812  X(II.ICP+42)=0.0
      ICP=ICP+43
      CALL GEDV(X(1.ICP).ALP2.FP2)
      ICP=ICP+1
      ICPC=ICP+34
 885  IF(ICP .LT. 523) GO TO 887
      IPLOT=1
 887  IF(ICP-I) 4.4.
      IF(ICP .NE. ICPC-24) GO TO 4
      ICP=ICP-1
      WRITE(6.720) ICP
 720  FORMAT( 35X14HPOINTS PLOTED= .I3.10X.16HPLOT HAS STARTED    )
      F(20)=F(79)
      F(67)=RSI(1)
      F(68)=RSI(2)
      F(69)=RSI(3)
      C(1)=1.0
      C(2)=0.0
      C(3)=0.0
      CALL ANG(C.C(9).C(10))
      F(25)=24.553/RAD
      F(26)= (-13.918+C(10))/RAD
      F(27)= -C(10)/RAD
      CALL FILNAV(0)
      CALL GRIDGN(G1.SS1.61.SS1.900.900.0.0)
      CALL IPLOT(F(25).F(26).0.0.F(20).0.34906585.0..0..2.F.F(27))
      ICP=ICP+1
 895  IF(K .NE. KMAX/2 ) GO TO 4
   4  CONTINUE
      GO TO 37
      END
```

```
      SUBROUTINE ANG(B.F.AL)
      DOUBLE PRECISION A.B.F.AL.HOUR.T.G.H.CC.RHA.BETA. RS1.O.DOT
C
      DIMENSION A(50).B(3)
      COMMON/ECL/ T(200).K.G.H.CC(3).RHA(3).BETA.RS1(9).O(15.200
      COMMON /DATE/ IYEAR.DAY.HOUR
      CALL UNVEC(B.A)
      A(10)=DAY
      F=ATAN(B(3)/SQRT(B(1)**2+B(2)**2))
      AL= ATAN2(A(2).A(1))
C
C   LATITUDE CORRECTION
C
      A(4)= 1.000D0
      A(15)= SQRT(DOT(B.B))
      A(20)= 1.00000D0 + O(J.K)
      A(21)= 0.99664767D0 + O(J.K)
       A(22)=                 (A(20)**2-A(21)**2)/(A(20)*A(15))
      DO 10 I=4.6
      A(I)=A(21)/A(20)+A(22)*A(4)/SQRT(COS(F)**2+A(4)**2*SIN(F)*
   10 A(4)=A(I)
      F= ATAN(A(6)*A(20)/A(21)*TAN(F))*57.2957795D0
C
C  GREENWICH  CORRECTION
C
     A(4)=((IYEAR-1960.)*365. +(IYEAR-1959.)/4.)*0.5064082D-14
      I=(IYEAR-1960)*365+(IYEAR-1957)/4
      A(7)=I
      A(4)= A(7)**2*0.5064082D-14
      A(6)= 6.2831853071795865D0
C  PDOT=A(25) . PSIDOT=A(26)
      A(25)= 2.737909265D-3*A(6)
      A(26)= 4.1780746219910-2*A(6)
      A(5)= (A(7)+A(10))*A(25)
      A(5)= A(5)+1.7221063D0+A(4)+(HOUR+T(K))*A(26)
      I=A(5)/A(6)
      A(9)=I
      A(11)= A(5)-A(9)*A(6)
      AL=(AL-A(11))*57.2957795D0
      IF(ABS(AL)-360.0D0) 30.30.20
   20 AL=AL-SIGN(360.0D0.AL)
   30 IF(ABS(AL)-180.0)100.110.110
  110 AL=AL-SIGN(360.0.AL)
  100 RETURN
      END
```

```
      SUBROUTINE ARLS(AA.BB.PB)
      IMPLICIT DOUBLE PRECISION (A-H.O-Z)
      REAL PB
      DIMENSION R1(50).AA(3).BB(3).P(16)
      DATA(P(I).I=1.16)/1.04234D-3.1.14318D-3.1.24402D-3.1.34486D-3.
    1 1.4457D-3.1.54665D-3.1.71139D-3.1.91016D-3.2.15257D-3.2.4677D-3.
    2 2.8749D-3.3.42760D-3.4.20330D-3.5.36680D-3.7.19460D-3.1.07877D-2/
      COMMON/ECL/ T(200).K.Y.Z.CC(3).RMA(3).BETA.RS1(9).O(15.200).J
      IJKL=0
      G=Y
      H=Z
      DO 4 I=1.3
      R1(I)=CC(I)
    4 R1(I+3) = AA(I)
      PB=1.0
     R=57.2957795
      W=0.262516
   40 A=R1(4)-R1(1)
      B=R1(5)-R1(2)
      C=R1(6)-R1(3)
      D=G**2/H**2
     E=(B**2+C**2*D)/A**2
      F=(2.0*R1(2)*B+2.0*R1(3)*C*D)/A
      B1=F-2.0*R1(1) *E
      A1=E+1.0
      C1=R1(2)**2+D*R1(3)**2-F*R1(1)+E*R1(1)**2-G**2
      ARG=B1**2-4.0*A1*C1
      IF(ARG) 500.50.50
      R1(7)=(-B1+SQRT(ARG))/(2.0*A1)
      R1(8)=R1(2)+B*(R1(7)-R1(1))/A
      R1(9)=R1(3)+C*(R1(7)-R1(1))/A
      CALL UNVEC(RS1.R1(40))
      CALL UNVEC(R1(7).R1(43))
      R1(44)= DOT(R1(40).R1(43))
      IF(R1(44)) 100.101.101
  100 R1(7) = (-B1-SQRT(ARG))/(2.0*A1)
      R1(8) = R1(2) + B*(R1(7)-R1(1))/A
      R1(9) = R1(3) + C*(R1(7)-R1(1))/A
  101 CONTINUE
      IF(IJKL) 14.14.13
   14 G=1.0+O(J.K)
      H=0.99664767D0 + O(J.K)
      IJKL=1
      DO 62 I=1.9
   62 R1(I+41)=R1(I)
```

```
      DO 11 I=1.3
   11 RI(I+18) = -RHA(I)
      CALL UNVEC(RI(19).RI(10))
      CALL UNVEC(RI(7).RI(13))
      A=DOT(RI(10).RI(13))
C** REFRACTION MODEL
      DOD= ACOS(A)
      REF = DOD*R
      IF(REF-90.000)205.205.215
  205 IF(REF-75.000) .210.210
      REF=REF/R
      A=2.922940-04*TAN(REF)- 3.240-07*TAN(REF)**3
      GO TO 230
  210 I= REF -74.0
      RI(16)= I
      RI(16)= REF-74.0-RI(16)
      A = P(I)+ ADS(RI(16)*(P(I+1)-P(I)))
      GO TO 230
  215 WRITE(6.220) REF
  220 FORMAT(///.7GH*********************************** INCIDENT ANGLE G
     1REATER THAN 90 DEG ANGLE= .F8.3.35H*******************************
     2****  )
      A=P(15)
  230 BETA=A
      CALL UNVEC(RI(1).RI(16))
      CALL CROSS(RI(10).RI(16).RI(25))
      CALL UNVEC(RI(25).RI(25))
      CALL CROSS(RI(10).RI(25).RI(25))
      CALL UNVEC(RI(25).RI(25))
      DO 12 I=1.3
      RI(I)= RI(I+24)*SIN(A)-RI(I+9)*COS(A)+RI(I+6)
   12 RI(I+3)=RI(I+6)
  991 CONTINUE
      GO TO 40
   13 CONTINUE
  435 CONTINUE
      DO 337 I=1.3
  387 BB(I) = RI(I+6)
      RETURN
  500 PB=0.0
      DO 1187 I=1.3
 1187 B3(I) =0.0
      RETURN
      END
```

```
      SUBROUTINE ART(C)
      DOUBLE PRECISION A.C.C1.C2
      DIMENSION A(90)
      DATA(A(I),I=75,90)/0.00104234.0.00114318.0.00124402.0.00134486.
    1 0.0014457.0.00154655.0.00171139.0.00191016.0.00215257.0.0024677.
    2 0.0028749.0.0034276.0.0042033.0.0053668.0.0071946.0.01028774/
      C=C*57.2957795
      IF(C-90.001) 2.2.5
  5   C=180.0-C
  2   IF(C-75.0000) 4.3.3
  4   C=C/57.2957795
      C= 0.000292294*TAN(C)-0.000000324*TAN(C)**3
      RETURN
  3   IF(C-90.01)10.10.20
 10   IF(C-90.0)11.19.19
 11   I=C
      C1=I
      C2=C-C1
      C= A(I)+ABS(C2*(A(I+1)-A(I)))
      RETURN
 19   C=A(90)
      RETURN
 20   WRITE(6.22) C
 22   FORMAT(47H INCIDENT ANGLE GREATER THAN 90  THE VALUE IS: .F6.2)
      C=0.0
 29   RETURN
      END
```

```
SUBROUTINE CROSS(USE1,USE2,C)
 DOUBLE PRECISION A,B,C,USE1,USE2
DIMENSION  A(3),B(3),C(3),USE1(1),USE2(1)
DO 1 I = 1,3
A(I) = USE1(I)
B(I) = USE2(I)
C(1)=A(2)*B(3)-A(3)*B(2)
C(2)=A(3)*B(1)-A(1)*B(3)
C(3)=A(1)*B(2)-A(2)*B(1)
RETURN
END
```

```
      SUBROUTINE CROSS1(USE1,USE2,C)
      DIMENSION  A(3),B(3),C(3),USE1(1),USE2(1)
      DO 1 I = 1,3
      A(I) = USE1(I)
    1 B(I) = USE2(I)
      C(1)=A(2)*B(3)-A(3)*B(2)
      C(2)=A(3)*B(1)-A(1)*B(3)
      C(3)=A(1)*B(2)-A(2)*B(1)
      RETURN
      END
```

```
      FUNCTION DOT(A,B)
      DOUBLE PRECISION A,B
     $ ,DOT
      DIMENSION A(3),B(3)
      DOT = A(1)*B(1) + A(2)*B(2) + A(3)*B(3)
      RETURN
      END
```

```
FUNCTION DOTI(A.B)
DIMENSION A(3).B(3)
DOTI= A(1)*B(1)+A(2)*B(2)+A(3)*B(3)
RETURN
END
```

```
SUBROUTINE GEDV(X,AL,F)
DOUBLE PRECISION AL,F,R
DIMENSION X(1)
R=57.295779500
X(1)=COS(AL/R)*COS(F/R)
X(2)=SIN(AL/R)*COS(F/R)
X(3)=SIN(F/R)
RETURN
END
```

```
C***   5/25/67  V2 CHANGES HOUR TO DOUBLE PRECISION                    JPLE00
       SUBROUTINE JPLEPH (KEPOCH,TT,IWANT,RS,RB,PNL,IERROR)            JPLE00
       COMMON /DATE/ IYEAR, DAY, HOUR                                  JPLE00
        DOUBLE PRECISION HOUR                                          JPLE00
C                                                                      JPLE00
C  THIS SUBROUTINE IS DESIGNED TO PROVIDE EPHEMERIS DATA FOR THE SUN,  JPLE00
C  MOON AND EARTH AND A MATRIX OF PRECESSION - NUTATION - LIBRATION    JPLE00
C  FOR SELENOGRAPHIC COORDINATE TRANSFORMATIONS. THE COORDINATE SYSTEM JPLE00
C  FOR ALL DATA IS DEFINED BY THE MEAN EQUATOR AND THE ECLIPTIC AT THE JPLE00
C  NEAREST BEGINNING OF A BESSELIAN YEAR. THE X AXIS TO THE VERNAL     JPLE01
C  EQUINOX. THE Z AXIS ALONG THE MEAN POLE. AND THE Y AXIS DESIGNED TO JPLE01
C  COMPLETE A RIGHT HAND COORDINATE SYSTEM.                            JPLE01
C                                                                      JPLE01
C    INPUT...    (NON-INTEGER ARGUMENTS ARE DOUBLE PRECISION)          JPLE01
C                                                                      JPLE01
C      KEPOCH - ON INITIAL ENTRY THIS ARGUMENT SHOULD CONTAIN THE      JPLE01
C               DESIRED BESSELIAN YEAR FOR REFERENCE EPOCH. IT SHOULD  JPLE01
C               BE AN INTEGER IN THE CLOSED INTERVAL FROM 1951 THROUGH JPLE01
C               1999.  THE BASE TIME(DESCRIBED BY THE FIRST 5 ARGUMENTSJPLE01
C               OF LABELED COMMON INPUT) MUST FALL IN THE 6 CALENDAR   JPLE02
C               MONTHS PRIOR TO OR AFTER THIS BESSELIAN YEARS START.   JPLE02
C            ** ON SUBSEQUENT ENTRIES, IF REFERENCE EPOCH AND BASE TIMEJPLE02
C               REMAIN CONSTANT, INPUT IEPOCH = 0 TO BY-PASS REDUNDANT JPLE02
C               INITIALIZATION.                                        JPLE02
C                                                                      JPLE02
C      TT     - TIME (HOURS) RELATIVE TO BASE TIME DESCRIBED IN COMMON.JPLE02
C      IWANT  - INTEGER CONTROL SWITCH, DETERMINES OUTPUT FORMAT       JPLE02
C                                                                      JPLE02
C    OUTPUT... IF IWANT                                                JPLE02
C               =1          =2          =3          =4          =5     JPLE03
C                                                                      JPLE03
C      RS    -  POS. ONLY   POS. ONLY   NOT         NOT         NOT    JPLE03
C               SUN WRT     SUN WRT      USED        USED        USED  JPLE03
C               EARTH       MOON                                       JPLE03
C              (12 CELLS)  (12 CELLS)                                  JPLE03
C                                                                      JPLE03
C      RB    -  POS + VEL   POS + VEL   POS + VEL   POS + VEL   NOT    JPLE03
C               MOON WRT    EARTH WRT   MOON WRT    MOON WRT     USED  JPLE03
C               EARTH       MOON        EARTH       EARTH              JPLE03
C              (24 CELLS)  (24 CELLS)  (24 CELLS)  (24 CELLS)          JPLE04
C                                                                      JPLE04
C      PNL   -   NOT        LIBRATION   LIBRATION   NOT        LIBRATION JPLE04
C                 USED      MATRIX      MATRIX       USED      MATRIX  JPLE04
C                          (18 CELLS)  (18 CELLS)             (18 CELLS) JPLE04
C                                                                      JPLE04
```

```
C          IERROR - INTEGER VALIDITY INDICATOR. IERR=0 IF ALL OK. NON-ZERO JPLE04
C                 VALUES REFERENCE ERROR CONDITIONS.  SEE COMMENTS IN CODE.JPLE04
C                                                                         JPLE04
C     DATA TAPE (COPY OF NO.      ) MUST BE HUNG ON FORTRAN IV UNIT 11    JPLE04
C                                           (7040/7094 LOGICAL NO. 15)JPLE05
C                                                                         JPLE05
      DOUBLE PRECISION TOP.BASET.EDT.TTAPE.TNORM.TT.RS.RB.PNL.BUFF.       JPLE05
     1  TREC.T.DY.TAB.DSUN.DLUN.ASUN.ALUN.DSORT                           JPLE05
      DIMENSION BUFF(276).TAB(1248).DSUN(11.3).DLUN(81.15).ASUN(3.6).     JPLE05
     1 DY(5).ALUN(17.15).RS(1).RB(1).PNL(1).KB(5).JB(5).JN(5).T(5).       JPLE05
     2 IBUF(552)                                                          JPLE05
      EQUIVALENCE              (TAB (    1).DSUN ) . (TAB (  34).DLUN )   JPLE05
     1. (BUFF(    4).ASUN ) . (BUFF(  22).ALUN ) . (BUFF(    1).IBUF )    JPLE05
      LOGICAL SETUP                                                       JPLE05
      DATA (KB(I).I=1.5)/4*33.519/.(JB(I).I=1.5)/4*4.10/.(JN(I).I=1.5)  JPLE06
     1 /9.18.18.9.18/.JEPOCH.NORG.EDT/1951.0.9.888888888888889D-3/         JPLE06
      IERR = 0                                                            JPLE06
      IEPOCH = KEPOCH                                                     JPLE06
      IF (IEPOCH) 5.65.5                                                  JPLE06
    5 IF (IEPOCH.GT.1950 .AND. IEPOCH.LT.2000)  GO TO 15                  JPLE06
      IERR = 1                                                            JPLE06
C              EPOCH NOT WITHIN LIMITS                                    JPLE06
      GO TO 225                                                           JPLE06
   15 BASE T = 24.D00*DAY + HOUR + EDT                                    JPLE06
      TOP = 8760.D00                                                      JPLE07
      IF (MOD(IYEAR-1.4) .EQ. 0) TOP = 8784.D00                           JPLE07
      IF (IYEAR - IEPOCH) 25.20.25                                        JPLE07
   20 TREC = BASE T + TOP                                                 JPLE07
      GO TO 35                                                            JPLE07
   25 TREC = BASE T                                                       JPLE07
      IF (IYEAR+1-IEPOCH) 30.35.30                                        JPLE07
   30 IERR = 2                                                            JPLE07
C              EPOCH AND BASE YEAR INCONSISTENT                           JPLE07
      GO TO 225                                                           JPLE07
   35 ISKIP = IEPOCH - JEPOCH                                             JPLE08
      IF (ISKIP) 50.45.50                                                 JPLE08
   45 IF (NORG) 65.55.65                                                  JPLE08
C              SKIP TO DESIRED FILE                                       JPLE08
   50 CALL FSBSFL (11. ISKIP. L )                                         JPLE08
      IF (L) 52.55.52                                                     JPLE08
   52 IERR = 3                                                            JPLE08
C              READ REDUNDANCY WHILE SKIPPING FILES                       JPLE08
   53 NORG = 0                                                            JPLE08
      JEPOCH = 1951                                                       JPLE08
      REWIND 11                                                           JPLE09
```

```
      GO TO 225                                                         JPLE09
   55 READ (11) L.JEPOCH.BTIME.L                                        JPLE09
      SETUP = .FALSE.                                                   JPLE09
      NORG = -4                                                         JPLE09
      IF (IEPOCH - JEPOCH) 60.65.60                                     JPLE09
   60 IERR = 4                                                          JPLE09
C               FAILED TO GET THE RIGHT FILE                            JPLE09
      GO TO 53                                                          JPLE09
   65 NREC = (TT+TREC-BTIME)/192.000 + 1.000                            JPLE09
      IF (NREC.GT.1 .AND. NREC.LT.55)  GO TO 75                         JPLE10
      IERR = 5                                                          JPLE10
C               TIME OF YEAR BEYOND LIMITS FOR THIS EPOCH               JPLE10
      GO TO 225                                                         JPLE10
   75 IF (SETUP .AND. NREC.GT.NORG .AND. NREC.LT.NORG+4) GO TO 155      JPLE10
C               NEED TO GET A NEW TABLE INTO CORE                       JPLE10
      SETUP = .TRUE.                                                    JPLE10
      I = NREC - 2                                                      JPLE10
      IF (I) 85.85.90                                                   JPLE10
   85 I = 1                                                             JPLE10
      GO TO 100                                                         JPLE11
   90 IF (I.GE.52) I = 51                                               JPLE11
  100 ISKIP = I - NORG - 5                                              JPLE11
      IF (ISKIP) 115.125.105                                            JPLE11
  105 DO 110 J=1.ISKIP                                                  JPLE11
C               SPACE UP TO THE RIGHT SET OF RECORDS                    JPLE11
  110 READ (11)                                                         JPLE11
      GO TO 125                                                         JPLE11
  115 ISKIP = -ISKIP                                                    JPLE11
      DO 120 J=1.ISKIP                                                  JPLE11
                BACK UP TO THE RIGHT SET OF RECORDS                     JPLE12
  120 BACKSPACE 11                                                      JPLE12
  125 DO 150 II=1.5                                                     JPLE12
C               NOW BUILD THE TABLE                                     JPLE12
      READ (11) BUFF                                                    JPLE12
      IF (II-1) 135.127.135                                             JPLE12
  127 NORG = IBUF(2)                                                    JPLE12
      TTAPE = BUFF(3)                                                   JPLE12
      IF (NORG-1) 129.130.129                                           JPLE12
  129 IERR = 6                                                          JPLE12
C               FAILED TO GET THE DESIRED RECORD                        JPLE13
      GO TO 53                                                          JPLE13
  130 JJ = 0                                                            JPLE13
      KK = 0                                                            JPLE13
      IF (IBUF(4) .EQ. IYEAR+1) TTAPE = TTAPE + TDP                     JPLE13
  135 DO 140 J=1.3                                                      JPLE13
```

```
      L = J + JJ                                                        JPLE13
      DO 140 K=1.3                                                      JPLE13
  140 DSUN(L.K) = ASUN(J.K)                                             JPLE13
      JJ = JJ + 2                                                       JPLE13
      DO 145 J=1.17                                                     JPLE14
      L = J + KK                                                        JPLE14
      DO 145 K=1.15                                                     JPLE14
  145 DLUN(L.K) = ALUN(J.K)                                             JPLE14
  150 KK = KK + 16                                                      JPLE14
C               NORMALIZE TIME TO STARTING TIME OF CORE TABLE           JPLE14
  155 TNORM = BASE T + TT- TTAPE                                        JPLE14
      IF (TNORM .LT. 0.000)  TNORM = TNORM + TOP                        JPLE14
      KK = IWANT                                                        JPLE14
      IF (KK - 3) 160.165.165                                           JPLE14
C               SET UP TO INTERPOLATE FOR SOLAR POSITION                JPLE15
  160 T = THORM/SG.000                                                  JPLE15
      KBASE = 0                                                         JPLE15
      JBASE = 1                                                         JPLE15
      JNSET = 3                                                         JPLE15
      KSTEP = 11                                                        JPLE15
      ASSIGN 165 TO ISW                                                 JPLE15
      GO TO 250                                                         JPLE15
C               SET UP TO INTERPOLATE FOR MOON VECTORS AND/OR MATRIX    JPLE15
  165 T = TNORM/12.000                                                  JPLE15
      KBASE = KD(KK)                                                    JPLE16
      JBASE = JB(KK)                                                    JPLE16
      JNSET = JN(KK)                                                    JPLE16
      KSTEP = 01                                                        JPLE16
      ASSIGN 170 TO ISW                                                 JPLE16
      GO TO 250                                                         JPLE16
C               STORE OUTPUT VECTORS                                    JPLE16
  170 GO TO (175.195.185.185.205).KK                                    JPLE16
  175 DO 180 I=1.3                                                      JPLE16
  180 RS(I) = BUFF(I)                                                   JPLE16
  185 DO 190 I=1.3                                                      JPLE17
      RB(I) = BUFF(I+3)                                                 JPLE17
  190 RB(I+6) = BUFF(I+6)                                               JPLE17
      IF (KK - 3) 215.205.215                                           JPLE17
  195 DO 200 I=1.3                                                      JPLE17
      RS(I) = BUFF(I) - BUFF(I+3)                                       JPLE17
      RB(I) = -BUFF(I+3)                                                JPLE17
  200 RB(I+6) = -BUFF(I+6)                                              JPLE17
  205 DO 210 I=1.9                                                      JPLE17
  210 PNL(I) = BUFF(I+9)                                                JPLE17
      IF (KK - 5) 215.225.225                                           JPLE18
```

```
  215 RB(5) = RB(1)*RB(1) + RB(2)*RB(2) + RB(3)*RB(3)                JPLE18
      RB(4) = DSQRT(RB(5))                                            JPLE18
      RB(6) = RB(4)*RB(5)                                             JPLE18
      IF (KK .GE. 3) GO TO 225                                        JPLE18
      RS(5) = RS(1)*RS(1) + RS(2)*RS(2) + RS(3)*RS(3)                JPLE18
      RS(4) = DSQRT(RS(5))                                            JPLE18
      RS(6) = RS(4)*RS(5)                                             JPLE19
  225 IERROR = IERR                                                   JPLE18
      RETURN                                                          JPLE18
C               INTERPOLATION SECTION (5TH ORDER NEWTON FWD. DIF.)    JPLE19
  250 K = T - 2.0D0                                                   JPLE19
      T = T - FLOAT(K)                                                JPLE19
      K = K + KBASE                                                   JPLE19
C               CALCULATE T COEFFICIENTS                              JPLE19
      T(2) = (T - 1.0D0)*T(1)/2.0D0                                   JPLE19
      T(3) = (T - 2.0D0)*T(2)/3.0D0                                   JPLE19
      T(4) = (T - 3.0D0)*T(3)/4.0D0                                   JPLE19
      T(5) = (T - 4.0D0)*T(4)/5.0D0                                   JPLE19
C               DIFFERENCE 3 POINTS ON EITHER SIDE OF IND. VARIABLE   JPLE19
      DO 255 J=JBASE,JNSET                                            JPLE20
      DY(1) = TAB(K+2)-TAB(K+1)                                       JPLE20
      DY(2) = TAB(K+3)-TAB(K+2)-DY(1)                                 JPLE20
      DY(3) = TAB(K+4)-TAB(K+3)-TAB(K+3)+TAB(K+2)-DY(2)               JPLE20
      DY(4) = TAB(K+5)-3.*(TAB(K+4)-TAB(K+3))-TAB(K+2)-DY(3)          JPLE20
      DY(5) = TAB(K+6)-4.*(TAB(K+5)+TAB(K+3))+6.*TAB(K+4)+TAB(K+2)-DY(4)JPLE20
C               AND INTERPOLATE IN EACH TABLE                         JPLE20
      BUFF(J) = TAB(K+1) + T(1)*DY(1) + T(2)*DY(2) + T(3)*DY(3)       JPLE20
     1                   + T(4)*DY(4) + T(5)*DY(5)                    JPLE20
      K = K + KSTEP                                                   JPLE20
C               BRANCH BACK                                           JPLE21
      GO TO ISW,(165,170)                                             JPLE21
      END                                                             JPLE21
```

```
      SUBROUTINE MPLOT(GLAT.GLON.THETA.DIS.SCALE.XX.YY.ISEL.RV.RAGR)
C *** GLAT IS THE LATITUDE OF THE POINT BENEATH THE VIEWPOINT. MEASURED MPLT00
C           DEGREES PLUS NORTH FROM THE EQUATOR.                        MPLT00
C *** GLON IS THE LONGITUDE OF THE POINT BENEATH THE VIEWPOINT. MEASUREDMPLT00
C           DEGREES PLUS EAST FROM THE GREENWICH MERIDIAN.              MPLT00
C *** ISEL DETERMINES THE BACKGROUND.  IF                               MPLT00
C           ISEL = 1. ONLY PICTURES SHOWING COASTLINES WILL BE FORMED.  MPLT00
C           ISEL = 2. PICTURES SHOWING BOTH GRID LINES AND COASTLINES WILMPLT00
C                BE FORMED.                                             MPLT00
      DIMENSION XD(181).YD(181).XPR(2).YPR(2)                           MPLT01
      DIMENSION XZ(3).YZ(3).ZZ(3).A(3).B(3).AP(3).RS(3).RV(1).VT(3).
     1PV(3).V(3.600).NLO(25).AMAT(9)
      DATA(XZ(I).I=1.3)/1.0.0.0.0.0/(YZ(I).I=1.3)/0.0.1.0.0.0/
      DATA(ZZ(I).I=1.3)/0.0.0.0.1.0/NPT/0/
       DATA DTWO/.34906585E-1/.DTEN/.174532925/.DFIVE/.872664626E-1/.   MPLT01
     $ DHETY/-1.3962634/. DNNTY/-1.57079633/                            MPLT01
       COMMON/EPL/ICP.XPLOTE(3.600)
      REWIND 14                                                         MPLT01
      XMAR = 451.0                                                      MPLT01
      YMAR = 451.0                                                      MPLT01
      DISR =ARSIN (1.0 / DIS)                                           MPLT01
      RAG  = SCALE / (2.0 * DISR)                                       MPLT02
      X =-XX / DISR                                                     MPLT02
      Y = YY / DISR                                                     MPLT02
      AVX=-X                                                            MPLT02
      AVY=-Y                                                            MPLT02
      ZXX = RAG                                                         MPLT02
      ZYB = RAG                                                         MPLT 0
       ZYT = ZYB                                                        MPLT02
       CALL PLOT1(1.1.-ZXX.ZXX.-ZYB.ZYB.XP.YP.1.1.1H )                  MPLT02
C                                                                       MPLT02
C     COMPUTE ROTATION MATRICES FOR GLAT.GLON.AND THETA....             MPLT03
C     CALL MPAMAT                                                       MPLT03
C                                                                       MPLT03
      PLAT = GLAT                                                       MPLT03
      PLON = GLON                                                       MPLT03
      THE  = THETA                                                      MPLT03
      CL=COS(PLON)                                                      MPLT03
      SL=SIN(PLON)                                                      MPLT03
      CP=COS(PLAT)                                                      MPLT03
      SP=SIN(PLAT)                                                      MPLT03
       STHE = SIN(THE)                                                  MPLT04
       CTHE = COS(THE)                                                  MPLT04
       AMAT(1) = -SL*CTHE - CL*SP*STHE                                  MPLT04
       AMAT(2) = SL*STHE - CL*SP*CTHE                                   MPLT04
```

```
      AMAT(3) = CL*CP                                              MPLT04
      AMAT(4) = CL*CTHE - SL*SP*STHE                               MPLT04
      AMAT(5) = -CL*STHE - SL*SP*CTHE                              MPLT04
      AMAT(6) = SL*CP                                              MPLT04
      AMAT(7) = CP*STHE                                            MPLT04
      AMAT(8) = CP*CTHE                                            MPLT04
      AMAT(9) = SP                                                 MPLT05
C                                                                  MPLT05
C   PLOT THE HORIZON.......                                        MPLT05
C     CALL MPHORZ                                                  MPLT05
C                                                                  MPLT05
      DO 100 I=1,361,2                                             MPLT05
      ANG=FLOAT(I)/57.29578                                        MPLT05
      J=I/2+1                                                      MPLT05
      XD(J)=COS(ANG)                                               MPLT05
      YD(J)=SIN(ANG)                                               MPLT05
  100 CONTINUE                                                     MPLT06
       NPT=1                                                       MPLT06
      NN = 181
  110  LNUM=2                                                      MPLT06
      DO 170 I=1,NN
       XD1  =XD(I)-AVX                                             MPLT06
       YD1  =YD(I)-AVY                                             MPLT06
      IF(ABS(XD1   )-ZXX)120,120,160                               MPLT06
  120 YZIP=YD1                                                     MPLT06
      IF(YZIP+ZYB)160,130,130                                      MPLT06
  130 IF(YZIP-ZYT)140,160,160                                      MPLT07
  140 XPR(LNUM)=XD1                                                MPLT07
      YPR(LNUM)=YD1                                                MPLT07
      LNUM=LNUM-1                                                  MPLT07
      IF(LNUM)150,150,170                                          MPLT07
  150 CALL VECTR(XPR(1),XPR(2),YPR(1),YPR(2),1)                    MPLT07
      LNUM=1                                                       MPLT07
      XPR(2)=XPR(1)                                                MPLT07
      YPR(2)=YPR(1)                                                MPLT07
      GO TO 170                                                    MPLT07
  160 LNUM=2                                                       MPLT08
  170 CONTINUE                                                     MPLT08
      IF (NN.LT.100) GO TO 176
C
C     PLOT THE TERMINATOR LINE
C
      NN=91
       CALL UNVECI(RV(67),VT)
      RAS=ATAN2(VT(2),VT(1))
```

```
      ALONG=RAS-RAGR
      VT(1)=COS(ALONG)
      VT(2)=SIN(ALONG)
       CALL UNVEC1(VT,VT)
      RS(1)=AMAT(1)*VT(1)+AMAT(4)*VT(2)+AMAT(7)*VT(3)
      RS(2) = AMAT(2)*VT(1)+AMAT(5)*VT(2)+AMAT(8)*VT(3)
      RS(3)=AMAT(3)*VT(1)+AMAT(6)*VT(2)+AMAT(9)*VT(3)
       CALL CROSS1(ZZ,RS,A)
       CALL UNVEC1(A,A)
       CALL CROSS1(A,RS,B)
       CALL UNVEC1(B,B)
      J=0
      DO 70 I= 1,361,2
      ANG = FLOAT(I)/57.29578
      DO 71 K=1,3
      AP(K) = A(K)*COS(ANG)+B(K)*SIN(ANG)
   71 CONTINUE
      IF (AP(3)-0.0) 70,72,72
   72 CALL ORTH (1,DIS,AP)
      STOP=SQRT(PV(1)*PV(1)+PV(2)*PV(2))
      IF (STOP.GE.1.0) GO TO 70
   80 J=J+1
      XD(J)=AP(1)
      YD(J) = AP(2)
   70 CONTINUE
      NN=J
      GO TO 110
  175 INDEX=2
      GO TO (520,180), ISEL
  1   INDEX=1
      GO TO 501
C                                                                       MPLT08
C           PLOT THE LAT LONG GRID, IF DESIRED ........                 MPLT08
C      CALL MPGRID                                                      MPLT08
C                                                                       MPLT08
  180  CALL LIGHT                                                       MPLT08
      VLAT = GLAT * 57.2957795                                          MPLT08
      VLON = GLON * 57.2957795                                          MPLT08
      IF(VLON)190,200,200                                               MPLT09
  190 VLON=360.0+VLON                                                   MPLT09
  200 CONTINUE                                                          MPLT09
      PMUL=-SIGN(1.0,VLAT)                                              MPLT09
      IMUL=(180.0-ABS(VLAT))/2.0+1.0                                    MPLT09
      IF(IMUL-05)210,220,220                                            MPLT09
  210 IMUL=5                                                            MPLT09
```

```
      GO TO 230                                                        MPLT09
  220 INUL=IMUL-81                                                     MPLT09
  230 CONTINUE                                                         MPLT09
      PLON=0.0                                                         MPLT10
       DLAT= DTWO                                                      MPLT10
       DLON= DTEN                                                      MPLT10
      DO350I=1,36                                                      MPLT10
      IF(FLOAT((I-1)/9)-FLOAT(I-1)/9.0)240,250,250                     MPLT10
  240  PLAT=DMETY*PMUL                                                 MPLT10
      IZL=IMUL-INUL                                                    MPLT10
      GO TO 260                                                        MPLT10
  250  PLAT=DMNTY*PMUL                                                 MPLT10
      IZL=IMUL                                                         MPLT10
  260 CONTINUE                                                         MPLT11
      LNUM=2                                                           MPLT11
      COL=COS(PLON)                                                    MPLT11
      SOL=SIN(PLON)                                                    MPLT11
      DO330J=1,IZL                                                     MPLT11
      COP=COS(PLAT)                                                    MPLT11
      SOP=SIN(PLAT)                                                    MPLT11
      VT(1)=COP*COL                                                    MPLT11
      VT(2)=COP*SOL                                                    MPLT11
      VT(3)=SOP                                                        MPLT11
      PV(1)=AMAT(1)*VT(1)+AMAT(4)*VT(2)+AMAT(7)*VT(3)                  MPLT12
      PV(2)=AMAT(2)*VT(1)+AMAT(5)*VT(2)+AMAT(8)*VT(3)                  MPLT12
      PV(3)=AMAT(3)*VT(1)+AMAT(6)*VT(2)+AMAT(9)*VT(3)                  MPLT12
      IF (PV(3)-.05) 270,270,251
  2F  CALL GRTH (1,DIS,PV)
      STOP=SQRT(PV(1)*PV(1)+PV(2)*PV(2))
      IF (STOP.LT.1.0) GO TO 280
  270 LNUM=2                                                           MPLT12
      GO TO 330                                                        MPLT12
  280 XPO=PV(1)-AVX                                                    MPLT12
      IF(ABS(XPO)-ZXX)290,290,270                                      MPLT12
  290 YPO=PV(2)-AVY                                                    MPLT12
      IF(YPO+ZYD)270,300,300                                           MPLT12
  300 IF(YPO-ZYT)310,270,270                                           MPLT13
  310 XPR(LNUM)=XPO                                                    MPLT13
      YPR(LNUM)=YPO                                                    MPLT13
      LNUM=LNUM-1                                                      MPLT13
      IF(LNUM)330,320,330                                              MPLT13
  320 CALL VECTR(XPR(1),XPR(2),YPR(1),YPR(2),I)                        MPLT13
      LNUM=1                                                           MPLT13
      XPR(2)=XPR(1)                                                    MPLT13
      YPR(2)=YPR(1)                                                    MPLT13
```

```
330 PLAT=PLAT+DLAT*PMUL                                    MPLT13
340 PLON=PLON+DLON                                         MPLT14
350 CONTINUE                                               MPLT14
501 CALL LIGHT
     PLAT =DMETY                                           MPLT14
     DELAT= DTEN                                           MPLT14
    DO510I=1,17                                            MPLT14
    IF(I-3)390,400,360                                     MPLT14
360 IF(I-6)400,410,370                                     MPLT14
370 IF(I-13)410,400,300                                    MPLT14
300 IF(I-16)400,390,390                                    MPLT14
390  DLON= DTEN                                            MPLT14
     IZL= 37                                               MPLT15
    GO TO 420                                              MPLT15
400  DLON= DFIVE                                           MPLT15
     IZL= 73                                               MPLT15
    GO TO 420                                              MPLT15
410  DLON= OTWO                                            MPLT15
     IZL= 101                                              MPLT15
420 COP=COS(PLAT)                                          MPLT15
    SOP=SIN(PLAT)                                          MPLT15
     LNUM=2                                                MPLT15
    PLON=0.0                                               MPLT16
     DO 490 J=1,IZL                                        MPLT16
    COL=COS(PLON)                                          MPLT16
    SOL=SIN(PLON)                                          MPLT16
    VT(1)=COP*COL                                          MPLT16
    VT(2)=COP*SOL                                          MPLT16
    VT(3)=SOP                                              MPLT16
    PV(1)=AMAT(1)*VT(1)+AMAT(4)*VT(2)+AMAT(7)*VT(3)        MPLT16
    PV(2)=AMAT(2)*VT(1)+AMAT(5)*VT(2)+AMAT(8)*VT(3)        MPLT16
    PV(3)=AMAT(3)*VT(1)+AMAT(6)*VT(2)+AMAT(9)*VT(3)        MPLT16
    IF (PV(3)) 430,430,429
429 CALL GRTH (1,DIS,PV)
    STOP=SQRT(PV(1)*PV(1)+PV(2)*PV(2))
    IF (STOP.LT.1.0) GO TO 431
430 LNUM=2                                                 MPLT17
    GO TO 490                                              MPLT17
431 IPASS=0
    IF (INDEX.EQ.2) GO TO 440
    PV(3)=SQRT(1.-PV(1)*PV(1)-PV(2)*PV(2))
     IF(ACOS(DOTI(RS,PV)).LE.90.0/57.29578) IPASS=1
440 XPO=PV(1)-AVX                                          MPLT17
    IF(ABS(XPO)-ZXX)450,450,430                            MPLT17
450 YPO=PV(2)-AVY                                          MPLT17
```

```
      IF(YPO+7YB)430.450.460                                             MPLT17
  460 IF(YPO-ZYT)470.430.430                                             MPLT17
  470 XPR(LNUM)=XPO                                                      MPLT17
      YPR(LNUM)=YPO                                                      MPLT17
      IF (IPASS.EQ.1) GO TO 489
      LNUM=LNUM-1                                                        MPLT18
      IF(LNUM)490.480.490                                                MPLT18
  480 CALL VECTR(XPR(1).XPR(2).YPR(1).YPR(2).1)                          MPLT18
      LNUM=1                                                             MPLT18
  489 XPR(2)=XPR(1)
      YPR(2)=YPR(1)                                                      MPLT18
  490 PLON=PLON+DLON                                                     MPLT18
  500 PLAT=PLAT+DELAT                                                    MPLT18
  510 CONTINUE                                                           MPLT18
      IF (INDEX.EQ.1) GO TO 175
       CALL DARK                                                         MPLT18
C                                                                        MPLT19
C     PLOT THE SHORELINE DATA ..................                         MPLT19
C      CALL MPSHOR                                                       MPLT19
C                                                                        MPLT19
  520 BRAG=(RAG/170.1)**2                                                MPLT19
      READ(14) NLOOP.(NLO(I).I=1.NLOOP)
      LNUM=2                                                             MPLT19
       NLUPE= NLOOP+1
       DO 640 I=1.NLUPE
       IF(I-NLOOP) . .524
      NPOX=NLO(I)                                                        MPLT19
      READ (14) ((V(J.K).J=1.3).K=1.NPOX)                                MPLT19
       GO TO 529
  524  DO 526 JJ=1.ICP
       DO 526 II=1.3
       V(II.JJ)=XPLOTE(II.JJ)
  526  CONTINUE
       NPOX= ICP
  529  CONTINUE
      DO 630 J=1.NPOX                                                    MPLT20
      IF(V(2.J))550.530.550                                              MPLT20
  530 IF(V(3.J))550.540.550                                              MPLT20
  540 LNUM=2                                                             MPLT20
      GO TO 630                                                          MPLT20
  550 PV(1)=V(1.J)*AMAT(1)+V(2.J)*AMAT(4)+V(3.J)*AMAT(7)-AVX             MPLT20
      PV(2)=V(1.J)*AMAT(2)+V(2.J)*AMAT(5)+V(3.J)*AMAT(8)-AVY             MPLT20
      PV(3)=V(1.J)*AMAT(3)+V(2.J)*AMAT(6)+V(3.J)*AMAT(9)                 MPLT20
      IF (PV(3)) 540.540.559
  559 CALL ORTH (1.DIS.PV)
```

```
      STOP=SORT(PV(1)*PV(1)+PV(2)*PV(2))
      IF (STOP.GE.1.0) GO TO 540
  550 IF(ABS(PV(1))-ZXX)570.540.540
  570 IF(PV(2)-ZYT)580.540.540                                          MPLT20
  580 IF (PV(2)+ZYB) 540.585.585                                        MPLT21
  585 IF (I.EQ.NLOOP) GO TO 625
  590 IF(LNUM-2)600.610.600
  600 IF((XPR(2)-PV(1))**2+(YPR(2)-PV(2))**2-BRAG)630.630.610           MPLT21
  610 XPR(LNUM)=PV(1)                                                   MPLT21
      YPR(LNUM)=PV(2)                                                   MPLT21
      LNUM=LNUM-1                                                       MPLT21
      IF(LNUM)630.620.630                                               MPLT21
  620 CALL VECTR(XPR(1).XPR(2).YPR(1).YPR(2).1)                         MPLT21
      LNUM=1                                                            MPLT21
      XPR(2)=XPR(1)                                                     MPLT21
      YPR(2)=YPR(1)                                                     MPLT22
      GO TO 630                                                         MPLT22
  625 PV(2)=PV(2)+SCALE/225.0
      CALL PLOT1(1.1.-ZXX.ZXX.-ZYB.ZYB.PV(1).PV(2).1.0.1H.)
  630 CONTINUE                                                          MPLT22
  640 CONTINUE                                                          MPLT22
  650 RETURN                                                            MPLT22
      END                                                               MPLT22
```

```
      SUBROUTINE ORTH(M,R,P)
C
C     ORTHOGRAPHIC PERSPECTIVE CORRECTIVE EQUATIONS
C
      REAL MU
      DIMENSION P(3),PV(3)
      RADIUS=1.0
      IF (M.EQ.2) RADIUS=.272506
      DO 1 I=1,3
    1 PV(I)=P(I)*RADIUS
      Z=PV(3)
      B=SQRT(RADIUS**2-Z**2)
      A=Z*B/(R-Z)
      MU=PV(1)/PV(2)
      DELT2=A*SQRT(1./(MU**2+1.))
      PV(2)=PV(2)+SIGN(DELT2,PV(2))
      DELT1=MU*DELT2
      PV(1)=PV(1)+SIGN(DELT1,PV(1))
      RETURN
      END
      DO 2 I=1,3
    2 P(I)=PV(I)/RADIUS
```

```
      FUNCTION QUAD(AZ.I)
      DOUBLE PRECISION QUAD.AZ.PI
      PI=3.14159265D0
      IF(I-1)3.4.4
      QUAD= AZ
      RETURN
      QUAD= 2.0*PI-AZ
      RETURN
      END
```

```
      SUBROUTINE UNVEC(A.B)
      DOUBLE PRECISION A.B.C
      DIMENSIGN A(3) . B(3)
      C= SORT(A(1)**2+A(2)**2+ A(3)**2)
      DO 1 I=1.3
    1 B(I)= A(I)/C
      RETURN
      END
```

```
      SUBROUTINE UNVEC1(A,B)
      DIMENSION A(3) , B(3)
      C= SQRT(A(1)**2+A(2)**2+ A(3)**2)
      DO 1 I=1,3
    1 B(I)= A(I)/C
      RETURN
      END
```

4.6 SAMPLE OUTPUT

DATA FOR SOLAR ECLIPSE ON JUL 10, 1972

PHYSICAL VALUES / SOLAR RADIUS = [illegible] NM LUNAR RADIUS = [illegible] NM EARTH RADIUS = [illegible] NM

KEY TIMES / RUN STARTS AT 192 19 0 0 RUN ENDS AT 192 21 0 0 CLOSEST UMBRAL APPROACH AT 192 19 46 4

TIME
(HR MIN SEC)

ALTITUDE (FEET)	FOCUS LONG (DEGREES)	SEMIMAJOR AXIS (NAUT MILES)	ELEV TOR ATMS (DEGREES)	PATH VELOCITY (KNOTS)	CONE AXIS LONG (DEGREES)	ELPS CNTR LONG (DEGREES)	SOLR POLE L (DEGREES)
DELT SOLAR RAD (NAUT MILES)	FOCUS LAT (DEGREES)	SEMIMINOR AXIS (NAUT MILES)	ELEV SO ATMOS (DEGREES)	VELOCITY AZMTH (DEGREES)	CONE AXIS LAT (DEGREES)	ELPS CNTR LAT (DEGREES)	SOLAR POLE (DEGREES)
CONE HALF ANGL (DEGREES)	ECCENTRICITY OF ELLIPSE	SEMILATUS RECT (NAUT MILES)	AZIMUTH OF SUN (DEGREES)	PATH WIDTH (NAUT MILES)	ADJUSTED POLE STATEMENT	POLE IN VIEW STATEMENT	SOLAR POLE (DEGREES)

19 0 0							
40000	-147.992	57.92116	.[illegible]+02	.000	-149.727	-141.739	-145.360
0	68.518	35.73107	.1562405+02	.00000	68.108	68.471	68.257
.26218260-00	.81282176-00	17.65454	126.58840	.00000		SOUTH POLE	51.12160
19 3 0							
40000	-143.478	56.41070	.3704411+02	.000	145.021	-145.031	-143.438
0	68.700	36.01802	.3702[illegible]+02	00000	68.192	68.195	68.418
.2621826[illegible]-00	.73837416-00	20.48721	142.[illegible]	00000		SOUTH POLE	46.04538
19 6 0							
40000	-139.071	55.27152	.3813182+02	1940.[illegible]	-140.416	-140.424	-139.060
0	68.778	34.26721	.38111[illegible]+02	88.21113	69.103	69.106	68.533
.26218267-00	.78461779-00	21.24497	138.22218	95.16179		SOUTH POLE	40.83553
19 9 0							
40000	-134.789	54.22692	.3951182+02	1888.378	-135.932	-135.918	-134.787
0	68.754	34.44081	.3945700+02	91.35818	69.308	69.311	68.489
.26218270-00	.77465134-00	21.41771	144.08251	95.88100		SOUTH POLE	35.37443
19 12 0							
40000	-130.846	53.32785	.4059635+02	1835.375	-131.589	-131.598	-130.654
0	68.641	34.69056	.4057801+02	94.41182	69.216	69.218	68.375
.26218273-00	.75949356-00	22.56672	149.87746	96.26353		SOUTH POLE	30.74230
19 15 0							
40000	-126.656	52.55219	.4158197+02	1792.836	-127.404	-127.407	-126.873
0	68.445	34.86793	.4156441+02	97.14848	69.033	69.036	68.176
.26218276-00	.74818393-00	23.13457	155.59052	96.61165		SOUTH POLE	25.74697
19 18 0							
40000	-122.829	51.88284	.4247381+02	1755.870	-123.389	-123.391	-122.834
0	68.171	35.02411	.4245677+02	100.14915	68.768	68.770	67.901
.26218279-00	.73776132-00	23.64343	161.20765	96.92739		SOUTH POLE	20.78206
19 21 0							
40000	-119.169	51.30641	.4327347+02	1723.777	-119.553	-119.555	-119.201
0	67.827	35.16013	.4325689+02	102.79989	68.427	68.429	67.555
.26218282-00	.72826377-00	24.09513	166.71763	97.21039		SOUTH POLE	15.81912

19 24 0							
40000	-115.[illegible]	50.[illegible]	.4394217+02	[illegible]	-115.[illegible]	-115.[illegible]	-115.714
0	67.414	35.276[illegible]	[illegible]	105.29155	68.016	68.018	67.144
.2621[illegible]-00	.7497[illegible]-00	24.[illegible]	172.[illegible]	97.45[illegible]		SOUTH POLE	10.4[illegible]
19 27 0							
40000	-112.361	50.19245	.4460018+02	1672.107	-112.431	-112.431	-112.403
0	66.952	35.45185	.4458482+02	107.61835	67.744	67.748	66.674
.2621[illegible]-00	.7121[illegible]-00	24.84274	177.32427	97.66098		SOUTH POLE	6.00063
19 30 0							
40000	-109.204	50.04472	.4512844+02	1651.746	-109.142	-109.142	-109.253
0	66.432	35.45183	.4511145+02	109.58214	67.014	67.016	66.151
.2621[illegible]-00	.7056[illegible]-00	25.12015	182.68442	97.30109		SOUTH POLE	1.27469
19 33 0							
40000	-106.214	49.74427	.4556882+02	1634.611	-106.028	-106.025	-106.264
0	65.881	35.51721	.4555127+02	113.14176	66.433	66.435	65.580
.2621[illegible]-00	.7002224[illegible]-00	25.35802	187.60546	98.01887		SOUTH POLE	356.07050
19 36 0							
40000	-103.383	49.51691	.4591831+02	1620.512	-103.082	-103.080	-103.428
0	65.251	35.56241	.4590314+02	113.62225	65.805	65.807	64.964
.2621[illegible]-00	.6958[illegible]-00	25.54015	192.57125	98.14898		SOUTH POLE	351.20297
19 39 0							
40000	-100.633	49.34165	.4617846+02	1609.271	-100.291	-100.212	-100.736
0	64.597	35.59067	.4616342+02	115.30926	65.135	65.137	64.307
.2621[illegible]300-00	.6925[illegible]-00	25.67248	197.36236	98.22588		SOUTH POLE	346.31627
19 42 0							
40000	-98.140	49.21514	.4634809+02	1600.763	-97.654	-97.652	-98.180
0	63.907	35.60222	.4633403+02	116.84951	64.427	64.428	63.613
.2621[illegible]-00	.6904[illegible]-00	25.75462	202.03416	98.26491		SOUTH POLE	341.43373
19 45 0							
40000	-95.715	49.14210	.4642981+02	1594.906	-95.152	-95.150	-95.751
0	63.183	35.59720	.4641489+02	118.25028	63.683	63.684	62.886
.2621[illegible]306-00	.6894087-00	25.78565	206.58582	98.26449		SOUTH POLE	336.56173
19 48 0							
40000	-93.408	49.11987	.4642088+02	1591.652	-92.777	-92.775	-93.439
0	62.428	35.57567	.4640594+02	119.51911	62.906	62.907	62.126
.2621[illegible]309-00	.6895213-00	25.76823	211.01741	98.22337		SOUTH POLE	331.70451

19 51 0			.4612217+02	1590.942	-90.519	-90.516	-91.235
40000	-91.210	49.11778	.4610718+02	120.46472	62.011	62.101	61.137
0	61.614	35.53763	215.32821	98.34014		SOUTH POLE	126.86573
.26218311-00	.69076858-00	25.69841					
19 54 0			.4611378+02	1592.951	-88.166	-88.363	-89.624
40000	-89.111	49.22711	.4611861+02	121.60079	61.261	61.266	60.523
0	60.832	35.48400	219.52156	98.01463		SOUTH POLE	122.04865
.26218314-00	.69344431-00	25.57111					
19 57 0			.4585551+02	1597.597	-86.407	-86.306	-87.110
40000	-87.101	49.15946	.4588027+02	122.60786	60.401	60.404	59.674
0	59.941	35.41164	223.59484	97.84496		SOUTH POLE	317.25601
.26218317-00	.69663730-00	25.40518					
20 0 0			.4548761+02	1603.012	-84.338	-83.335	-85.172
40000	-85.171	49.54640	.4547219+02	123.42117	59.515	59.516	58.809
0	59.130	35.32331	227.54958	97.43039		SOUTH POLE	312.48989
.26218320-00	.70123120-00	25.18317					
20 3 0			.4501005+02	1615.407	-82.443	-82.439	-83.304
40000	-83.313	49.79118	.4501436+02	124.13667	58.603	58.604	57.917
0	58.243	35.21773	231.38682	97.36983		SOUTH POLE	307.75154
.26218323-00	.70690491-00	24.90980					
20 6 0			.4448261+02	1624.929	-80.614	-80.610	-81.494
40900	-81.518	50.09780	.4446665+02	124.75974	57.667	57.668	57.001
0	57.333	35.09449	235.10836	97.86217		SOUTH POLE	303.04120
.26218326-00	.71363306-00	24.58838					
20 9 0			.4384513+02	1645.863	-78.843	-78.839	-79.748
40000	-79.777	50.47144	.4382478+02	125.29515	56.707	56.708	56.061
0	56.198	34.95312	238.71066	96.70605		SOUTH POLE	298.35798
.26218329-00	.72138656-00	24.20817					
20 12 0			.4311696+02	1666.556	-77.120	-77.116	-78.040
40000	-78.083	50.91872	.4310018+02	125.74710	55.724	55.724	55.097
0	55.441	34.79301	242.20105	96.30093		SOUTH POLE	293.69971
.26218332-00	.73013317-00	23.77423					
20 15 0			.4229728+02	1691.446	-75.436	-75.432	-76.370
40000	-76.425	51.44800	.4228001+02	126.11914	54.715	54.716	54.109
0	54.459	34.61344	245.57972	95.84243		SOUTH POLE	289.06281
.26218335-00	.73983409-00	23.28740					

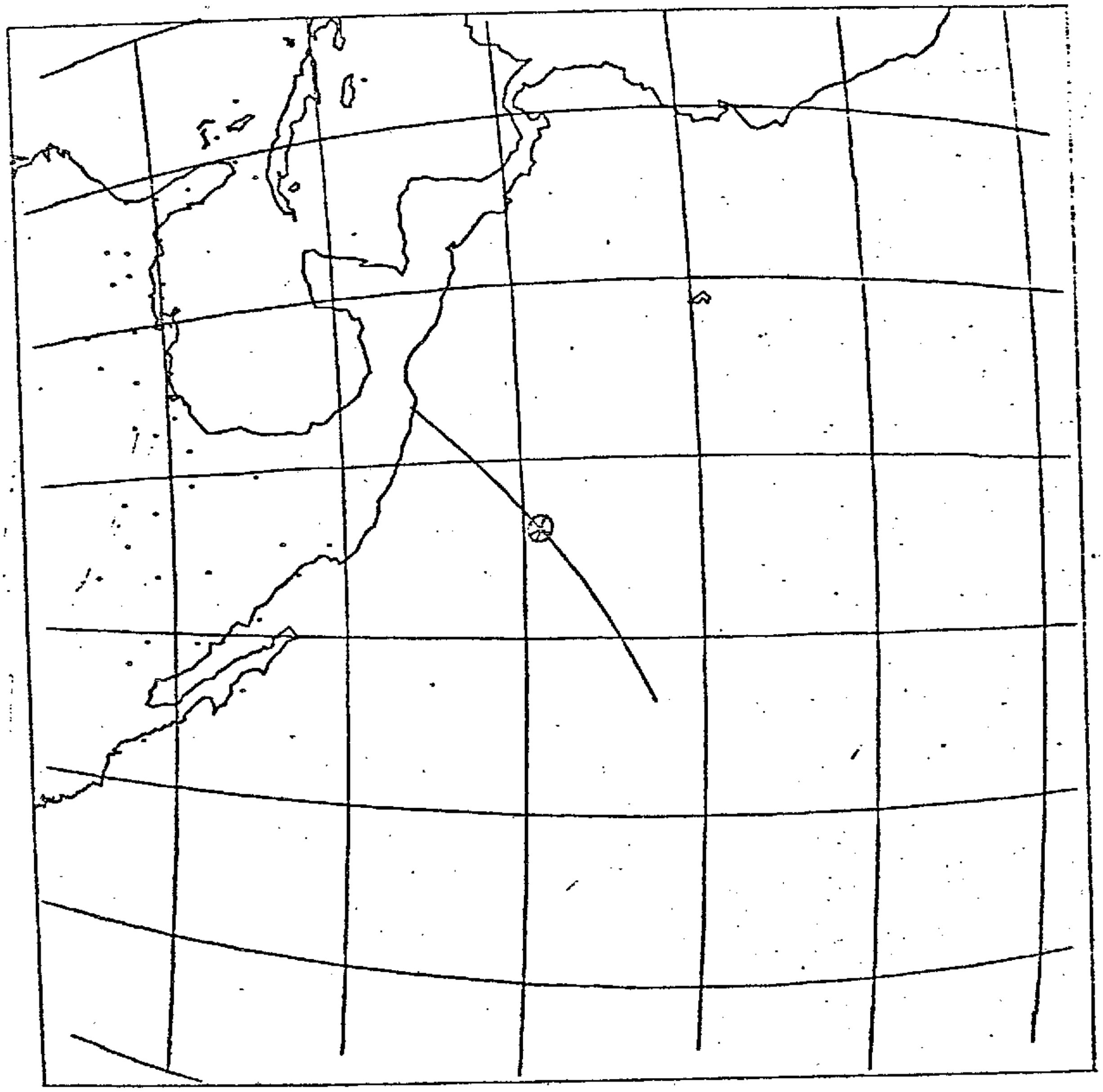
20 18 0							
40000	-74.744	52.06[illegible]	.4134865+02	1721.095	-73.744	-73.779	-74.729
0	53.453	34.41355	.4136685+02	126.41420	53.641	53.642	53.036
.26218331-00	.75046463-00	22.7482[illegible]	248.44935	95.33121		SOUTH POLE	248.44211
20 21 0							
40000	-73.192	52.79731	.4037715+02	1756.220	-72.151	-72.147	-73.107
0	52.421	34.19228	.4035471+02	126.63351	52.421	52.422	52.037
.26218340-00	.76137468-00	22.14116	252.01322	94.76115		SOUTH POLE	279.81072
20 24 0							
40000	-71.597	53.64934	.3927198+02	1787.748	-70.534	-70.528	-71.497
0	51.361	33.94840	.3925285+02	126.78170	51.533	51.531	50.990
.26218343-00	.77432939-00	21.48196	255.07517	94.13899		SOUTH POLE	275.21977
20 27 0							
40000	-70.005	54.64686	.3806530+02	1848.885	-68.917	-68.910	-69.887
0	50.273	33.68039	.3804537+02	126.85649	50.415	50.415	49.893
.26218346-00	.78748952-00	20.75817	258.01969	93.45214		SOUTH POLE	270.53808
20 30 0							
40000	-68.405	55.82010	.3675192+02	1905.230	-67.290	-67.243	-68.268
0	49.152	33.34641	.3673106+02	126.85883	49.264	49.264	48.765
.26218348-00	.80141597-00	19.96866	260.91196	92.70026		SOUTH POLE	265.95172
20 33 0							
40000	-66.786	57.20920	.3532483+02	1974.932	-65.642	-65.635	-66.628
0	47.997	33.06422	.3530292+02	126.78766	48.076	48.076	47.600
.26218351-00	.81607015-00	19.10356	263.64796	91.87926		SOUTH POLE	261.26339
20 36 0							
40000	-65.134	58.86951	.3377462+02	2058.959	-63.959	-63.950	-64.953
0	46.802	32.71102	.3375150+02	126.64070	46.846	46.846	46.105
.26218354-00	.83141429-00	18.17598	266.40464	90.98452		SOUTH POLE	256.51135
20 39 0							
40000	-63.433	60.87979	.3208851+02	2161.516	-62.222	-62.211	-63.227
0	45.562	32.32329	.3206394+02	126.41415	45.570	45.569	45.144
.26218356-00	.84741174-00	17.16161	269.04014	90.01092		SOUTH POLE	251.66798
20 42 0							
40000	-61.664	63.35647	.3024890+02	2288.777	-60.410	-60.397	-61.428
0	44.270	31.89650	.3022270+02	126.10219	44.237	44.237	43.840
.26218359-00	.86402725-00	16.05813	271.61431	88.95325		SOUTH POLE	246.69742

20 45 0 40000 0 .2621[illegible]362-00	-59.[illegible]01 42.915 .[illegible]122729-00	66.[illegible]007 31.[illegible] [illegible]	.2[illegible]21049+02 .2[illegible]20279+02 274.[illegible]	2[illegible] 125.[illegible] [illegible]	-5[illegible] 42.[illegible]	-5[illegible].479 42.[illegible]37 SOUTH POLE	-59.510 42.172 241.55164
20 48 0 40000 0 .2621[illegible]36[illegible]-00	-57.[illegible]09 41.4[illegible] .[illegible]949[illegible]-00	70.[illegible] 30.[illegible] 13.5[illegible]	.259[illegible]50+02 .25[illegible]+02 276.[illegible]	2[illegible].212 125.[illegible] [illegible]	-56.[illegible] 41.[illegible]	-56.417 41.35[illegible] SOUTH POLE	-57.497 41.024 21[illegible].16371
20 51 0 40000 0 .2621[illegible]367-00	-55.639 39.956 .91725[illegible]42-00	76.0[illegible]66 30.[illegible] 12.07206	.2[illegible]50+02 .21[illegible]76+02 279.11216	29[illegible].[illegible] 124.[illegible] [illegible].25[illegible]	-5[illegible].177 39.766	-5[illegible].151 39.762 SOUTH POLE	-55.274 39.475 230.43517
20 54 0 40000 0 .2621[illegible]370-00	-53.212 38.29[illegible] .93603[illegible]-00	[illegible].22012 29.6[illegible] 10.[illegible]	.2062[illegible]+02 .2059061+02 2[illegible].[illegible]	[illegible] 123.35102 [illegible].92331	-51.621 3[illegible].02[illegible]	-51.5[illegible] 3[illegible].022 SOUTH POLE	-52.778 37.790 224.20976
20 57 0 40000 0 .2621[illegible]373-00	-50.393 36.452 .95531430-00	97.60796 2[illegible].[illegible]212 [illegible].32[illegible]	.1721[illegible]36+02 .171747[illegible]+02 2[illegible].200[illegible]	40[illegible] 122.7[illegible] [illegible]2.7[illegible]052	-4[illegible].600 36.071	-4[illegible].537 36.056 SOUTH POLE	-49.[illegible]55 35.903 217.21053
21 0 0 40000 0 .2621[illegible]375-00	-46.[illegible]93 34.236 .97516909-00	125.9792[illegible] 27.[illegible]9937 [illegible].17[illegible]	.12[illegible]1916+02 .1276[illegible]+02 2[illegible]6.9[illegible]655	5313.7[illegible] 121.47915 [illegible]3.03216	-44.701 33.717	-44.549 33.675 SOUTH POLE	-46.171 33.673 2[illegible].[illegible]63

...CTION TERMINATED BY AN ATTEMPT TO READ THRU AN END OF FILE

I/O CALLED AT SEQUENCE NUMBER 00217 OF MAIN PROGRAM

4.7 SAMPLE PROGRAM PLOT



SUMMARY DATA ON

SR-71A TYPE AIRCRAFT

CAPABILITIES & LIMITATIONS

AS AN OBSERVING PLATFORM FOR

SOLAR ECLIPSES & OTHER SCIENTIFIC STUDIES

Robert D. Mercer
Research Associate

November 8, 1968

Dudley Observatory
Albany, New York

Scientific observations of a total solar eclipse for periods up to 90 minutes at altitudes of about 70,000 feet are technically feasible, and the unusual capability to maintain a position along the umbral-penumbral boundary will present new and unusual opportunities for solar investigations that can not be made available from balloons, rockets, or satellites, or from the ground. It could provide more useful time in a single eclipse than the sum of all previous events; in fact, it would increase coronal observation time more than an order of magnitude and chromospheric observation time more than two orders of magnitude. A potential capability exists to resolve heights near the solar limb to 25 km or less, and all points on the circumference of the disk are equally accessible for study. Carefully controlled positioning of the aircraft to use a region of a mare on the lunar limb will produce a knife-edge free of Bailey's Beads for obtaining the very low height resolution crucially important to any physically sound study of the chromosphere and its interface with the photosphere below and the corona above. Atmospheric seeing would be improved by observations made through: (1) no cloud cover or shadow bands, (2) only about 25 mm Hg of overlying atmosphere, (3) 0.50 microns of water vapor and less masking by other telluric absorption, and (4) considerably reduced scattering and polarizing contributions from background light.

A series of eight eclipses will occur over the next eleven and one-half years (see attached list and diagrams). All of these eclipses are accessible using this type vehicle, which can be aerially refueled, even though more than half of the best eclipse observing locations occur over water or in very remote regions of the world.

SCIENTIFIC REQUIREMENTS & POSSIBLE METHODS OF ACCOMPLISHMENT USING AIRCRAFT AS OBSERVING PLATFORMS

SCIENTIFIC REQUIREMENTS

1. IMPROVE TEMPORAL RESOLUTION BY INCREASING NUMBER & DURATION OF OBSERVATIONS
2. IMPROVE SPATIAL RESOLUTION OF IMAGE
3. EXTEND USEABLE SPECTRAL RANGE
4. IMPROVE SIGNAL-TO-NOISE
5. LOWER THRESHOLD OF DETECTABILITY
6. INCREASE TYPE & SIMULTANEITY OF OBSERVATIONS
7. MAINTAIN RESPONSIBLE CONTROL OVER COSTS

METHODS OF ACCOMPLISHMENT

A. MAXIMIZE DURATION IN ECLIPSE UMBRAS & ALONG THEIR BOUNDARIES (1, 2 & 4)

B. UTILIZE HIGHEST ALTITUDES (2, 3, 4 & 5)

C. MAXIMIZE OPTICAL APERTURE (4 & 5)

D. MAXIMIZE FOCAL LENGTH (2 & 5)

E. MAXIMIZE NUMBER & TYPE OF EXPERIMENTS BY UTILIZING AVAILABLE WEIGHT, VOLUME & PRESENT AIRCRAFT SYSTEMS (1, 6 & 7)

F. USE MODIFIED AIRCRAFT IN THE MAXIMUM POSSIBLE NUMBER OF ECLIPSES & USEFUL NON-ECLIPSE SCIENTIFIC STUDIES (6 & 7)

G. MINIMIZE APPARATUS MODIFICATIONS & OPERATIONAL TECHNIQUES FOR EXPERIMENTS (7)

H. MINIMIZE ENGINEERING MODIFICATIONS & NEW FLIGHT TECHNIQUES FOR THE AIRCRAFT (7)

YF-12A/SR-71A Capabilities Useful for the March 7, 1970 Solar Eclipse

1. Approximately 90 minutes observing time within the umbra, and manueverability along the umbral-penumbral boundary.

2. Best operating altitudes are 60,000 to 80,000 feet (18.3 to 24.4 km).

3. Telescopic system can be accommodated with 10 inch aperture, up to 24 feet single-pass, heliostat stabilized image to several arcseconds per second, and carried at ambient pressure in the right-hand equipment bay.

4. Up to 4 additional 4 1/2 inch windows can be installed in the nose section subject to reduced pointing accuracy and stabilization.

5. Experiment systems observer available in-flight for remote observations, adjustments, alignments, and flight path modification. Radio contact with the observer will be possible during the eclipse flight.

6. More than 1000 lbs. and 20 cubic feet available for experimental apparatus in addition to the same amount used for the telescopic system or multiple telescopes in the right-hand equipment bay. More than 2 kilowatts of power available in either 115 volts AC, 3 phase, 400 Hz or 28 volts DC. On-board timing system available with accuracy of 1 part in 10^8 or access to WWV. Filtered cooling air will be available for equipment; equipment bays are normally maintained at +80°F and nose compartment at +160°F. External skin temperature will be approximately 250°F with a very thin, laminar flow boundary layer.

Some Further Astronomical Studies Utilizing Vehicle Modifications Proposed for the 1970 Eclipse

1. Subsequent eclipse flights throughout the 1970's.

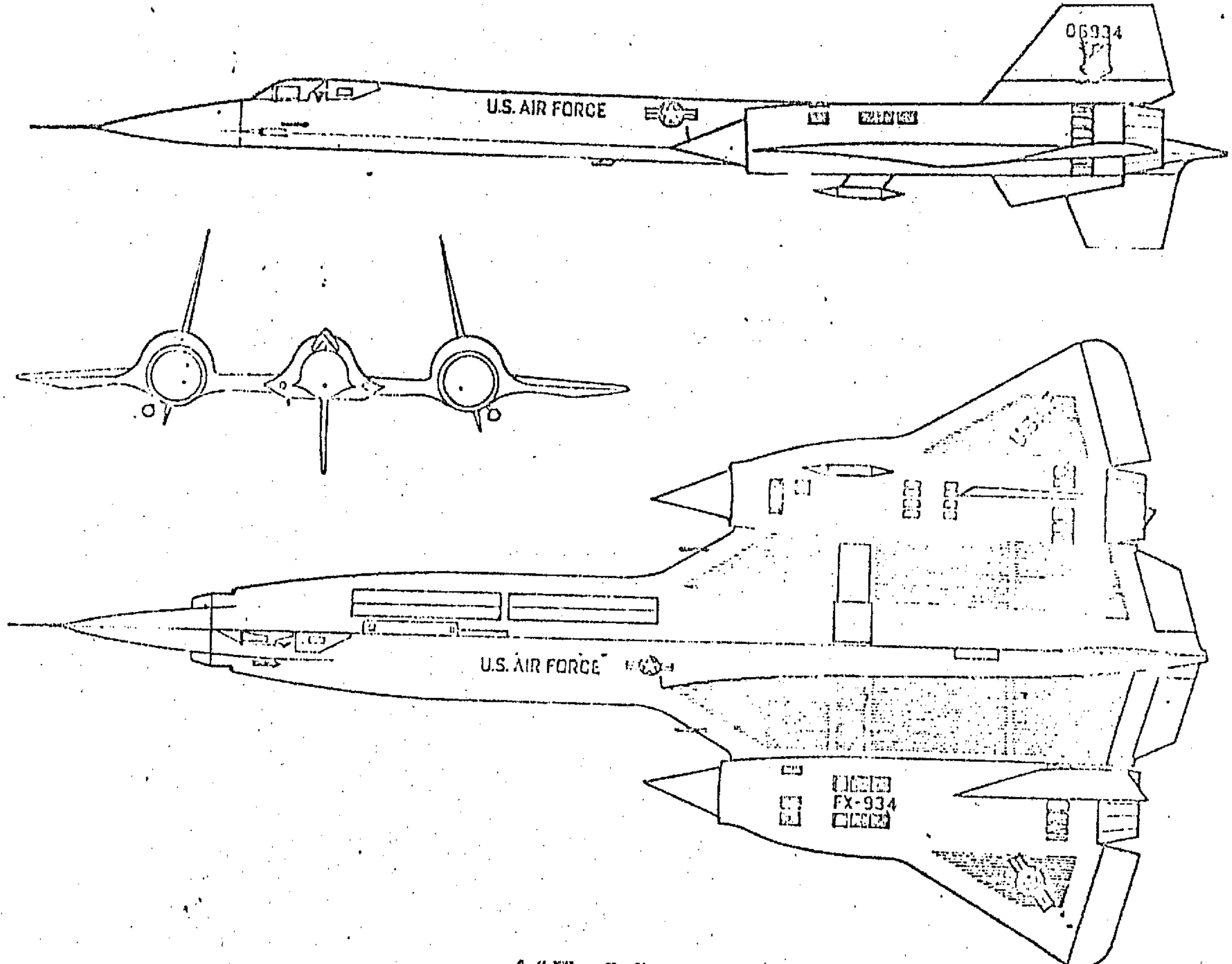
2. Uneclipsed solar physics studies with emphasis on improved capabilities in the earth atmospheric attenuation regions of the spectrum.

3. Stellar astronomy of low intensity sources, and extension of ground-based spectral studies in the attenuated regions.

4. Planetary atmospheric studies.

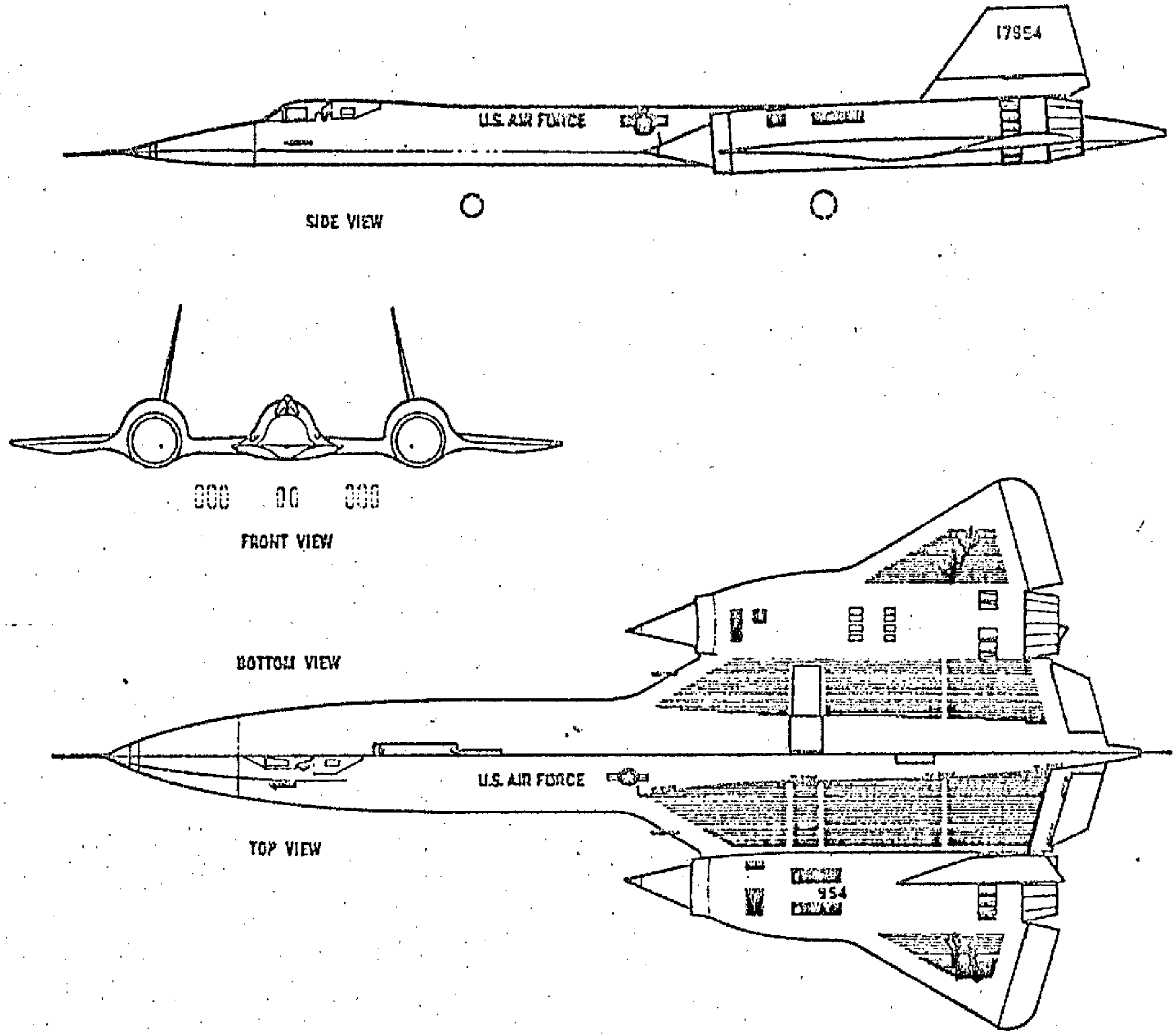
5. Wide area survey work on the aurora, airglow, Zodiacal light, and Gegenschein.

6. Infrared surveys of the lunar surface.

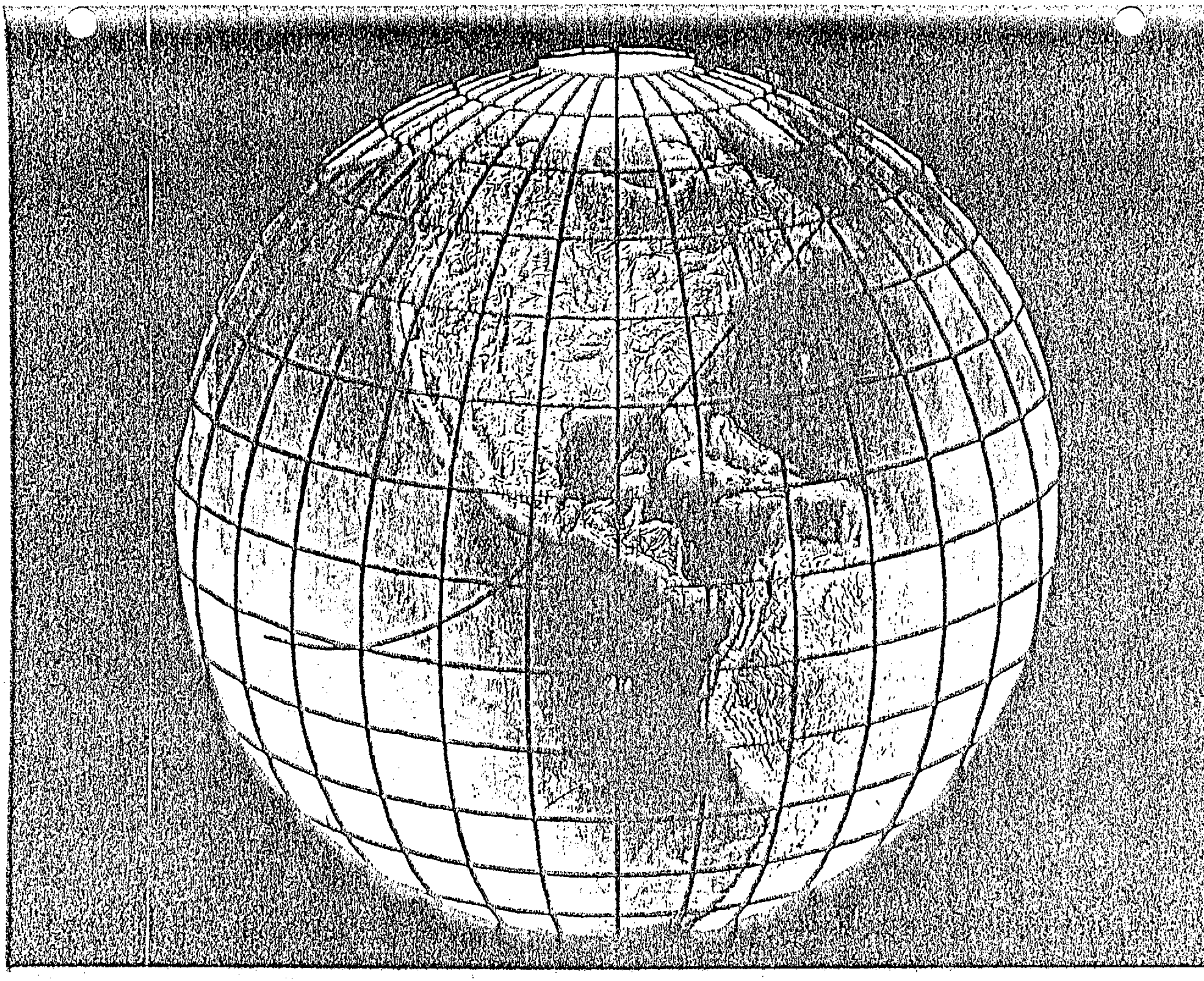


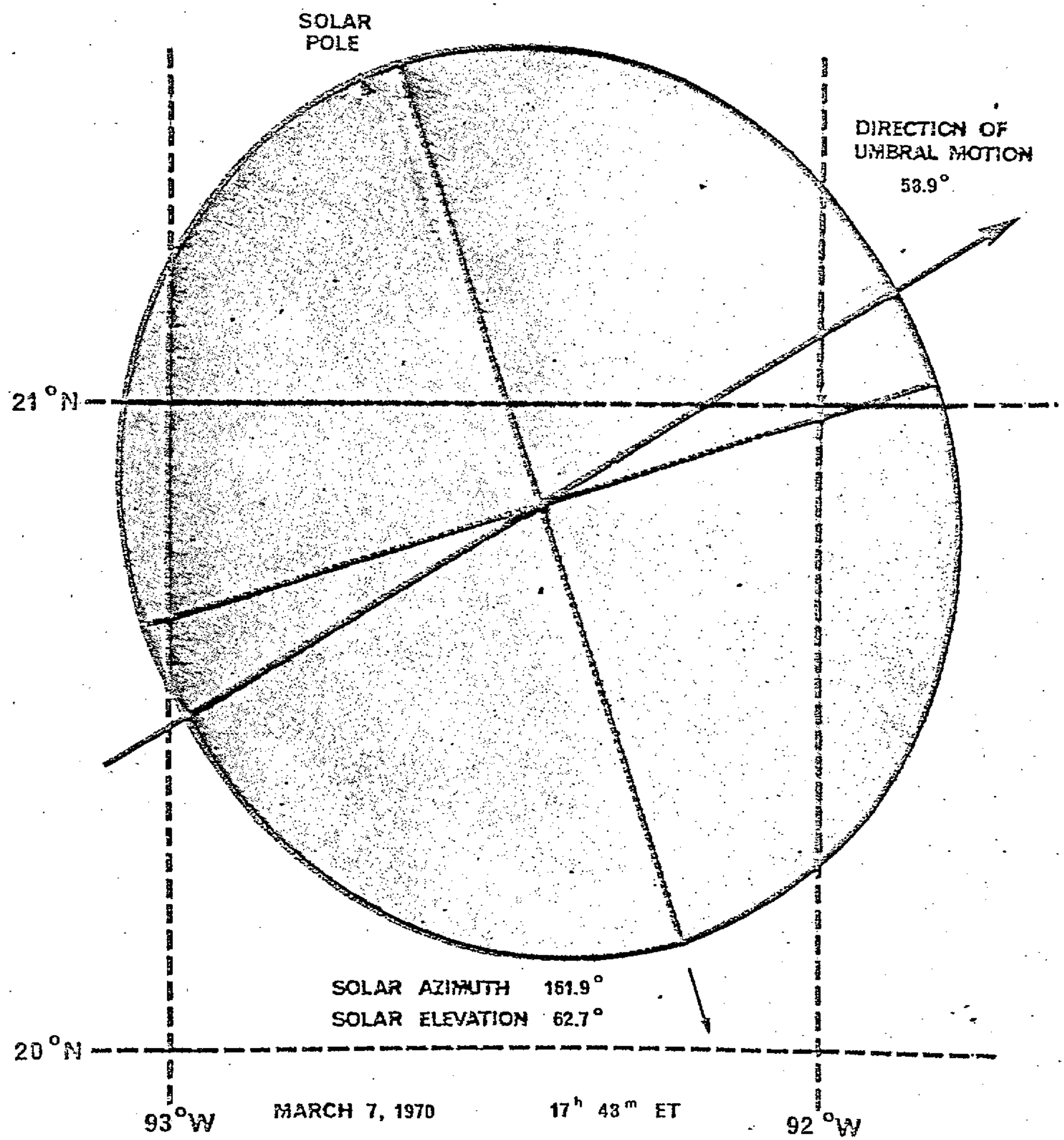
YF-12A

3-VIEW DRAWING

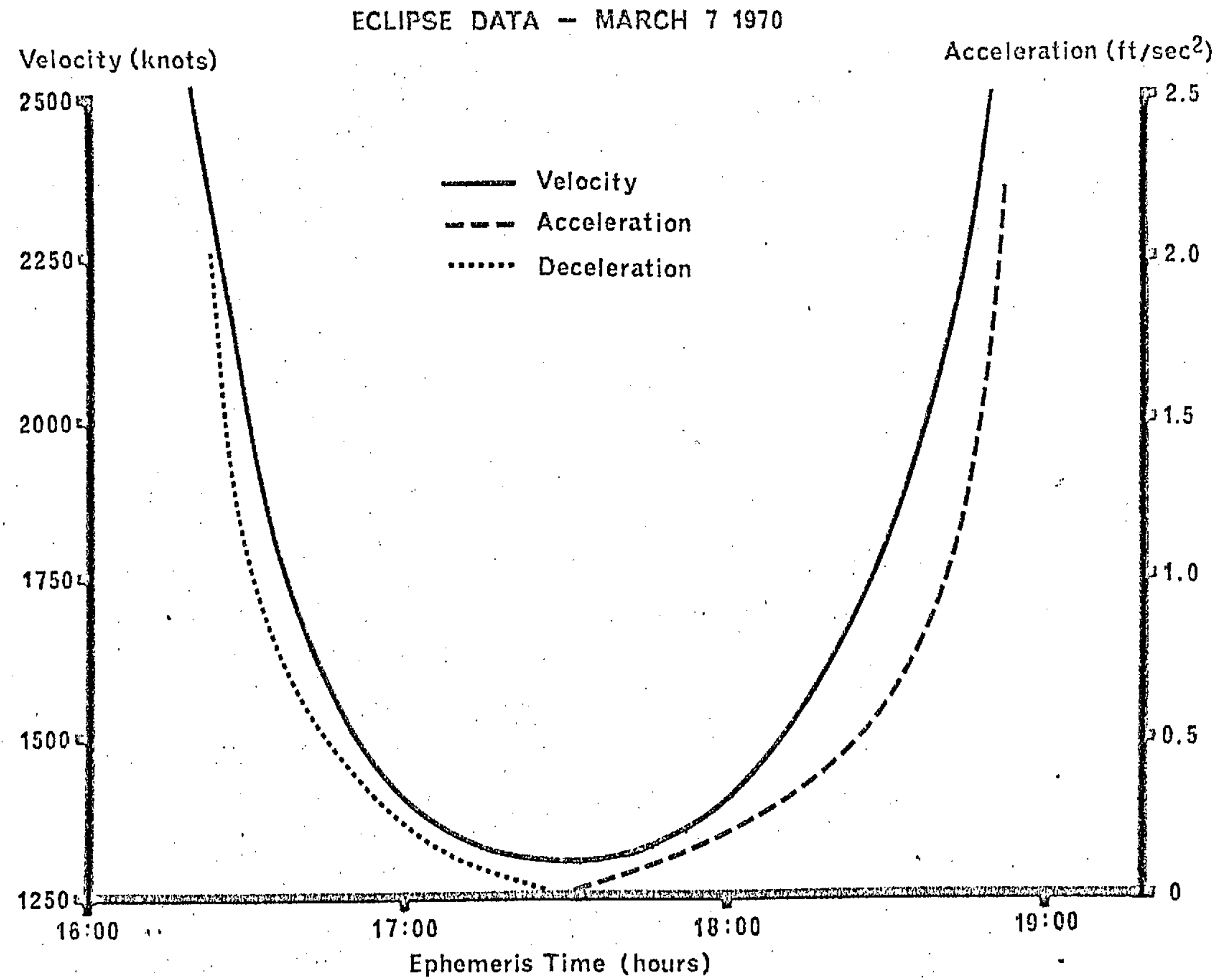


SR-71A



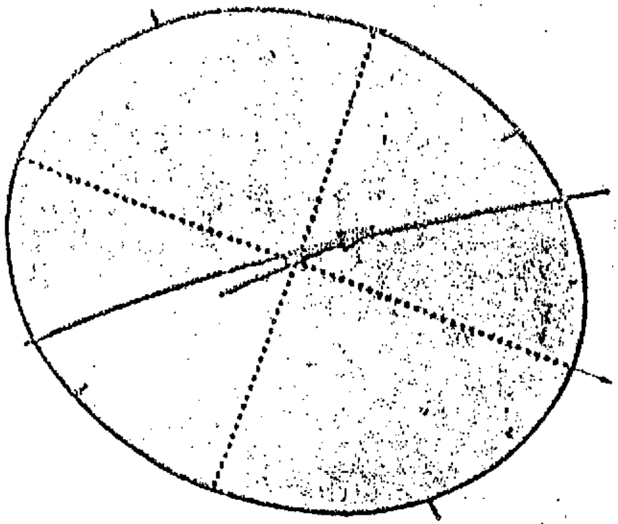


ECLIPSE PATTERN

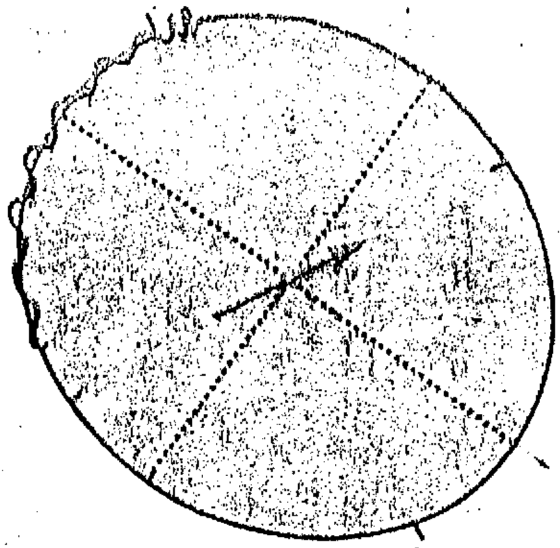

ECLIPSE DATA — MARCH 7 1970
Velocity (knots)
Acceleration (ft/sec2)
Velocity
Acceleration
Deceleration
2500
2250
2000
1750
1500
1250
2.5
2.0
1.5
1.0
0.5
0
16:00
17:00
18:00
19:00
Ephemeris Time (hours)

EXPERIMENTS OPERATIONAL PLAN - GENERAL

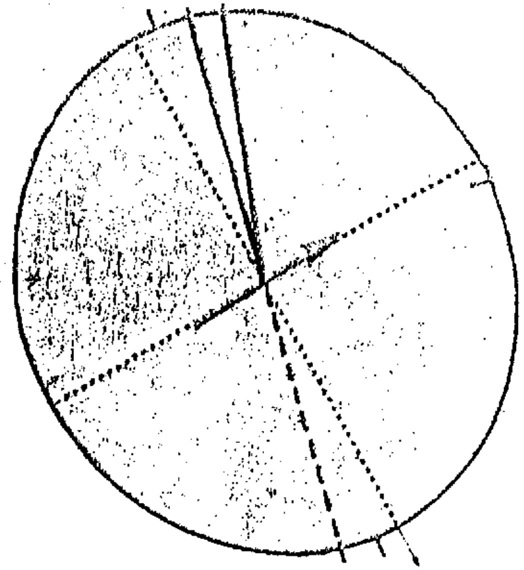
Mission Phase	Experimental Objectives of Interest	Time Available in Minutes	Altitude Range in Feet (Km.)	Eclipse Path Location
A	1. Corona 2. Wide Field Work 3. Zodiacal Light	15	40,000 to 65,000 (12.2 to 19.8)	East Limb across disk to west limb
B	1. Chromosphere 2. Photosphere 3. "Limb Darkening" 4. Active Centers	20	65,000 to 75,000 (19.8 to 22.9)	West limb along limb to north limb
C	1. Corona 2. Wide Field Work 3. Zodiacal Light 4. Calibration Data	20	65,000 to 75,000 (19.8 to 22.9)	North limb to center and back out to either polar limb
D	1. Chromosphere 2. Photosphere 3. "Limb Darkening" (4. Active Centers)	30	65,000 to 75,000 (19.8 to 22.9)	Either solar pole limb along limb to east limb
E	1. Corona 2. Wide Field Work 3. Zodiacal Light	5	75,000 to 60,000 (22.9 to 18.3)	East limb across disk to west limb
	Total Time	90	Minutes	



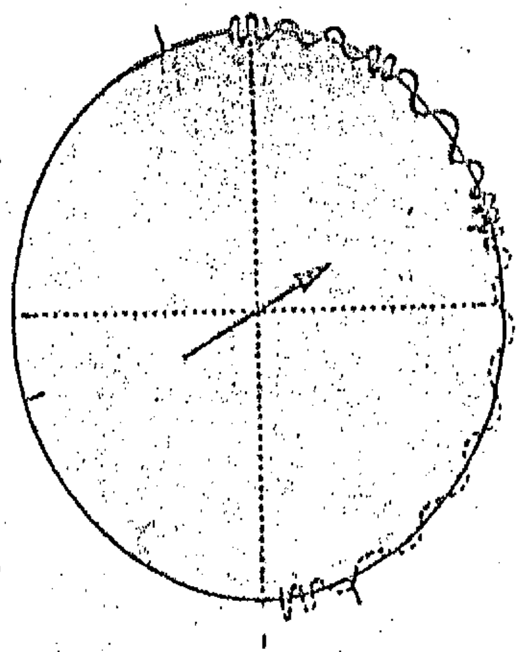
PHASE A



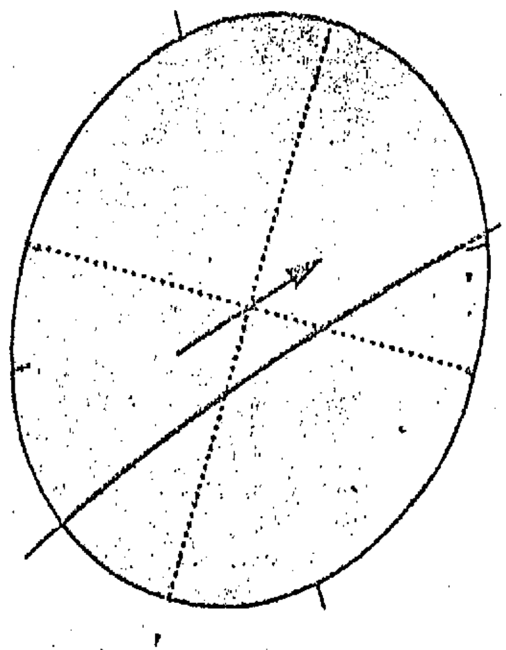
PHASE B



PHASE C

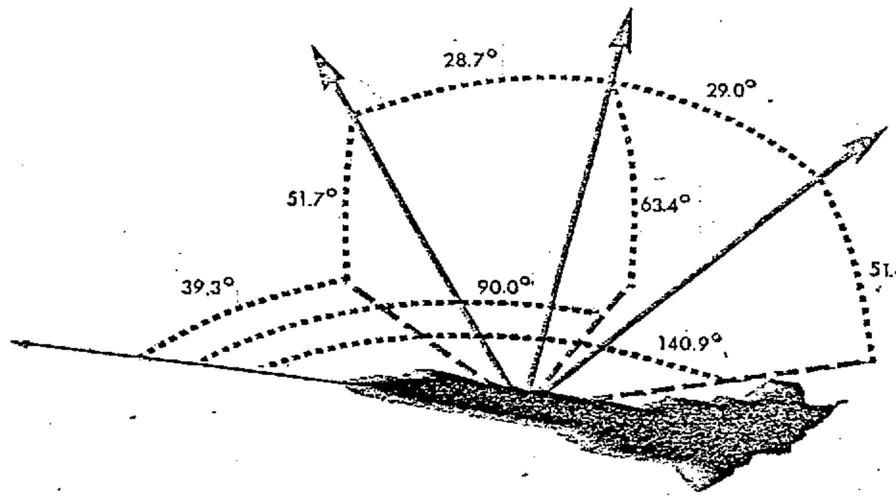


PHASE D



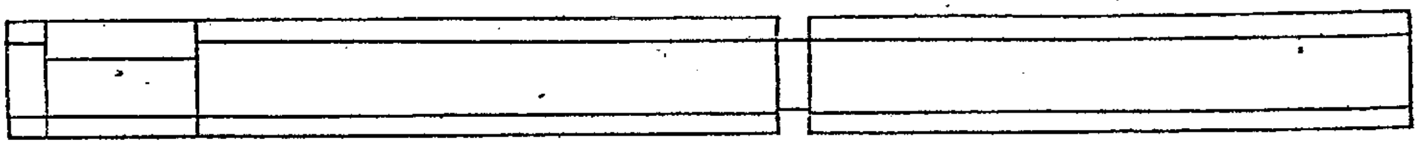
PHASE E

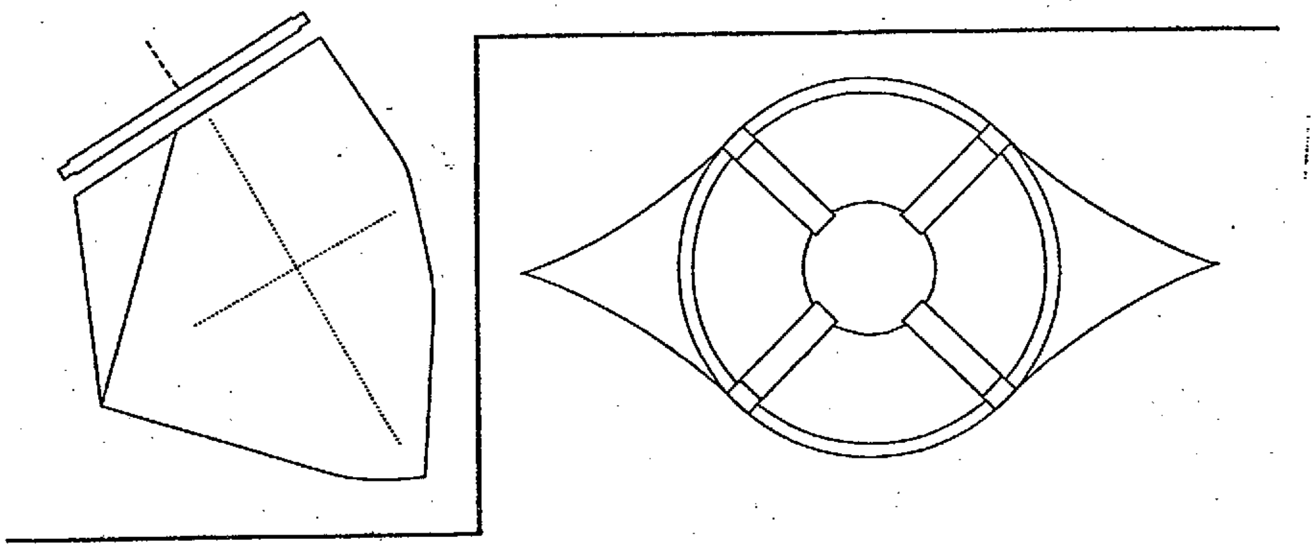
AIRCRAFT POSITION & OBSERVING DATA FOR MARCH 7, 1970 ECLIPSE

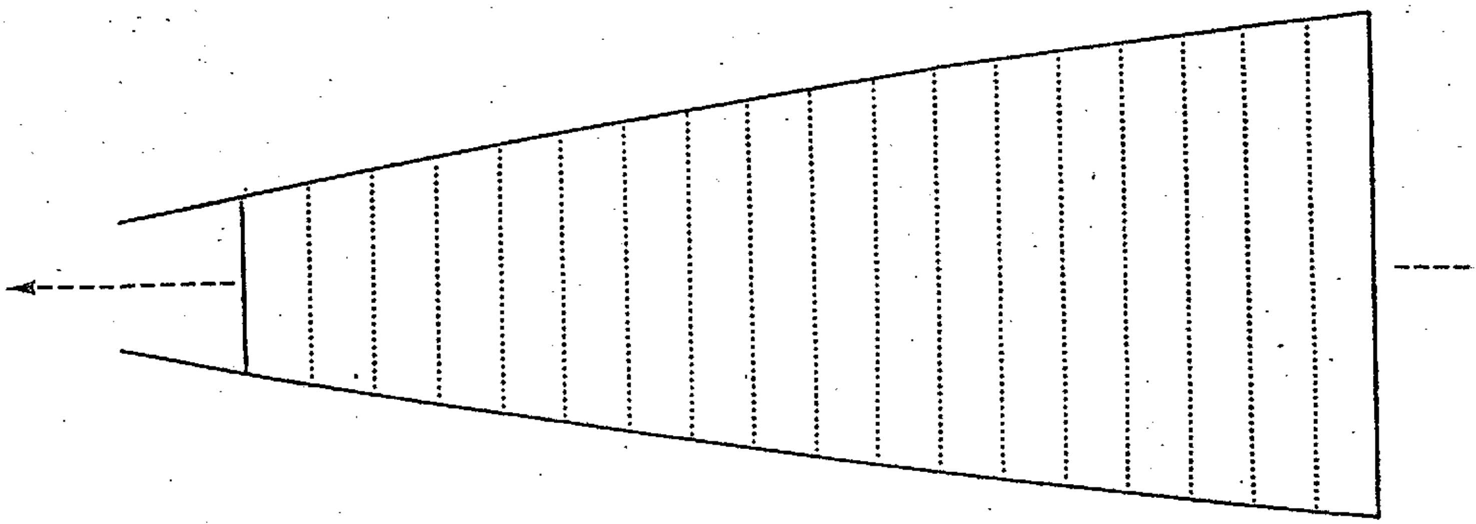


POSITION INFORMATION VERSUS UT	1653	1738	1823
SOLAR AZIMUTH FROM A/C (°)	39.3°	90.0°	140.9°
SOLAR ELEVATION FROM A/C (°)	51.7°	63.4°	51.4°
A/C HEADING (°)	67.9°	60.0°	57.2°
A/C ALTITUDE (FT) " " (KM)	40,000 12.19	75,000 22.86	40,000 12.19
LONGITUDE OF UMBRAL CENTERLINE	109.96°W	94.6°W	81.71°W
LATITUDE OF UMBRAL CENTERLINE	6.60°N	18.1°N	31.85°N
UMBRAL VELOCITY (KNOTS) " " (KM/HOUR)	1465 2715	1311 2429	1656 3069

INSTRUMENTATION BAYS







AIRCRAFT ATTITUDE STABILITY INFORMATION

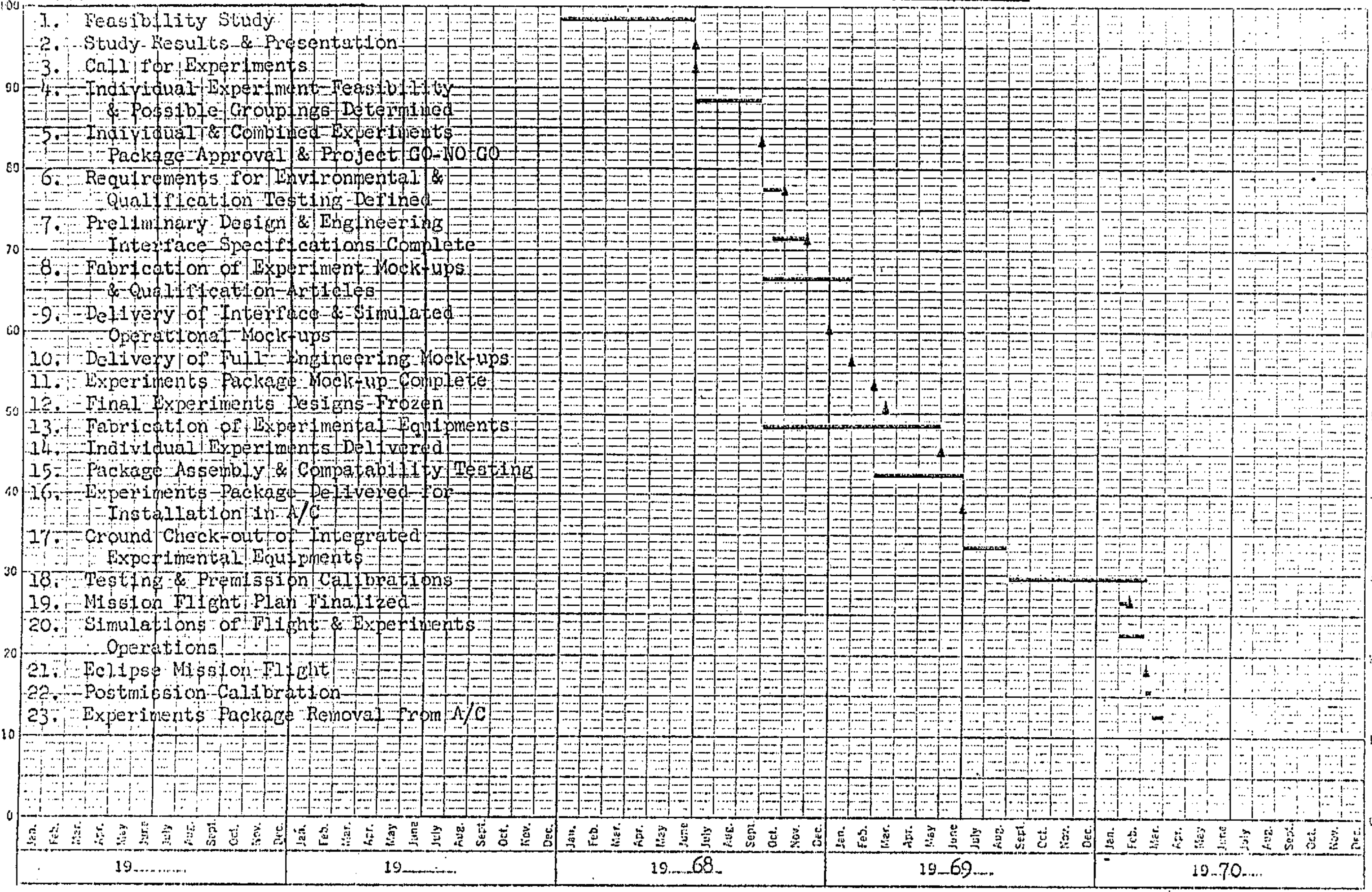
FLIGHT CONTROL STABILITY CHARACTERISTICS
(Maximum Values - Occuring less than 3% of time)

AXIS	ANGULAR RATE (Milliradians/sec)	FREQUENCY (Cycles/sec)
Pitch	3.5	0.25
Roll	3.5	0.75
Yaw	1.7 3.5	0.50 1.00

LOW FREQUENCY STRUCTURAL VIBRATIONS IN VERTICAL DIRECTION

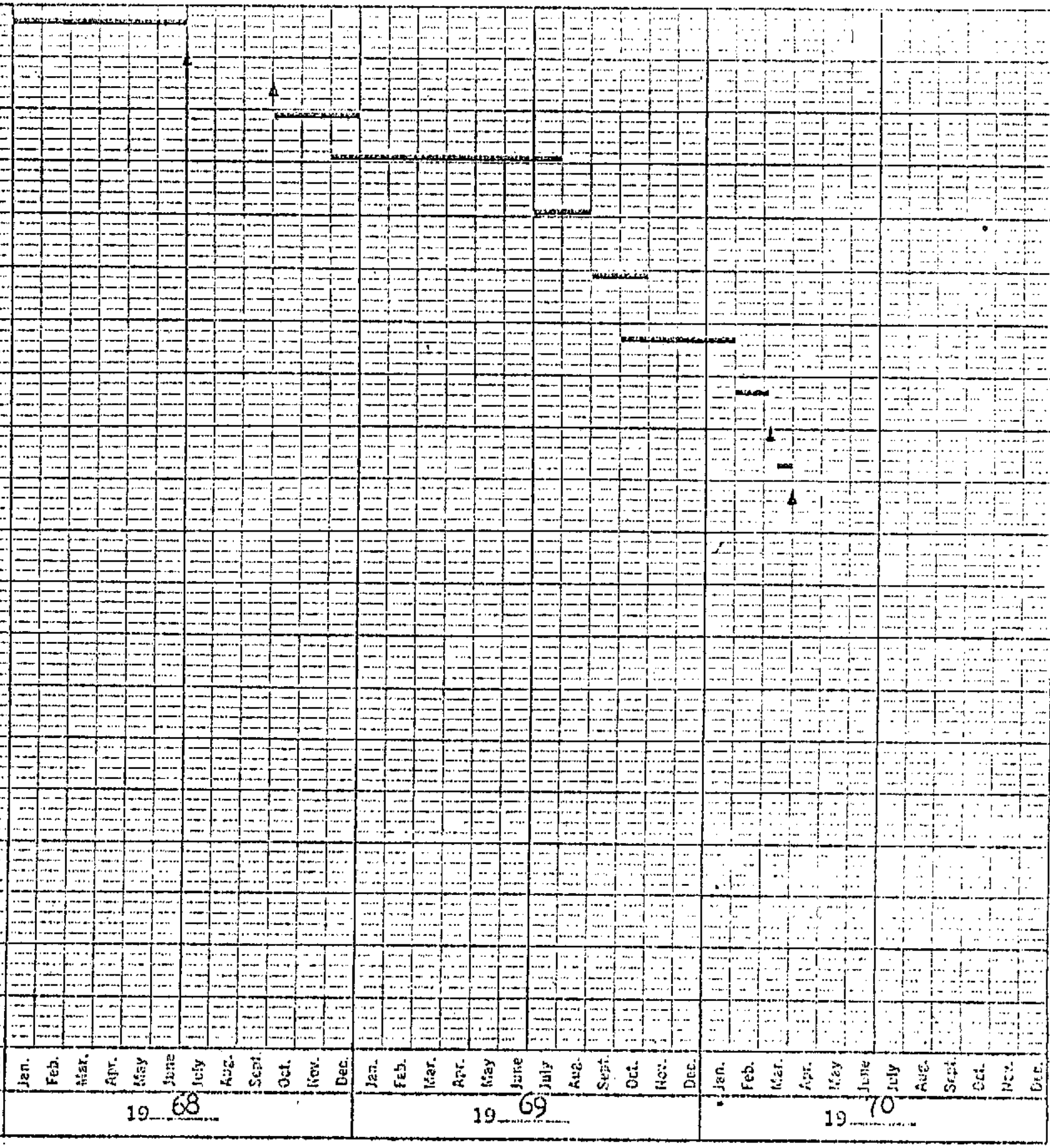
EXCITATION INPUT		RESPONSE OUTPUT	
Acceleration:	0.12 G	Rate:	0.76 milliradians/sec
Occurance Frequency:	68% of time	Frequency:	2.3 cycles/sec

ECLIPSE EXPERIMENTS SCHEDULE:



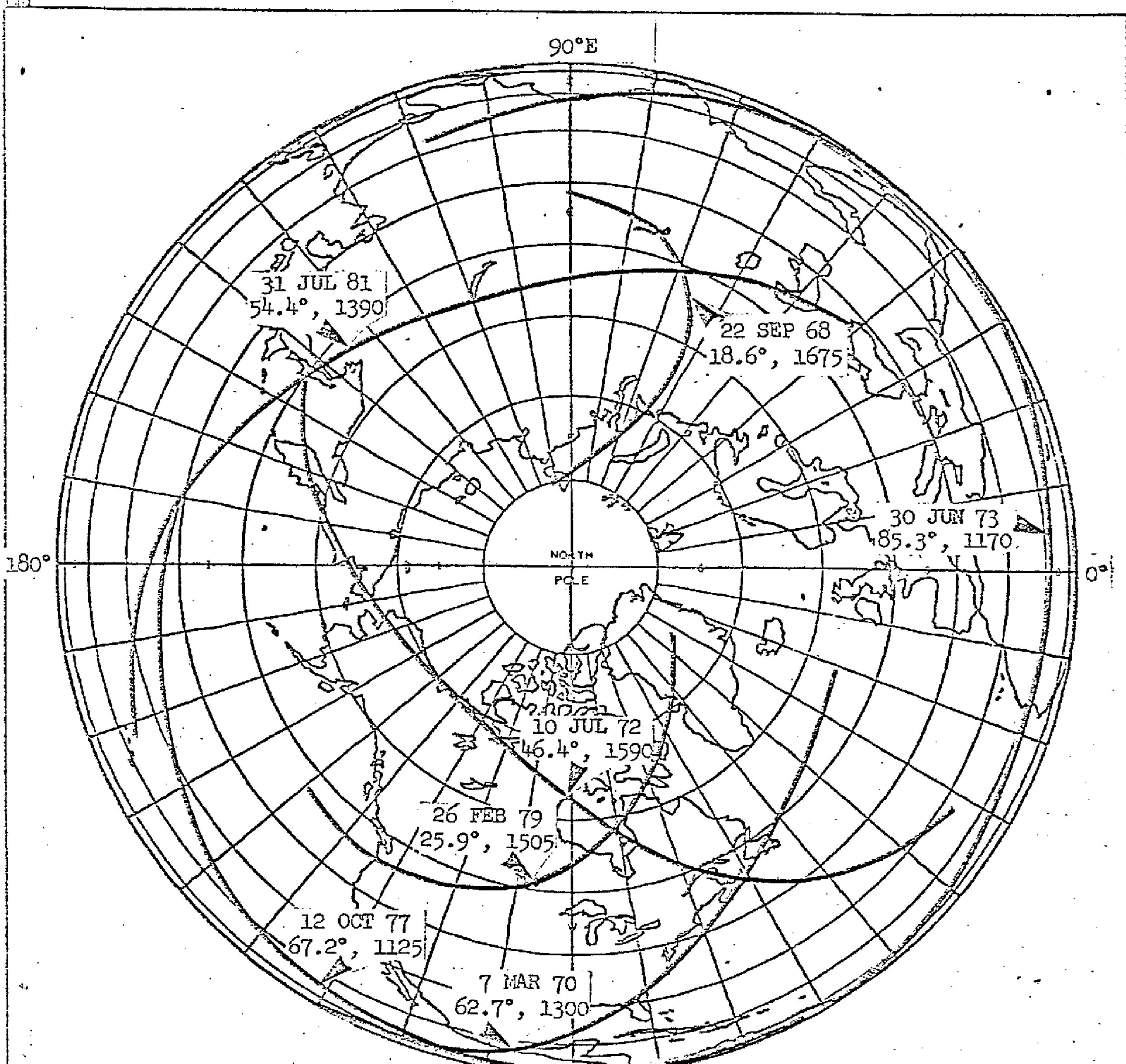
ECLIPSE PROJECT AIRCRAFT SCHEDULE:

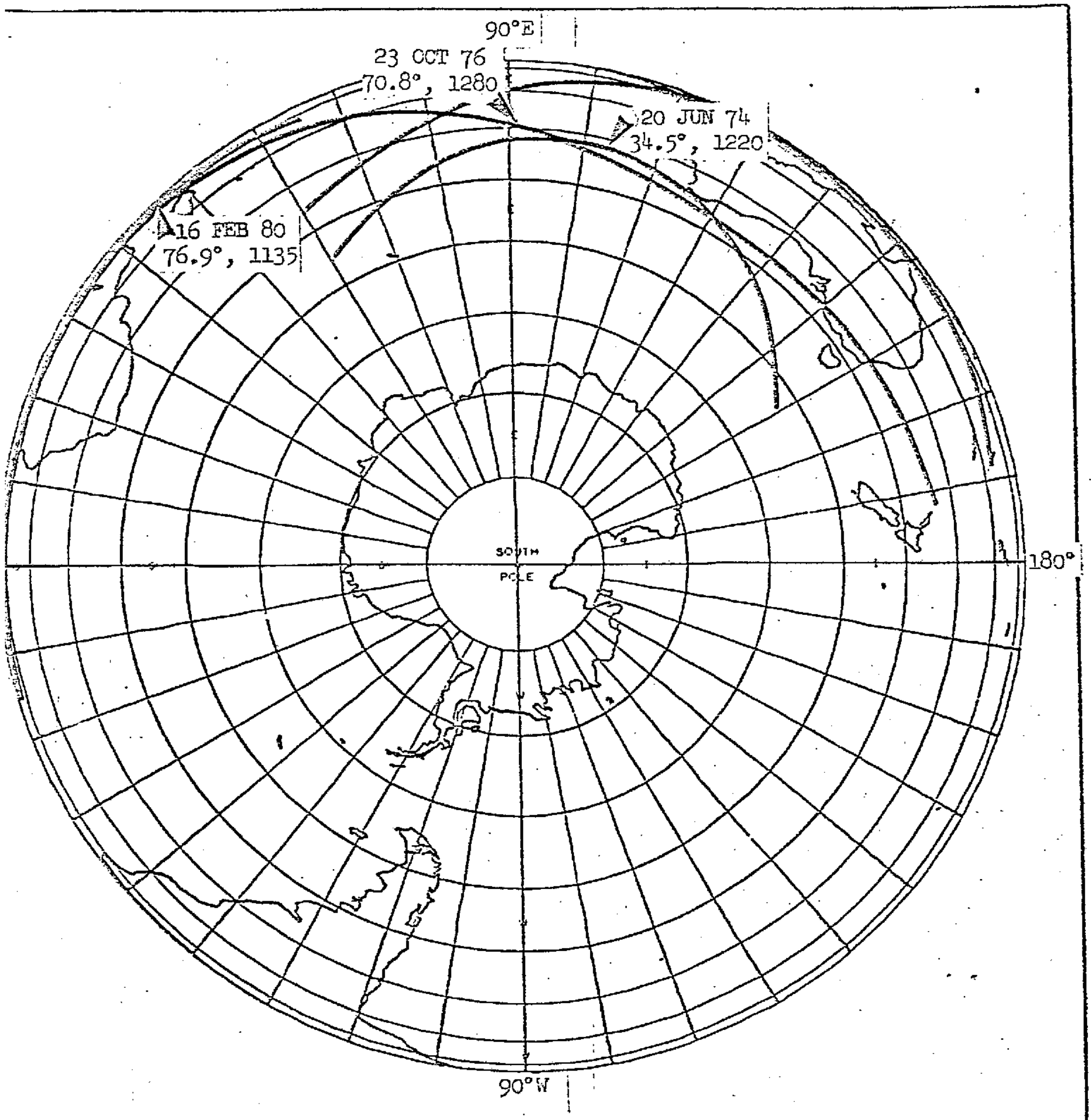
1. Feasibility Study
2. Study Results & Presentation
3. GO-NO GO Decision on Project
4. A/C Modification Design Work
5. Modifications Fabrication & Experimental Equipments Installation
6. Ground Check-out of Modifications & Experimental Equipments
7. Modifications Verification & Mission Profile Development Flight Tests
8. Final Modifications, Failure & Discrepancy Repair Work/Rework
9. Mission Simulations, Calibrations & Premission Data Collection Flights
10. Eclipse Mission Flight
11. Experimental Equipments Removal from A/C
12. A/C Available for Other Projects



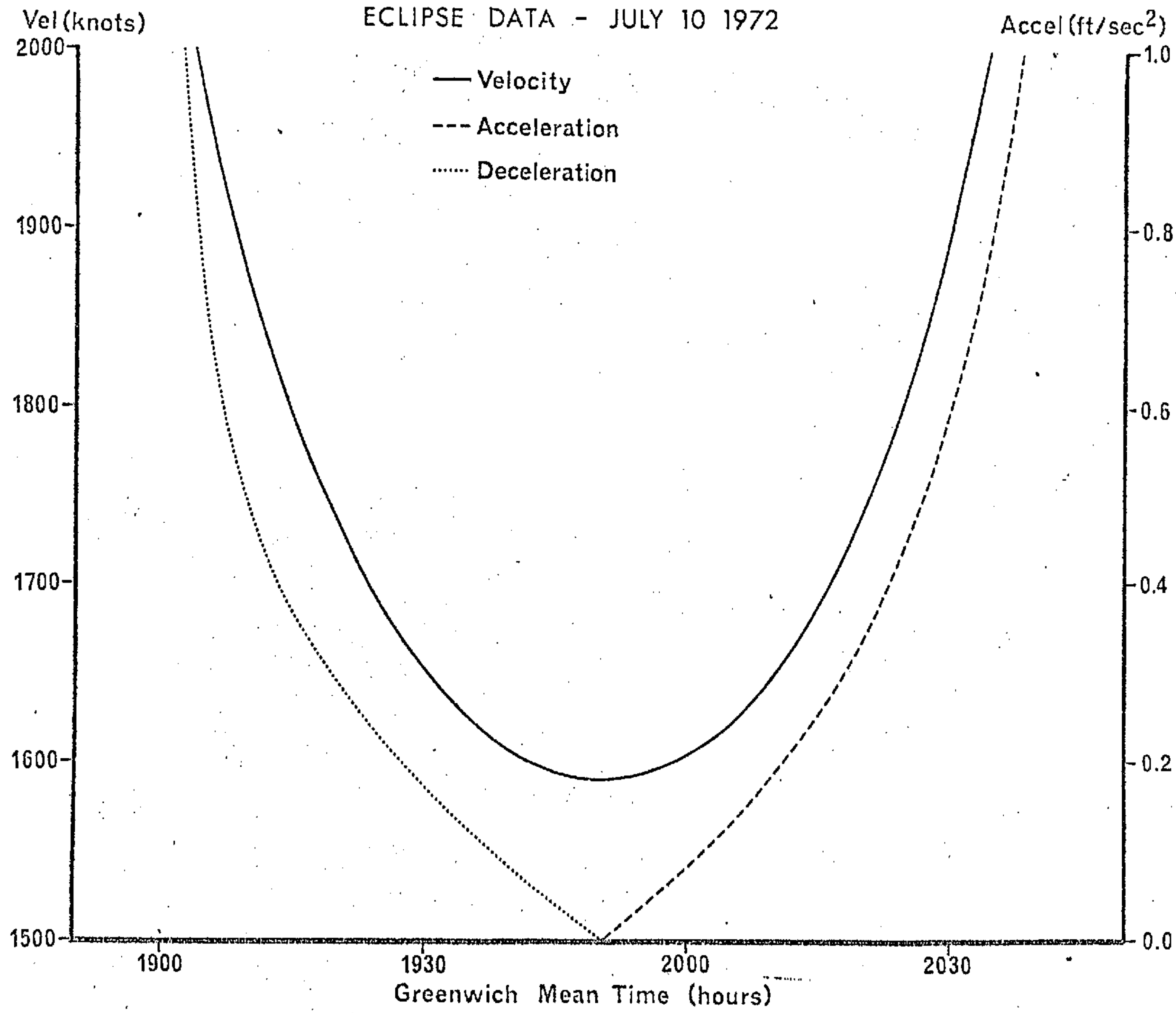
TOTAL SOLAR ECLIPSE DATA FOR OBSERVATIONS
FROM VEHICLES AT 70,000 FT. ALTITUDE

DATE	MIN. VELOCITY, $V_{min.}$ & U. T. of $V_{min.}$	SOLAR ELEVATION MAX. & AT $V_{min.}$	EARTH REGION IN UMBRA LAT. & LONG. AT $V_{min.}$	REMARKS
22 Sep. 1968	1675 Kts. 1126 Hrs.	19.2° 18.6°	Artic-Russia-China 66.0°E, 52.0°N	Very low elevation, too soon for scientific/diplo. arrang.
7 Mar. 1970	1300 Kts. 1127 Hrs.	63.3° 62.7°	Mexico-U.S.-Canada 97.4°W, 15.1°N	Excellent for North American observers.
10 Jul. 1972	1590 Kts. 1950 Hrs.	46.5° 46.4°	Russia-Alaska-Canada 91.0°W, 62.2°N	Moderate elevation. Good for N. Amer. observers.
30 Jun. 1973	1170 Kts. 1136 Hrs.	85.5° 85.3°	Atlantic-Africa-Ind. Oc. 4.6°E, 19.0°N	Excellent but located in somewhat remote regions.
20 Jun. 1974	1220 Kts. 0446 Hrs.	34.5° 34.5°	Ind.Oc.-S.Austr. Basin 103.1°E, 31.8°S	Low elevation over water. Remote but near Austraila.
23 Oct. 1976	1280 Kts. 0511 Hrs.	70.8° 70.8°	Africa-Ind.Oc.-Australia 91.5°E, 29.6°S	Excellent and mostly over water but remote.
12 Oct. 1977	1125 Kts. 2034 Hrs.	67.4° 67.2°	North Pacific-South America 121.6°W, 12.9°N	Excellent and mostly over water. U.S. & Hawaii nearby.
26 Feb. 1979	1505 Kts. 1649 Hrs.	26.1° 25.9°	U.S.-Canada-Greenland 97.2°W, 50.5°N	Low elevation. Useful for vehicles already modified.
16 Feb. 1980	1135 Kts. 0849 Hrs.	77.2° 76.9°	Africa-India-China 45.8°E, 0.7°S	Excellent but located in somewhat remote regions.
31 Jul. 1981	1390 Kts. 0349 Hrs.	54.5° 54.4°	Russia-North Pacific 135.7°E, 52.7°N	Moderate elevation but long scientific/diplo. arrang.

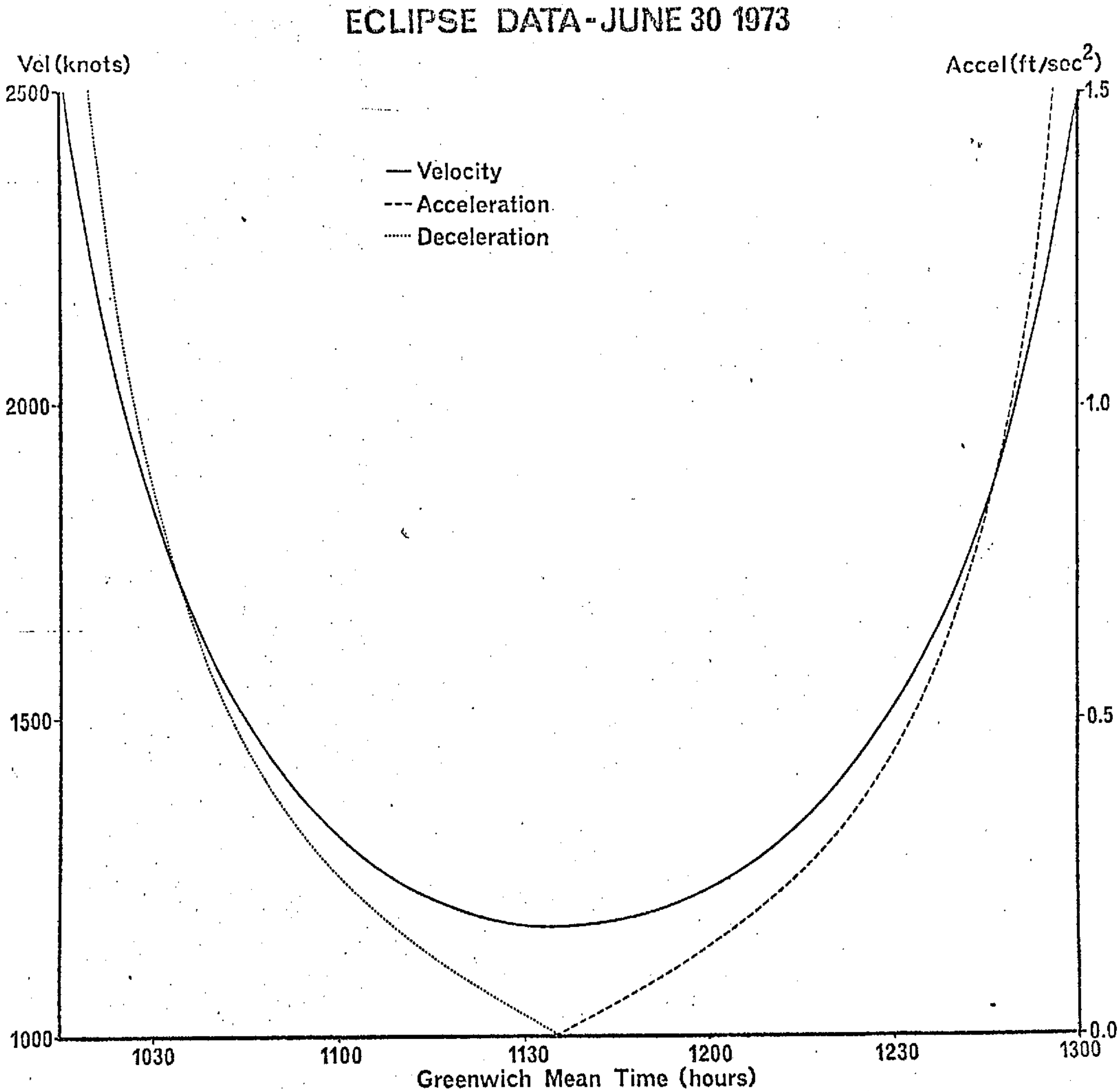

90°E
31 JUL 81
54.4°, 1390
22 SEP 68
18.6°, 1675
30 JUN 73
85.3°, 1170
180°
0°
NORTH
POLE
10 JUL 72
46.4°, 1590
26 FEB 79
25.9°, 1505
12 OCT 77
67.2°, 1125
7 MAR 70
62.7°, 1300
90°W



90°E
23 OCT 76
70.8°, 1280
20 JUN 74
34.5°, 1220
16 FEB 80
76.9°, 1135
SOUTH
POLE
180°
90°W



ECLIPSE DATA - JULY 10 1972
Vel (knots)
Accel (ft/sec2)
Velocity
Acceleration
Deceleration
2000
1900
1800
1700
1600
1500
1.0
0.8
0.6
0.4
0.2
0.0
1900
1930
2000
2030
Greenwich Mean Time (hours)



ECLIPSE DATA - JUNE 30 1973
Vel (knots)
Accel (ft/sec2)
2500
2000
1500
1000
1.5
1.0
0.5
0.0
Velocity
Acceleration
Deceleration
1030
1100
1130
1200
1230
1300
Greenwich Mean Time (hours)

DUDLEY OBSERVATORY

REPORTS

OBSERVATIONS OF SOLAR ECLIPSES USING SR-71A TYPE AIRCRAFT

An Informal Conference
Held at The Dudley Observatory
July 25–26, 1968

ROBERT D. MERCER
DONALD C. SCHMALBERGER
Editors

REPORT No. 3
DECEMBER 1968

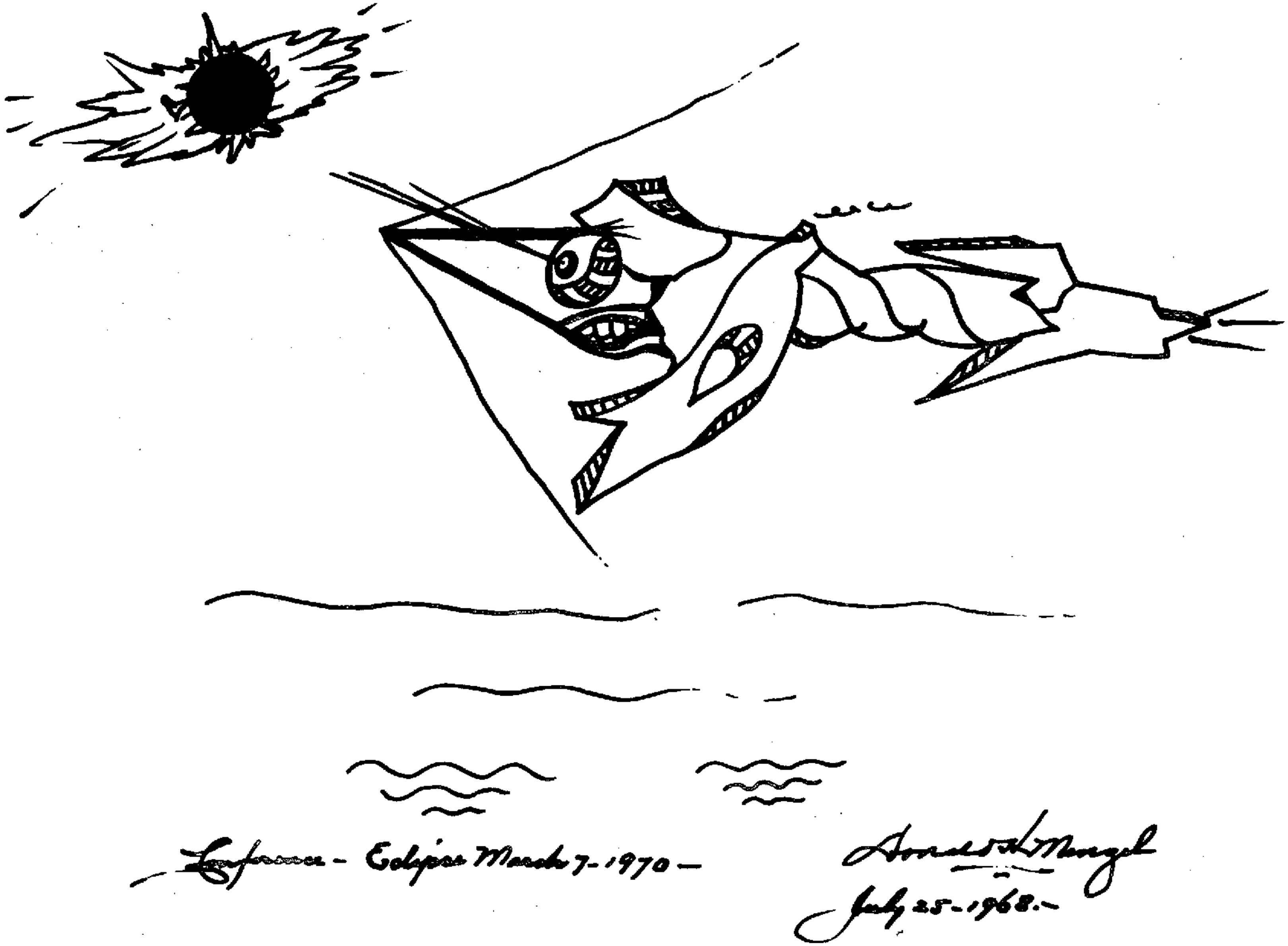
I

Dudley Observatory Reports is a serial publication of the Dudley Observatory which excludes reprint material. It is intended to carry a broad spectrum of writing reflecting the activities of the observatory's resident and visiting staff and students.

The reports are individually bound and numbered consecutively with no consolidation into volumes. Issues are released aperiodically, as prepared, and sent without charge to cooperating institutions.

D. C. Schmalberger
Editor

Christine A. Bain
Librarian



Frontispiece. "Moodle"--the mood of the discussions captured in a doodle by participant Donald H. Menzel.

DUDLEY OBSERVATORY REPORTS

OBSERVATIONS OF SOLAR ECLIPSES USING SR-71A TYPE AIRCRAFT

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Report No. 3
December 31, 1968

Dudley Observatory
Albany, New York 12205

PREFACE

In midsummer, 1968, R. D. Mercer was nearing completion of a technical review on the suitability of SR-71A type supersonic aircraft as possible observing platforms for significantly extending duration of totality during solar eclipses. The study showed that such flights are feasible and provide the observer with a unique systems base. Since this method of observation would require a large and carefully planned program to be effective, it seemed wise to bring the preliminary results to the attention of at least a small group of potentially interested investigators as early as possible. Wider dissemination of this information was also planned in the form of a digest of remarks made at an informal meeting of this group. On rather short notice, then, sixteen persons kindly agreed to gather at Dudley Observatory last July to discuss some of the scientific aspects of such a supersonic flight. A taped recording of the discussions was of good quality and has allowed us, with the permission of the participants, to provide this rather complete account. We are very pleased to acknowledge our appreciation for the cooperation given us by all the participants.

For the details of the SR-71A aircraft, we are grateful to the Air Force YF-12A/SR-71A Program Office and their contractor, the Lockheed Aircraft Company. The NASA Manned Spacecraft Center and the U. S. Weather Bureau provided computations and analysis of the eclipse track, vital to this conference as well as to the feasibility study.

We are also very grateful for the efforts of Mrs. Christine Bain, Mrs. Elizabeth Sterrett, and Mr. David Wachtel in the preparation and dissemination of this report.

R. D. Mercer

D. C. Schmalberger

PARTICIPANTS

Michel Bader; NASA Ames Research Center

James G. Baker; Harvard College Observatory

John C. Brandt; NASA Goddard Spaceflight Center

Richard B. Dunn; AFCRL Sacramento Peak Observatory

A. Neal de Gaston; Bellcomm, Inc.

H. Alistair Gebbie; National Bureau of Standards

Curtis L. Hemenway; Dudley Observatory

Donald H. Liebenberg; National Science Foundation

William Mankin; University of Massachusetts

Donald H. Menzel; Harvard College Observatory

Robert D. Mercer; Dudley Observatory

Goetz K. Oertel; NASA Headquarters

Jay M. Pasachoff; Harvard College Observatory

Donald C. Schmalberger; Dudley Observatory

Richard N. Thomas; Joint Institute for Laboratory Astrophysics

Spencer R. Weart; California Instite of Technology

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SPEAKERS

Meeting participants. Left to right, front row: Mercer, Gebbie, Bader, Menzel, Hemenway; middle row: Schmalberger, Mankin, deGaston, Weart; back row: Brandt, Liebenberg, Dunn, Oertel, Baker, Pasachoff.

CURTIS L. HEMENWAY

Dudley Observatory

I should like to welcome all of you to Dudley Observatory and wish you a fruitful stay.

Perhaps I can tell you briefly about the relationship between the Dudley Observatory and the State University of New York at Albany. Dudley is an old institution, founded in 1852, and is independent of the State University. I serve as Director of the Observatory and as Chairman of the Department of Astronomy and Space Science at the University. We are hopeful that the cooperative relationship that we are establishing between the Observatory and the University will strengthen both institutions measurably and that in a few years we will have an important astronomical center here in Albany. We will have a staff of nine professors this year; and our Ph.D. program begins in the fall, although we have had a Master's program almost two years now.

The purpose of this conference is to give consideration to the science that can be carried out with a supersonic aircraft. I might say that this idea probably originated in many people's minds but I first heard of it from Bob Mercer. Prior to coming here, Bob was with the MOL program and prior to that was the experiments coordinator for the Gemini program and also the Mercury program. He is used to thinking in terms of enormous programs and, also, is used to the very large and detailed technical problems that result when one tries to do something of this order of magnitude. We were so intrigued by this idea of his that we prevailed on him to come here to Albany to do graduate work and make this his major field of interest.

As you see, we propose to run a tape recorder today. It has been our experience, and certainly yours too, that when you are at a meeting somebody has a nice idea but later nobody can phrase it in quite the same way, and we sometimes have a problem recalling the exact sense of a comment.

I would like to thank you all for coming here. We are going to reverse the order a little bit because of time constraints on some people who have to get away. Don Schmalberger will act as moderator and will next make a few additional comments. Then Dick Thomas, since he must leave about midafternoon will make whatever comments he would like next. He has been briefed this morning on some of the technical capabilities of the aircraft that is being considered.

SCHMALBERGER: I would like to make only some general remarks at this time and add particular comments later. In some ways it would be easier for the scientist looking at potential uses of this aircraft for eclipse experiments and studies of the solar atmosphere if one had all the parameters of the aircraft. As it is, we find out we don't have all the information we would like. We do have a great deal, however, and Bob will elucidate this for you.

Now, just a brief statement about what I think are probably the most salient features about the whole thing. I think that the group is interested in considering in what ways this program is unique. I feel that the answer to that is in the total time duration and a possibly large plate scale; hopefully, therefore, great time resolution and great spatial resolution in the solar atmosphere. I would, myself, consider these the greatest scientific/technical features that we have available and that we can capitalize on in terms of experiments.

As for comparison of things that can be done with other aircraft at lower altitudes, recall that certain aspects of infrared or visual work, for example, can be done from 990's at 37,000 feet or so. The extra gain by perhaps a factor of two in altitude is not tremendously significant at these altitudes—it is the duration that's the crucial thing. So what I have done with Bob, in a very rough way, is to look at some kinds of trial systems which he or I will discuss in more detail later. The idea of these was to generate things we would discuss as a group. We don't think we have any "best" system; in fact we've gone through modifications ourselves always looking at the plane in terms of the most optimistic thing we could get out of it. The hope is that out of this meeting, as an ad hoc working group, we can both solidify some of our own plans and also come up with a general package including the sort of instruments which are likely to be the most effective on a first flight.

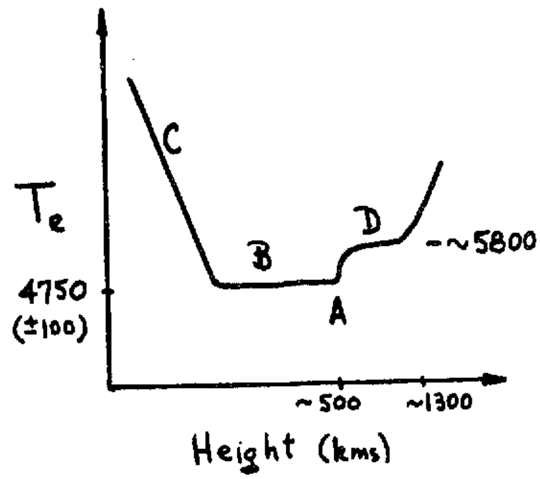
With that very brief introduction, I'll turn the program over to Dick Thomas who has some comments he'd like to make but who must leave the meeting shortly.

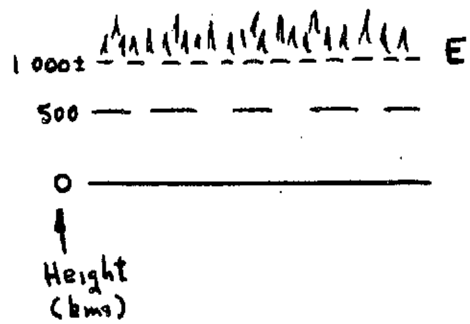
RICHARD N. THOMAS

Joint Institute for Laboratory Astrophysics

I've already been told a bit about the capabilities of the aircraft; and I should mention that most of the things that I want to suggest here have come from talking with Alistair Gebbie over the last couple of years.

To me, the aircraft has three noteworthy charactertistics: the height it can attain, its speed, and its physical length. Let me draw a picture of the sun, and ask: what are the outstanding problems that one would like to try to solve in terms of the capabilities that you have here? They are these: let me plot here temperature versus height, and I'm also going to, somehow, try to plot another parameter here, which is uniformity of the surface against height— it's a hard thing to do but I'm going to try. The temperature drops off rapidly, comes down to a minimum, and then goes up again. Now





the height scale in this sketch is something like this: this point (A) is at a height of about 500 kms in the solar atmosphere. This region (B) is around 500 kms thick. These distances on the abscissa are above a height zero with respect to unit tangential optical depth at around 5000A along the line of sight.

So we have a region here of about 500 kms with a temperature minimum. And at the time that we did all of this eclipse work on the basis of the 1952 eclipse, most of us thought that the temperature minimum was around 4000–4300 or something like that: but I was never sure whether it was a real situation or not. Now everything that I could see of the thinking on the temperature minimum over the last three years—the last five years—has been that estimates of the temperature at the minimum have been going more and more towards this 4750. Remember, at the Tucson meeting it was supposed to be—well some said 3800, others said 4400, or 4500. Some of these results have now been revised and 4750 plus or minus 100 degrees seems to be a reasonable value. What is very interesting however, is the way in which the temperature falls to the minimum in this region (C), and the way in which it rises out of the minimum in this region (D).

As far as I can see there are two kinds of experiments which really make some contributions to these things: One is the submillimeter region—the region between a tenth of a millimeter and a millimeter (although I can put in a factor of two, one way or the other). This gives me the region right in the minimum and up into here(D). All of the observations so far are essentially a point integrated over the temperature minimum. We don't really have good spatial resolution. The other region, in which one has some good resolution, is the work which Jim Faller and Spencer Weart did over the last several eclipses (handicapped by clouds and the like). They have very cordially given to Kathryn Gebbie and myself some of the data that they obtained, and Spencer has been leading us by the hand looking at it. So we have hopes that we can do better in this region than we had done in the 1961 monograph by Athay and myself, where we used essentially Dick Dunn's data plus a few poor points that we had from the 1952 eclipse.

Now, there are two kinds of uncertainties here: What is the temperature structure in each of these regions?; and, second: What is the degree of homogeneity of the solar atmosphere in these two regions? The temperature structure is extremely important from the standpoint of the basic science. I can get a temperature rise, maybe up to about 5800 degrees, according to a suggestion that Cayrel made based on the old planetary nebula model. If I have any further rise, however, it has to come from mechanical heating in the atmosphere.

In spite of all the work that has been done since the 1945-1947 period on mechanical heating in the solar atmosphere, we really don't know anything of its details. Our models are weak, our empirical evaluation is weak; we don't really have a lot to say about the kind and degree of mechanical heating in the atmosphere. So it's most essential to be able to know what the temperature distribution is in order to work back and ascertain how much mechanical energy is being put in. If you know how much is coming in, you can make a distinction between all the various mechanisms like gravity waves, acoustic waves and so on.

At the time we did this thing in 1961, the temperature at the 500 km level was believed to be about 6300; and from that level rose gradually until, at about 1300 kms, it really began to jump up. The big question is, then, does it go up to coronal values here or is there a plateau for 1000 kms or so, at the end of which it rises up to coronal values?

Now, again, right in this region (E) it becomes very clear that the sun is inhomogeneous (unless we do a lot to the helium/hydrogen ratio). But it is not clear what the inhomogeneity situation is below here. Because of the solar granulation, we know there are inhomogeneities down in here (C). Now a lot of people think that what happens is that they fade out, you have the homogeneous region (B) above, and in here (D) you get the chromospheric granulation. I'm not sure how much of this is terminology and how much is science—it would be very nice to know.

What we would like to do is to supplement things like H_α filtergrams, which give you a very high level in the solar atmosphere, by something which gives you a picture in here (B). Alistair has been pushing very hard; and it would be very nice to have even rough pictures from the submillimeter regime of the sun over this minimum region in order to answer this question about inhomogeneities—at the same time that you are answering some questions about temperature structure, you see. So there is really a sequence of experiments which you could make here.

More than anything else, I would recommend for our consideration here the observation: let us not take an airplane and load it up with ninety-five experiments each of which, if it comes off well, will give us epsilon contribution to our knowledge. Because if we have ninety-five, some of them are bound to succeed; so, we go home feeling happy. I would much rather see you put one or two experiments in the aircraft which, if they come off, really tell you something in detail. Pick a really good payload, do your best to make it work; and if it doesn't work—OK, you tried. But at least you tried for significant experiments.

Now it seems to me that the kind of aircraft that Mike Bader has in California could work in conjunction with the eclipse observations and also outside of eclipse, of course, so that one could do steadily a couple of experiments at a time. Things that can be done with a balloon or with a slower moving aircraft are only done redundantly with this aircraft. That is why I put this point down; for it seems to me that what I could have with the SR-71 aircraft is a long interferometric base line, and the speed to follow the eclipse.

The other region of possible interest is the rocket UV. There, you might get to the MgII lines at 2800A but that's the most you can expect. So it seems to me that you're forced into the far infrared and the submillimeter region of the spectrum for your thinking (with the possible exception of using Spencer's equipment at all wavelengths). For example, I can do the kind of work that Alistair and Mike Bader did in their first observations with the interferometer. Maybe I can get some information on the inhomogeneities, and then progress to a longer base line interferometer; maybe I could use the rigid frame of the airplane. We were talking about this this morning; and it seems one can get 25 feet, possibly 40 feet. Certainly, on that aircraft you have out there, Mike, I can get close to 100 feet. But the point is that I have double the height with the SR-71 aircraft compared to the 990. So it seems to me one wants to use these things in tandem, doing part in one plane and part in the other. These experiments should always be thought of not as just one experiment at the time of the eclipse but an experiment both in eclipse and out of eclipse employing both the 990 and the SR-71.

BADER: Just what is it you want to get out of the submillimeter region? Just what do you want to see?

THOMAS: If I plot opacity to a given depth in the sun as a function of wavelength, or, if I plot as a function of wavelength how deep into the solar atmosphere I see, then it just so happens that in the submillimeter range I hit the region of the temperature minimum. If I look at a wavelength of 5000A, for example, I don't get anywhere near it; get down into here (C) someplace. It's just the combination of circumstances. We do hit the temperature minimum region in the submillimeter waves. It seems to be a long flat minimum. That means two things: from center to limb, in the submillimeter region, I see about the same region of the disk; and, second, if I scan from, say, one millimeter to a tenth of a millimeter, again, I see about the same portion of the disk. Differences would give me the temperature gradient.

We have a piece of equipment which is particularly aimed at submillimeter waves and it, in turn, is particularly aimed at one of the last boundaries of solar work; important not just for empirical structure but for knowing the theoretical model of the atmosphere, both with respect to heating and with respect to inhomogeneities. And I would like to stress also that what is seen in the last twenty years in the literature about how well we understand these problems is misleading. We are no better off than we were when I wrote my thesis in 1946-1948; there is a lot of discussion but no tying down. If I can take the Nice symposium as a good summary of the situation there is literally an uncertainty of a factor of 10 or 10^2 in the amount of mechanical energy coming into the atmosphere, and that's largely because we don't know what are the sources of this mechanical energy. So this, to me, is a very pressing scientific problem.

SCHMALBERGER: Do you expect that the submillimeter center-limb variation gives you the beginning of the temperature rise or are you still in the isothermal zone?

THOMAS: I don't think we know well enough because I don't think we know the opacity. We'll get the answers to that from the observations. Incidentally, I'm all for limb darkening observations in the visual region of the spectrum, getting good line profiles and the like. Until I talked to Jim Baker, I wasn't convinced that one could use this aircraft to get line profiles because I didn't think you could stabilize well enough to get either line profiles or integrated intensities in the region of, say 4000A to 5000A as a function of height. He tells me you can but then you'll be using very short exposures—that's something for which you can put him on the spot. I think he's talking about thousandth of a second exposures with image converters or image tubes, but I'm ignorant of these possibilities. If it could be done, though, I'd change my thinking. Maybe one should look at the visual on this, too. In any event, what should be argued are things unique to this kind of height, speed, and length.

HEMENWAY: Dick, does this type experiment consume a significant portion of the potential ninety minutes that this project would have?

THOMAS: Yes, sure! That's exactly why the speed is important.

HEMENWAY: But why do you need extended time for this type of observation?

THOMAS: You mean why do I uniquely need it?

HEMENWAY: Yes.

THOMAS: You're putting me on the spot! (Laughter) No, Curt; I'd like to be able to compare events during eclipse with those outside of eclipse. Comment, Alistair?

GEBBIE: Yes. I think you may very well need the time to get the flux; because during the eclipse you will be working with only a very small part of the sun, and these are only rather flabby photons we are dealing with. (Laughter)

HEMENWAY: You mentioned that we ought to focus on a limited number of experiments but you've mentioned only one that you've placed a considerable amount of emphasis on.

THOMAS: No, I've mentioned three. Each just happens to operate in the submillimeter region. One is the exact duplication of what Gebbie has already done; a second is to use a medium aperture mirror and try to get a picture of the sun in these wavelengths; and the third is to use a longer, say 25 foot, baseline interferometer. An additional experiment is the kind of work that Spencer Weart and Jim Faller did with a beat technique of comparing what goes on in one part of the spectrum with that in another part of the spectrum.

MENZEL: How "sub" is "sub"?

THOMAS: A third of a millimeter, plus or minus a factor of three.

GEBBIE: I would say that with this height capability one should go to a hundred microns.

PASACHOFF: Are you proposing to image? With what kind of resolution?

THOMAS: That will depend on the aperture we have.

GEBBIE: With something like a two foot aperture, one could think of making a hundred picture points across the sun.

MENZEL; Does this point you see at a third of a millimeter correspond to unit tangential optical depth?

THOMAS: No; radial.

MENZEL: But then you are not interested in doing this at an eclipse?

THOMAS: No! The problem is that the temperature minimum is very flat and the optical depth decreases as we go toward the limb. Unfortunately we don't know enough about the temperature distribution or the opacity to say in what manner it does so—and that's why we want to do it. And we can't observe from the ground because of the high opacity in the earth's atmosphere.

GEBBIE: You can't build an interferometer big enough to get the limb darkening. The initial interest would be to get the total sun outside eclipse.

SCHMALBERGER: What you're saying then is that you need the speed of the plane to get adequate fluxes at the limb. You really need ninety minutes!

GEBBIE: Yes, you do. To do a good limb darkening experiment you will need all the time you can get.

SCHMALBERGER: Thank you for your comments, Dick. If there are no further questions, I'll call on Bob Mercer.

ROBERT D. MERCER

Dudley Observatory

The idea for this flight occurred to me about eighteen months ago. It is not new, but I happened to know about the particular aircraft we will be discussing and I had looked at its capabilities with regard to such a flight. As a result, I felt we could do something with an aircraft of this nature and so went on to ask: What are the sort of things that one can do with this aircraft, even in very gross terms, scientifically? It is this topic we will be discussing here, and to establish a frame of reference I shall present some of the results I have and some suggestions about what might be done.

The aircraft has an astro-inertial navigation system on it, and we will know position to about a tenth of a nautical mile. But if you can take a series of position fixes and put them together after the flight you might be able to resolve the position of the aircraft much better than that. Then we're talking about just a few hundred feet in position with respect to the umbral shadow or something less than a hundred kilometers on the sun. Also, of course, we'll be able to extend the usable spectral range and improve signal-to-noise ratios without more sensitive detectors.

We have talked about the possibility of using two aircraft. It is important to note that two aircraft, at this eclipse, future eclipses, or even for solar work done outside of eclipse, can accomplish things which two aircraft used at different times could not do. However, for our immediate consideration, the two-airplane idea is not an essential scientific requirement. Also, it's rather more involved with regard to breakdown of costs. So we looked at the sort of things we could do in terms of a single aircraft.

We asked: What could be the maximum duration we could get? What is the highest altitude obtainable? Now, a lot of these things tie together. If you want to go to higher altitudes, you're going to diminish your range and time in the eclipse. The exact point where you get on the velocity profile of the path will determine how long you can stay in it; also, what altitude you want to use. What is the maximum optical aperture? With the present aircraft, it looks like the maximum aperture is about ten inches.

THOMAS: I thought you were saying about 14 by 29 inches.

MERCER: That is the maximum size of the external window through which a heliostat would look in order to obtain a useful ten-inch aperture. The problem is that the aircraft is moving from west to east along the eclipse path, and there is quite a wide traverse of the solar position with respect to the aircraft. The aircraft moves more than 2000 miles during this period and the sun is going through almost a sixty degree arc. So one is going to have to have a bigger outer window just to get an unvignetted ten inches. Remember we were looking at optimizing--how big can you get? That was the idea here.

Maximizing focal length—there are lots of ways this can be done, depending on the amount of optical folding, the experiment, and the scattered light in the system. Dr. Baker, here, can give us some help in some of these areas. We have considered the possibility of a ten-inch aperture system at about f/40 to f/50 as a trial system for our study because NASA has queried us concerning costs from time to time, and we wanted to use some set of instrument parameters as a kind of straw-man in terms of potential experiments one might do. There's nothing golden about such a system, of course. The values can be changed and should be looked at in terms of what science needs doing and what experiments will get that done.

I would very much like to emphasize my agreement with what Dr. Thomas just said about overcrowding of experiments. We ought to limit the number to a few, but those to be done well. I should tell you, too, that I've had a letter from Gordon Newkirk (who couldn't be here personally) saying the very same words. Dr. Houtgast, who couldn't be here either, has also written us, and I'll pass his letter around for all of you to read. He wanted to identify what experiments he is interested in seeing done on such a vehicle; or, at least, those he would like us to consider.

We can talk not only about eclipses, but non-eclipse work as well. There's a list of non-eclipse work which comes to mind readily and which I sent to all of you. Certainly uneclipsed solar work as well as stellar observations could be made with this aircraft. I talked to Gerard Kuiper about some of the things he had a need for doing aboard such an airplane once it is modified with an upward-looking window. Using the aircraft for these other things would keep the costs down for each experiment.

For eclipse work we necessarily picked a target event (see Figure 1). I picked the 1970 eclipse for several reasons. In the first place it's generally near the U.S. We're using a new vehicle in a new way, and as a result the operational costs increase very rapidly the further away you get from the U.S. We ought not

Fig. 1. — Path of the March 7, 1970 total solar eclipse. (Grid and eclipse track computer generated by Computation and Analysis Division, NASA Manned Spacecraft Center; globe photograph courtesy Rand-McNally and Company).

experiment with a new technique as far away from our boundaries as we can get. This flight could be operated out of the United States, and the modus operandi for the 1970 eclipse would be to take off from the West coast, fly to a point about 110° West and 6° North, refuel from a tanker aircraft, and shortly after refueling begin climb and acceleration from about 400 or 500 knots—the tanker speed—so that in 15 minutes the observing aircraft would be at about the 70,000 foot region and moving at a speed of about 1400 knots. We would collect data while tracking the umbra, with the maximum solar elevation occurring at about 95° West and 18° North, and continue on until we have to drop away to meet another tanker aircraft. If, for some reason, we didn't meet that tanker, several good airfields would be nearby. That's one of the reasons for having the final refueling near the Florida coast, because they do have to concern themselves about aircraft safety-of-flight. The aircraft costs many millions to build. They were built, as you know, for reconnaissance purposes (a basic need in the military) and so that cost has been written off. We can take advantage of that. Also, it looked like good timing; we might be able to make the necessary preparations for this eclipse; but after that, the next eclipse near the U.S. is not until 1977, off the West coast. So, if we don't get a start on this new observing technique pretty soon, we're going to be starting with eclipses a long time off.

Figure 2 shows the velocity curve for the 1970 eclipse. The aircraft has a capability of about 2000 nautical miles an hour, but that's only when it's up to full speed and there's virtually no acceleration or maneuverability left. The 1970 eclipse has a fairly low minimum velocity as eclipses go, around 1300 knots. If you utilize the bottom part of the solid curve, you can get the 90 minutes duration, and you have the acceleration capability which gives you the maneuverability about the umbral-penumbral boundary. That, of course, was a new feature that was very exciting because of the work you could do on the chromosphere.

Figure 3 is just a typical eclipse pattern. This is near maximum during the 1970 event. The solid black arrow shows the direction of motion of the path. The tick mark at the upper left indicates the solar North Pole. The size of the pattern is about 85 by 75 nautical miles at this point.

MENZEL: Is that the umbra?

MERCER: That's right; a view of the umbra projected on the earth.

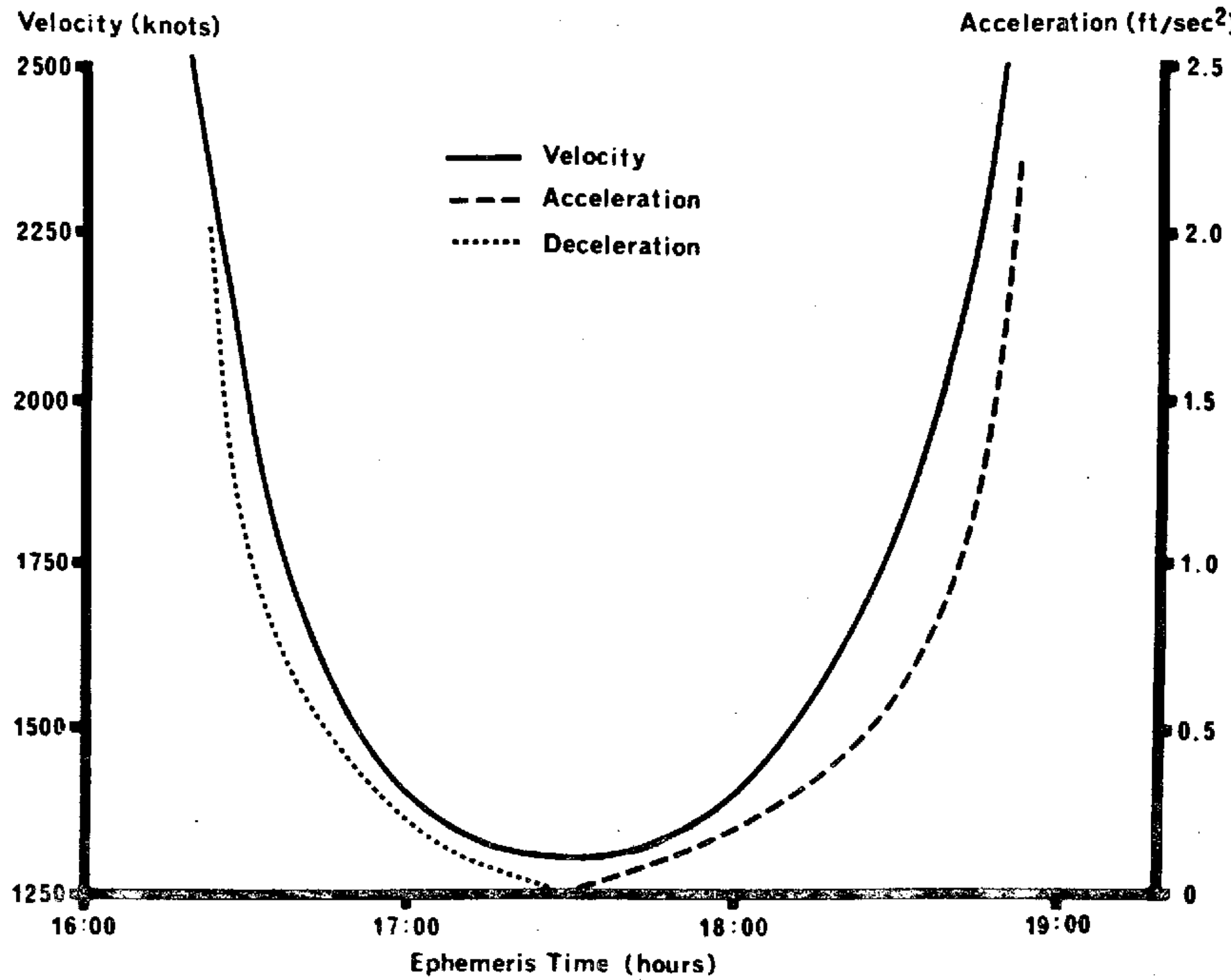


Fig. 2. — Umbral velocity and acceleration data for March 7, 1970 eclipse at 70,000 feet above mean sea level.

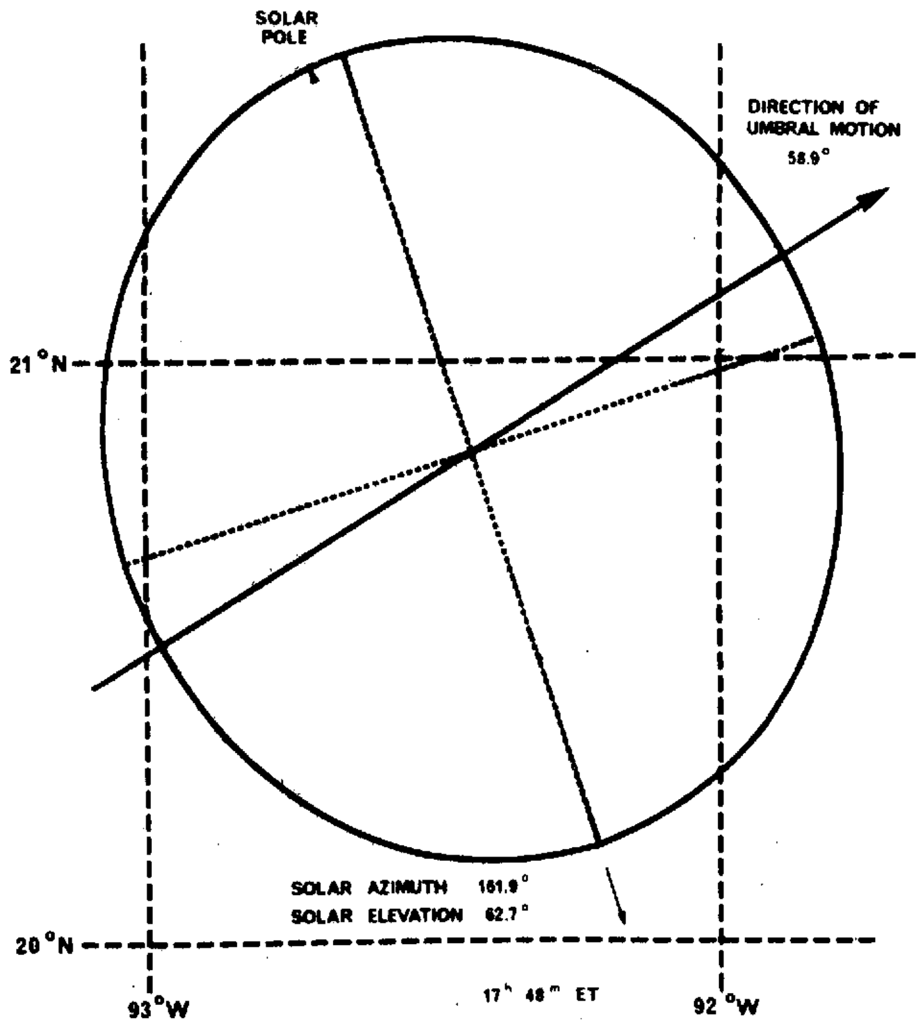


Fig. 3. — Typical pattern formed by intersection of March 7, 1970 eclipse umbra with the 70,000 foot level; view looking eastward.

Figure 4 is a picture of the airplane, in the event that you aren't familiar with it. This is the SR-71A. There are several of these strategic reconnaissance aircraft flown by the Strategic Air Command.

THOMAS: Can you give us some dimensions?

MERCER: From tail tip to nose is about a hundred feet; that's about the length of a DC-9. It's a two-man airplane; the pilot sits in front, and there's a systems operator behind him in a tandem fashion. Figure 5 is a three-view of the airplane taken from the Revell model kit plans. There is a stub "wing" running forward along both sides of the fuselage right up to the nose; it is called the "chine".

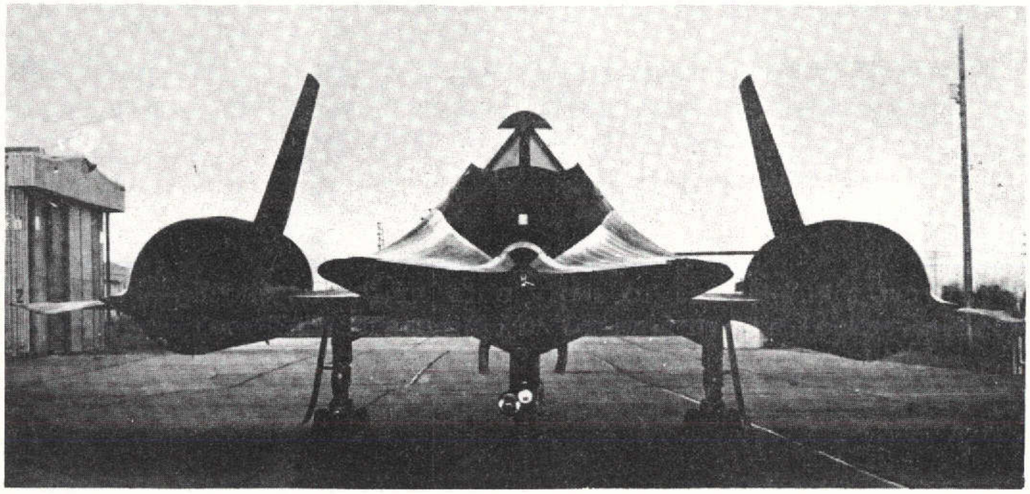
Basically you have three equipment bays on the aircraft. One equipment area is in each chine, and you get access through a set of underside doors. These areas each have a bulkhead at their longitudinal midpoints and are about 26 feet in overall length. The underside chine doors can come off; that is, they can be completely disconnected for installation, ground test, or removal of equipment. The third equipment area is in the nose. In the basic airplane there is electronic equipment in the nose. There was also a less complex nose built for test work, called a "light-weight nose", which is simply a titanium shell around a rib and longeron section. Such a nose can be made into a very useful equipment bay. Several hundred pounds of ballast are used when flying with the light weight nose, anyway, to properly position the aircraft center-of-gravity.

DUNN: You mean you can cut a window in the nose?

MERCER: Yes, indeed.

PASACHOFF: What are the problems with heating?

MERCER: At the speeds we're talking about, the stagnation temperature is about 322 °F, and the skin temperature is going to run about 250 °F. The nose is insulated to some degree, and is cooled by ducted air. Inside the nose bay it is only about 160 °F, and 80 °F in the chine bay areas. To get an airflow through for cooling, the bays are all at ambient pressure plus a little overpressure of about one pound per square inch.



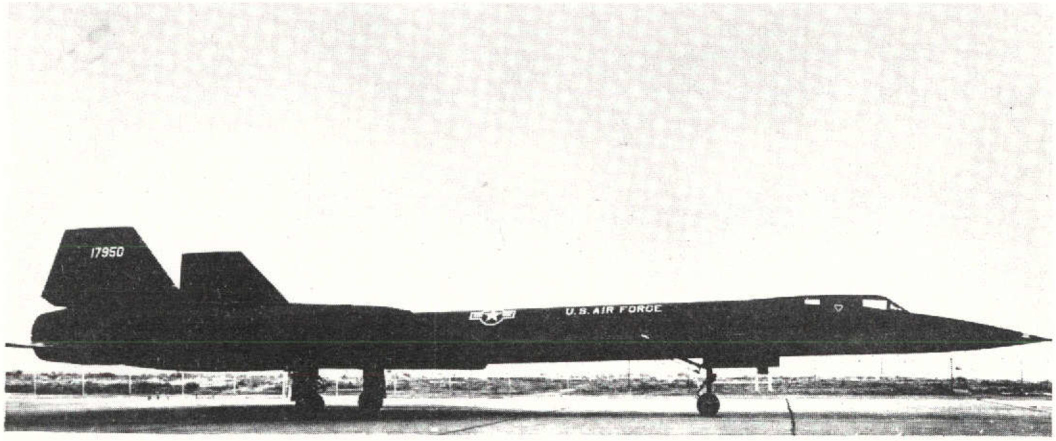


Fig. 4. — Front and right side views of the SR-71A aircraft, built for USAF Strategic Air Command by the Lockheed Aircraft Company (official U.S. Air Force photographs).

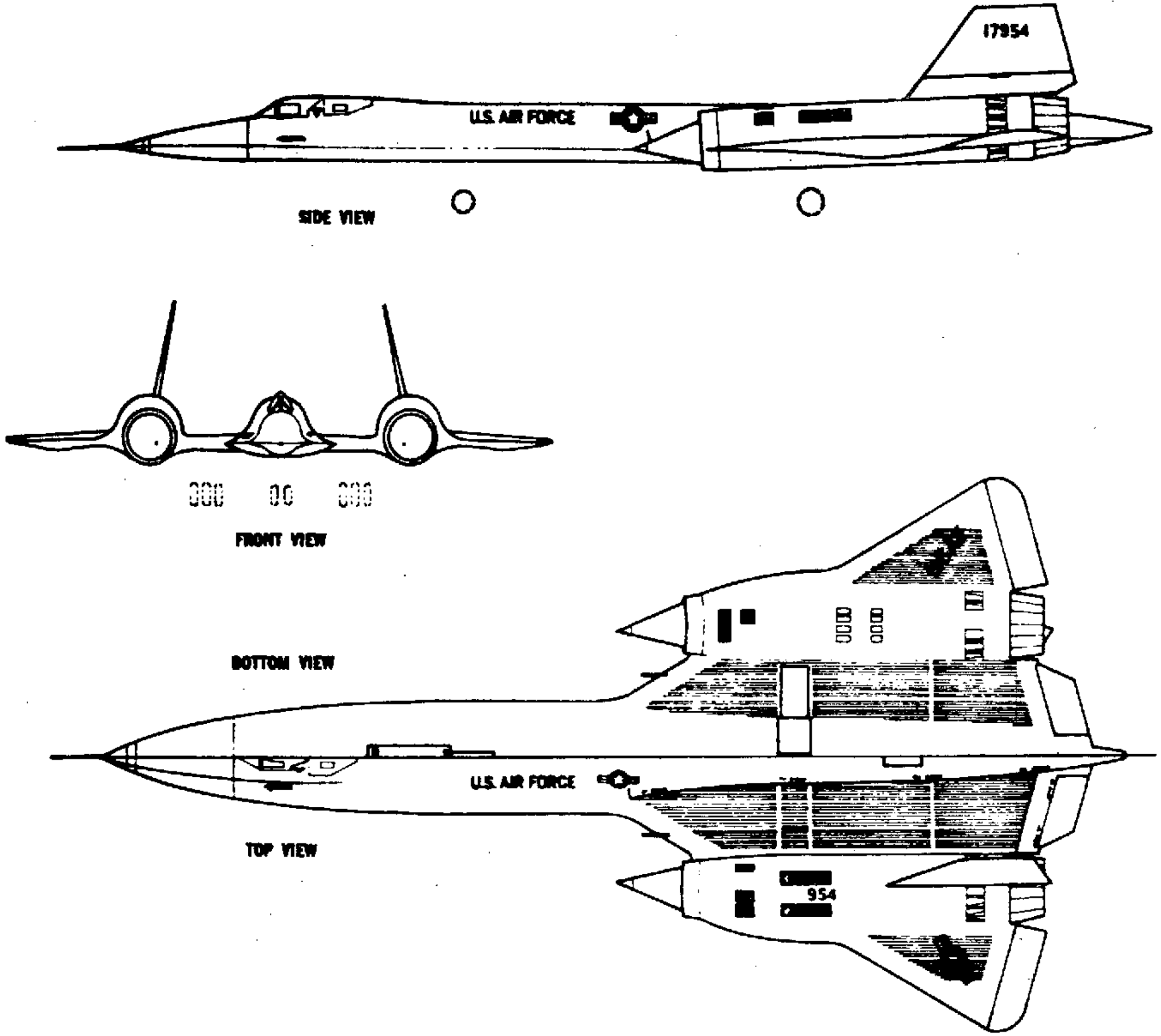


Fig. 5. — Three-view drawing of the SR-71A aircraft. (Drawing courtesy of Revell, Inc.)

BAKER: What is the basis for the 10 inch window diameter?

MERCER: It can be a little larger depending on the type of equipment and experiments one wants to use. So I don't want to say that ten inches is a final number. But it's an upper limit if you want a long focal length system where you have to lay out the optical path in the longitudinal direction in the chine bays, and you have to view the object with a heliostat behind a flat window.

BAKER: It would have to be an elliptical or rectangular window.

MERCER: That's correct. We are talking about a 29 by 14 inch rectangular window, as a matter of fact. This provides room for the heliostat to move and yet not strike the window in one extreme position, but also not vignette the image in the other extreme, and it will still allow a 10 inch beam to come down the bay. The window can be at the forward or aft end of the bay but we recommend it be aft so that it's nearer the center of gravity of the airplane.

PASACHOFF: Can you please show that bay from the top and the side view?

MERCER: Figure 6 shows this. The chine has one upper surface and one lower surface. For our purposes we would need to be looking up from the right hand side. You would have to cut open the right hand side and put in a flat window that would lie flush with the skin, or nearly flush, which is possible since the amount of curvature in the upper chine skin line isn't very much. But there might be a slight shock wave off of the window. How bad, we'll have to wait and see, because we will be flying at speeds above Mach 2.

BADER: How much room do you have back from the window before you hit the floor? What is the distance along the window normal inside the bay?

MERCER: The normal to the window is at 58° elevation but the bay is trapezoidal in cross-section. The distance downward, inside the bay and along the window normal, to this opposite corner runs about 24 to 28 inches, but the bay is getting smaller in width. I have more accurate drawings and will show them to anyone interested in details. If you aligned a heliostat, for instance, with one heliostat gimbal

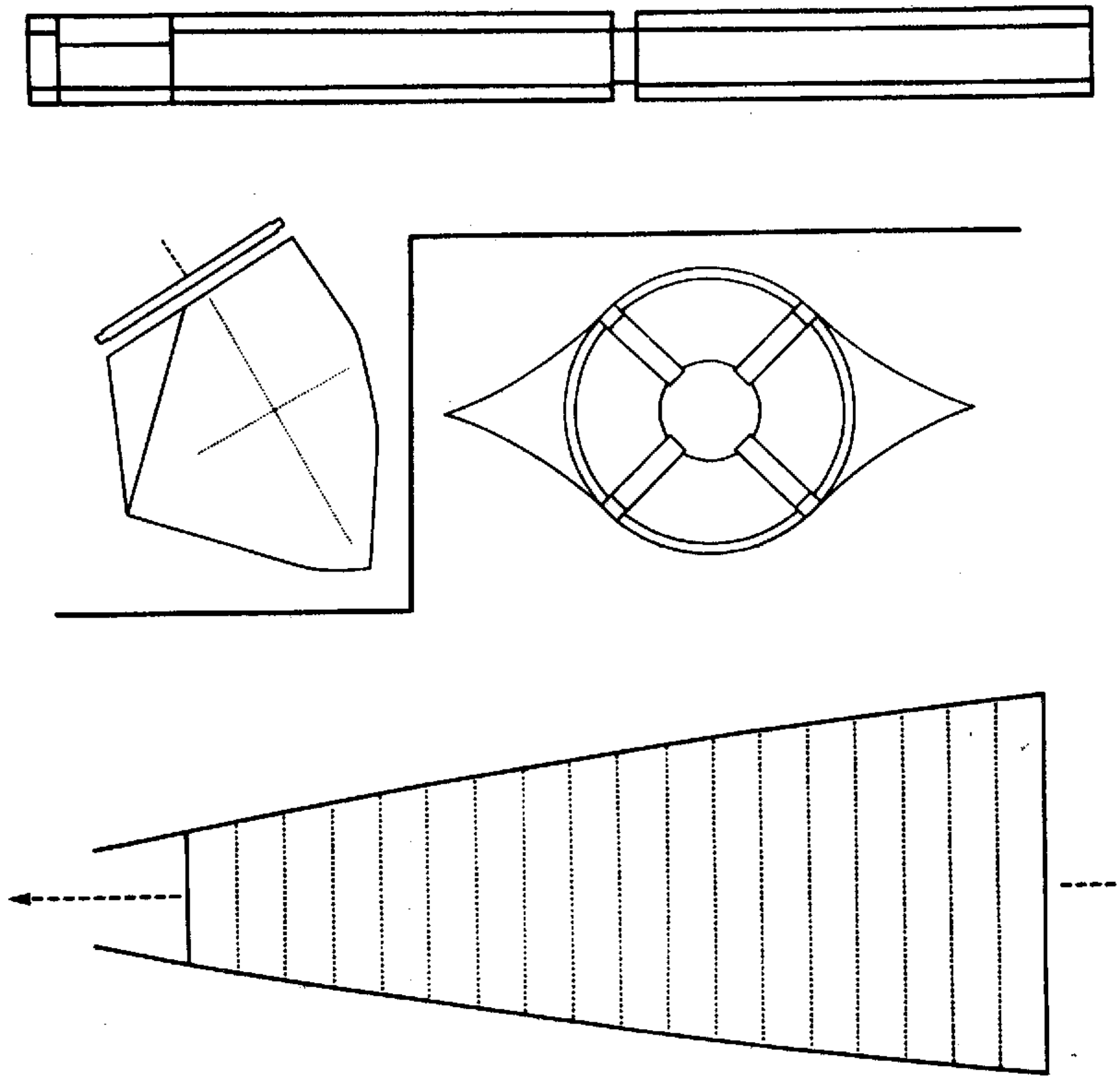


Fig. 6. — Schematic drawing of SR-71A instrumentation bays in side and end views of left chine bay and nose cone.

axis almost mutually perpendicular to the window normal and to the aircraft longitudinal axis and having a clearance of eleven inches below the window, that would give just enough space so that the far edge of the mirror doesn't touch the inner wall. So, you can re-direct the optical path to get an image running longitudinally. You can get a 10 inch aperture in this way, but you're pushing it, and a properly proportioned heliostat is not available today. That means we might have to have special specifications on the gimbals to keep them narrow enough.

BADER: What is the 29 in the 14 x 29 inches?

MERCER: It is distance along the longitudinal axis of the vehicle.

MANKIN: Is there any possibility of having an opening with no window?

MERCER: No, I would say not. You're moving at Mach 2.2 to 2.5 and the shock would cause extremely disturbing forces. I don't know what the temperatures or pressures would be in there. The ram pressures would be very great.

BAKER: What is the pressure on the window plate?

MERCER: Well, this bay is normally at ambient pressure. However, if you want cooling, you must dump air into the bay at slight overpressure forcing it to run down the length of the bay, or else introduce a cooling air duct along the bay that people can tie their equipment into.

BADER: Bob, do you have any numbers on the time, the duration, if you ran a constant bearing course? In other words, a preliminary trade-off between that and the full aperture of the window dimension?

MERCER: You mean you want to keep the same angle to the sun all the time?

BADER: That's right.

MERCER: Well, you'd move out of the eclipse pretty quickly because you've only got about 80 miles across that shadow. If you kept constant angle, it would be necessary to fly a curved course, and ....

BADER: Well, you'd seem to stay with the shadow.

MERCER: No. You can't, you see; because the shadow is going off in a northeasterly direction and if you try to fly a curve to keep this angle constant you can't do that and stay with the shadow. The two are incompatible.

MENZEL: Not unless you're in orbit.

MERCER: Well, it's even worse there. If you kept a constant angle for the period you're interested in, you would very quickly move to one side. Maybe you'd get the equivalent of 150 miles from the time you started until you got out of it, but 150 miles at the speed of this eclipse is about six minutes.

BADER: You wouldn't fall back, because that's just about the speed of the sun.

MERCER: You still couldn't do what you said because you would get out of the umbra. For non-eclipse work, it's an entirely different story. You could do that sort of thing there, assuming you just wanted to look at the solar disk from some particular angle. Now, there might be other eclipses that fit the constant bearing maneuver a little better but we'd have to look at these individually.

BADER: I'm still puzzled. We did something like this with the 990 in the Southern Hemisphere. We held a constant bearing path and flew in the same general direction as the shadow. We lengthened the eclipse by 50 to ....

MERCER: But you were going from east to west. That was a help on that matter. This time we're going the other direction; so, it tends to make that angle change very rapidly.

BADER: Oh, we are on the other side of the aircraft!

MERCER: That's right. This is the problem. Now some eclipses in the Northern Hemisphere do have the properly directed kind of curve. The 1973 eclipse in the Sahara has such a curvature. It's a very high eclipse; it's about 85° or 87°.

MENZEL: You mentioned 26 feet as the length of this bay?

MERCER: Yes; and maybe all of that isn't usable on the right side because there is a recorder there. It's on the end of the middle bulkhead, but it can be moved forward with an extension cord. So one can put it on one end, and then have the remaining volume of the two bays for equipment. I should emphasize that we can't remove all of the material in the bulkhead between the two bays. We can only take out some of it.

GEBBIE: Could there be a window at each end of the bay? Windows of approximately the same size?

MERCER: Yes; there's no reason why several additional windows couldn't be put in. Then there might not be any need to get between the two end-to-end bays. This allows possibilities of one experiment in one bay and another experiment in the other bay. Or, one could put a window at each end to get a long base line for interferometry work. Costs must certainly be considered but it can be done.

HEMENWAY: The second window is not quite the cost of the first.

MERCER: No, that's right.

THOMAS: Could you give us the cost for a window if it were small?

MERCER: Well, the trouble is, we haven't gotten a cost from the contractor yet.

THOMAS: I see. Would you estimate that the experiment might cost about $3000 or $4000?

MERCER: We should ask someone from NASA since they will be funding some of this, certainly.

OERTEL: What are you asking me exactly?

MERCER: Well, we're asking you how much money, for instance ....

OERTEL: We've asked you to come up with an estimate on what it would cost. We would look into the possibilities of coming up with that money. The first number you've given us is $10 million.

MERCER: For the total operation.

OERTEL: Yes; and for the moment I don't see where this money would come from.

MERCER: OK; but if $8 million of this were operations, and the Air Force said they might pick this up, then it might turn out that there would be about $2 million left over. This would allow, say, a million for modifications and a million for experiments, or numbers similar to this with different breakdowns depending on what we're going to do.

THOMAS: Well, it doesn't take a million to put a hole in an aircraft. It seems that $10,000 would be more like it.

MERCER: This is a titanium aircraft though!

THOMAS: Even so. All I'm really asking is the cost of one window versus the cost of two windows. Both of them together are a very minor thing compared to the whole cost. What really costs is what the Air Force is putting in for operating the airplane. All the rest of this experimental expense is relatively trivial.

MERCER: Agreed. In other words, if the experimentation and modification costs are $2 million, that's minor compared to the operations. And I'd simply add that since this is in a supersonic aircraft made of titanium the window really has to be aerodynamically clean.

BADER: It's got to be tested, too!

MERCER: Yes. It's not simple. Maybe we won't need that big a window. The reason for the 29 inches is that the aircraft has ribs every 15 inches in this region. Thus, if you're going to put a window in, it ought to be about 14 inches or 29, or some multiple of 15 inches less space for a mounting frame. You don't actually need the full 29 inches for your clearance (it's something like 25 inches for the optical clearance) but with heating differences at the edges and bending, it was advisable to go to this length anyway.

MENZEL: Will they cut out a rib, or will there be one ....

MERCER: Yes, they can cut out a rib, and they will reinforce around it. The contractor has notified the Air Force that they know the basic problems relative to this project. They are ready to go ahead with a study on how much it costs to do all these things but they are maintaining that they need money to do the detailed engineering study. And right now the Air Force is looking to me and to NASA and asking: "Is there any way that you can supply money to us so that we, in turn, can have the contractor complete the costing of this project?"

THOMAS: What amount of money is needed for this engineering study?

MERCER: Well, the Air Force is telling me it could be anywhere from $15 to $50 thousand; they don't know.

BAKER; Are the surfaces structural on all sides of the chine? Could you modify them to get bigger bays?

MERCER: Well, the outer wall of the chine bays runs the whole length of the chine. Now, if we put the window in, we will have to get 14 inches clearance to take care of the elevation change in the 1970 eclipse; so, they would have to move a 30-inch section of that wall outwards.

BAKER: I wonder if they could change the shape of ....

MERCER: They can't move inward, towards the center of the fuselage. This is load bearing structure and insulation around the fuel tanks. The fuel cell area can't be touched, and this is most of the center fuselage from behind the second man back to the tail.

BAKER: Could they change the upper chine surface to give more area in the bay?

MERCER: You mean, "Could they fair it in a little higher on the upper side of the chine?" Yes, but you'd be talking about a major modification, plus the fact that this would be an aerodynamic change and would certainly require wind tunnel testing, flight testing, and so forth. In our work we've simply tried to stay away from such modifications. We've tried to keep changes internal and not touch the outside except to get a window on the surface, and this has to be as simple as possible.

Now I might mention another thing. The airflow is generally longitudinal, but there's a vortex effect off of these chines. The air flows up and around, giving a very large diameter vortex. So, the air actually streams slightly diagonally downward from the expected longitudinal flow direction on the upper surface of the chine. It's washing downward at the same time it's flowing back. This is good in some ways because it keeps the boundary layer thin by cleaning it out on the top-side. There are some tests on this that we would have to perform.

I was concerned about the refueling which goes on right behind the systems observer's station on top of the fuselage. I asked them to consider a cover over the observing window but it's impossible to get a cover on the outside. That's a major modification. I asked them to consider a frangible throw-away cover, but the engine inlet is very close by, and so is the tail. So, during refueling they would have to assure that all pumping and residual draining had ceased before they disconnect in order to have the minimum amount of fuel in the slipstream and to prevent any kind of an oily surface forming on the observing window. That would be something of concern, but we feel we can overcome that problem.

The cooling air ducted into the equipment bays comes from the engines. This air is bled from the last stage of the engine compressor section for various internal operations. It is cooled; but below about 45,000 feet it still contains a lot of water vapor.

By delaying the use of cooling air until the aircraft is at 45,000 feet, it will be dry. After filtering, it can be dumped into the bays directly or first ducted through the experimenters' equipment. Although it is cooled down to -30 °F at one point there is the possibility of some engine oil in that air, and the contractor has suggested everything from fairly heavy oil content to no oil at all. So, this is a problem we had to concern ourselves with from the very beginning, and is one of the main reasons we considered enclosing all the optics in a box.

Another advantage of using a box would be the additional stiffness and control of focal alignments. In flight these two bays, from end to end, can move up to three-quarters of an inch in the pitch direction in large air bumps. The thought that we had would be to build a box that hangs inside the bay—a box that has its own stiffness and acts as an exoskeleton, so to speak, around the optics. It would provide the stiffness by being hung on some sort of shock absorbing type hangers. One can hang a 1000 pound box in there without any trouble even if tied at only a couple of points so it is free to sway and take advantage of its own inertial stability. Furthermore, if we had a box of this nature, we could duct the cooling air inside the bay but outside the optics and get some cooling effects to keep the temperature from getting too high in there while avoiding the air currents and oil problems inside the box. It could be almost air-tight, and have cold plates or cooling areas on the outside of the box to get some heat out of those areas where light concentrating optics might require it. Thus, you see, the exoskeleton box has several nice features that we like. It would also require a tie-in to the outer window using some sort of flexible bellows. The shock absorbing hangers would counter aircraft sway from roll or pitch, diminishing their amplitude and rates so that the heliostat could better follow and stabilize. I think with the proper design of the heliostat, we could get about the same values of stability that Mike Bader is getting in the 990, or on that order. That is about 5 arc seconds—right, Mike?

BADER: Yes.

MERCER: Equipment in the nose is going to get more loads, more bumping and jostling, and so forth; so, if you put something up there it will be a little different.

DUNN: Do you know anything about the vibration?

MERCER: I have some numbers here. There are two kinds. There's a high frequency sort of buzz, the systems operations vibrations. There's also low frequency vibrations due to attitude changes or local bumps in the air. The U.S. Weather Bureau has done a pretty thorough study for me at the season of the eclipse around 70,000 feet; and there are fewer bumps than there are at 40,000 feet, and only 15 to 50 knot winds. So, chances are, the air is fairly smooth. Pilots' and crews' comments also indicate that they only very occasionally run into the kind of bumps that, say, shake them off autopilot, although that can happen in the 990 frequently in bad weather.

PASACHOFF: Have they done some studies in the ones that have been modified for aerial reconnaissance to check on this?

MERCER: Yes, they have. I don't have that data. If I had, I couldn't give it out here anyway, because it has to do with the capabilities of the aircraft for those purposes.

LIEBENBERG: Well, it must have been done for the structural design of the aircraft. It would have to do with how long before fatigue sets in.

MERCER: That's true; but the structural considerations are different from those of stability for optical reasons. And, again, you can use image stabilization devices on the optical systems to compensate for some of these other things. There are several ways to solve that problem, and I don't know how they have done so. It probably depends on what resolution they are looking for and what the operational conditions are.

PASACHOFF: Well, you say that even if you had a number, you couldn't give it to us—which is reasonable, I guess. But, then, will the Air Force let a group of civilians make a very careful measurement of the optical stability of the airplane for scientific dissemination and publication?

MERCER: If you do it using a heliostat, and there is no knowledge about what the aircraft is putting in and what the heliostat is taking out, then ....

PASACHOFF: Any scientific publication is going to try to separate these as much as possible.

MERCER: Well, that may be a problem; we'll have to look into it further.

DUNN: You don't know of a Dutch roll frequency or anything like that?

MERCER: No. But there is a fugoid motion in pitch, they say, under certain conditions. You always have to consider specific flight profile, the altitudes used, and so forth, to determine exactly what some of these vibrations will be. I do have some basic vibrational numbers, however.

DUNN; Well, these other ones are the ones we need to design the heliostat. We know what the heliostat will do, and if we know what we're trying to take out, I can tell you how well we are going to guide.

MERCER: Well, let me give you what numbers I've picked up, and you can calculate some of this.

DUNN: On the 990 it's the Dutch roll.

MERCER: Yes, I know, and it may be so for this aircraft. At the higher altitudes you ought to have less stability, but at the higher speeds you're getting better dynamic pressures so that you may be able to hold against the instabilities. I'll list these data on the board. I hope these are the kind of numbers that help you out. (See Table 1),

DUNN: If I have the numbers right, it does.

BAKER: What's in the fuselage proper? Can that be made known?

MERCER: Yes; it's just fuel. The round portion of the fuselage almost from behind the second man back to the tail is all fuel.

TABLE 1

ATTITUDE STABILITY AND STRUCTURAL VIBRATION INFORMATION FOR THE SR-71A AIRCRAFT

Flight Control Stability Characteristics
(Maximum Values - Occurring less than 3% of time)

Axis	Angular Rate (Milliradians/sec)	Frequency (Cycles/sec)
Pitch	3.5	0.25
Roll	3.5	0.75
Yaw	1.7 3.5	0.50 1.00

Low Frequency Structural Vibrations in Vertical Direction

Excitation Input		Response Output	
Acceleration:	0.12 G	Rate:	0.76 milliradians/sec
Occurrence Frequency:	68% of time	Frequency:	2.3 cycles/sec

BAKER: Is there no way of stealing space out of that volume?

MERCER: No. In fact, it's sealed and has a thermal isolating system around it. It's used as a heat sink, and the bays must be insulated from it.

BAKER: I had a feeling they would have put the fuel in the chines instead of the fuselage. Just to get a space there for optical ....

MERCER: The problem is they wouldn't have enough fuel volume. They apparently can do enough with available working space in the chines and the nose section.

DUNN: Are the bays in the chines?

MERCER: That's correct; the bays open right into the chines. That chine cross-section that I drew was a trapezoid. Almost the whole width and length of it's bottom surface are used as doors to the chine equipment bays.

Table 2 and Figure 7 give the idea we had for flying in the 1970 event. This, again, is an example of a possible flight program. The idea is that we would join the eclipse track while climbing and accelerating right after breaking off with the tanker aircraft. The umbra would be behind, but catching up quite rapidly, and in the 15 minutes it takes to get up to speed we would pass through the umbra and be stationary on its western limb. We would get a very good pass right through the center during this 15 minute period. It would not all be at the maximum altitude since we would be climbing all that time.

Then, within the limited maneuvering capability at these speeds—there are 400 or 500 knots additional to call upon—we might work our way around the edge of the shadow doing work on the chromosphere. Ewen Whitaker is prepared to provide me with good data on the lunar limb for the particular libration conditions of the 1970 event. One might wish to know exactly where a Bailey Bead would be formed, for example, to be used for limb darkening studies. Or you can get to an area that you know is going to be devoid of any beads, over a nice, flat mare. This could be very carefully worked out in advance so that you would know where to go on the umbral boundary and what work to best do there.

TABLE 2

EXPERIMENTS OPERATIONAL PLAN

EXAMPLE FOR MARCH 7, 1970 ECLIPSE

Mission Phase	Experimental Objectives of Interest	Time Available (Minutes)	Altitude Range Feet (Km.)	Eclipse Path Location
A	1. Corona 2. Wide Field Work 3. Zodiacal Light	15	40,000 to 65,000 (12.2 to 19.8)	East Limb across disk to west limb
B	1. Chromosphere 2. Photosphere 3. "Limb Darkening" 4. Active Centers	20	65,000 to 75,000 (19.8 to 22.9)	West limb along limb to north limb
C	1. Corona 2. Wide Field Work 3. Zodiacal Light 4. Calibration Data	20	65,000 to 75,000 (19.8 to 22.9)	North limb to center and back out to either polar limb
D	1. Chromosphere 2. Photosphere 3. "Limb Darkening" (4. Active Centers)	30	65,000 to 75,000 (19.8 to 22.9)	Either solar pole limb along limb to east limb
E	1. Corona 2. Wide Field Work 3. Zodiacal Light	5	75,000 to 60,000 (22.9 to 18.3)	East limb across disk to west limb

Total time: 90 Minutes

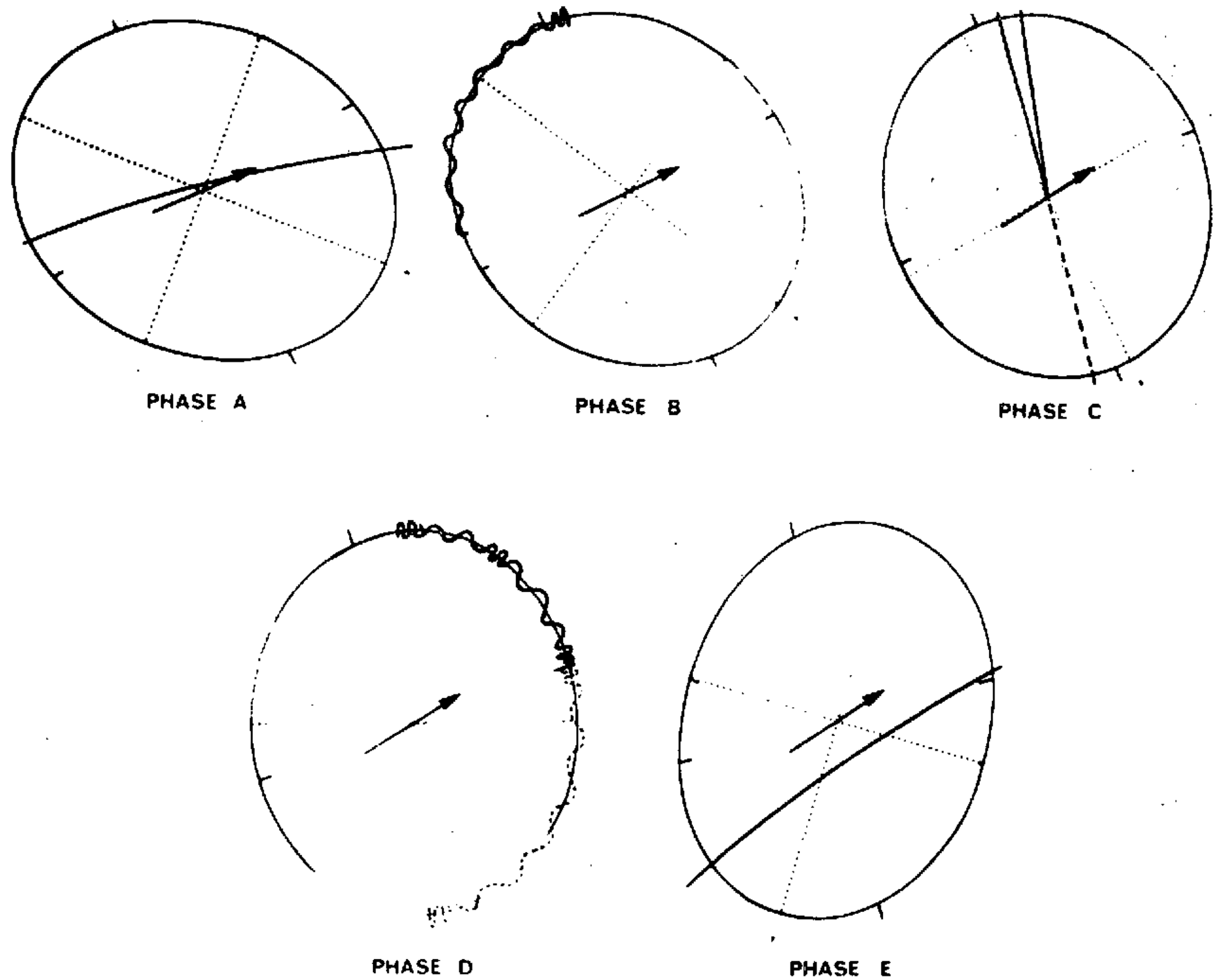


Fig. 7. — Flight paths of SR-71A aircraft relative to umbra during operations shown in Table 2.

In the middle of the flight, at some time near maximum elevation, we could schedule another slide in across the umbra and back out, spending time wherever we felt it would be important to study the coronal image.

Then we can come out to the edge at the southern pole point or back to the northern pole point and work our way over to the east limb. By the time we got low on fuel and had to leave, we would again get another pass through the center of umbra. By using operational optimization like this, we can get the 90 minutes. If we did not optimize and just tried to catch up and stay on the velocity profile, the time would be considerably less. Unless you do optimize the duration drops down to 60 minutes.

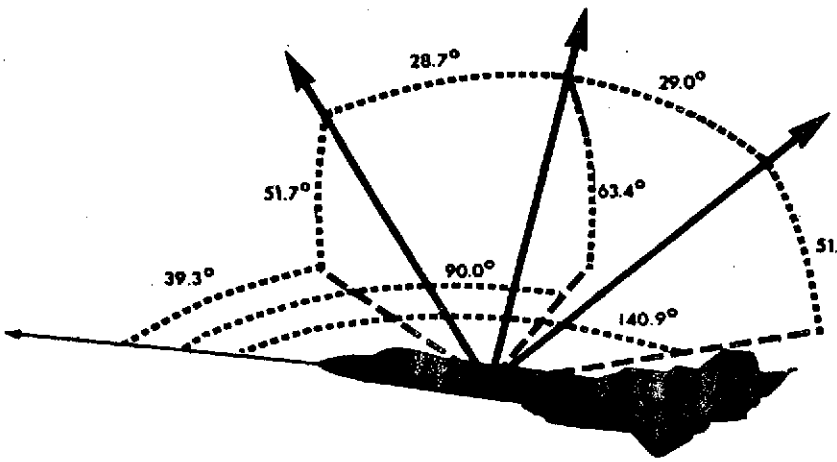
MANKIN: Is the limit the fuel capacity?

MERCER: It is the fuel capacity for this particular flight with its constraints of operating conditions, changes in altitudes, changes in airspeeds, and so on.

Figure 8 shows the changing aspects of the 1970 eclipse with respect to the flight direction of the aircraft itself. At the beginning of the eclipse it would be about 40° off the aircraft nose and about 52° elevation. You can also see what the maximum elevation and final values would be. The eclipse traverses a great circle route of some 60°. I think this figure may help answer the question that Mike asked. It shows what a wide change there is in relative bearing. If one tried to hold a constant bearing angle, you can imagine how short a time one would stay in the eclipse. I've also included other position and velocity data from some calculations that we've already made.

LIEBENBERG: What's the attitude change of the aircraft as a function of fuel usage? Is there any?

MERCER: Very little. It's a funny airplane; it flies and climbs at about the same pitch angles, or changes a couple of degrees, perhaps. It usually sits nose up about 6°. When you climb, it goes to, perhaps, 7° and in level flight is about 6°, then goes back to 5° or so during descent. That's about it; it doesn't change a lot. In this particular eclipse there would be little effect with respect to the change in heliostat angles required; that is, it doesn't cross-couple very badly with the gimbal angles.



POSITION INFORMATION VERSUS UT	1653	1738	1823
SOLAR AZIMUTH FROM A/C (°)	39.3°	90.0°	140.9°
SOLAR ELEVATION FROM A/C (°)	51.7°	63.4°	51.4°
A/C HEADING (°)	67.9°	60.0°	57.2°
A/C ALTITUDE (FT) " " (KM)	40,000 12.19	75,000 22.86	40,000 12.19
LONGITUDE OF UMBRAL CENTERLINE	109.96°W	94.6°W	81.71°W
LATITUDE OF UMBRAL CENTERLINE	6.60°N	18.1°N	31.85°N
UMBRAL VELOCITY (KNOTS) " " (KM/HOUR)	1465 2715	1311 2429	1656 3069

Fig. 8. — Aircraft position and observing data in March 7, 1970 eclipse for operations plan of Table 2.

Table 3 is a resume slide of the eclipses for the next 12 years. The velocities shown are the minimum speeds. The 1968 eclipse minimum speed is 1675 knots and the implicit picture is equivalent to taking a similarly shaped curve to that in Figure 2 with lowest value at 1675 knots. If an aircraft has a 2000 knot capability you couldn't spend as long a time in the 1968 eclipse, for instance, as in the 1970 eclipse. And, secondly, you certainly don't have the maneuverability. It would just be a hard task to stay up with an eclipse like this one in 1968 for any useful length of time compared to one at, say, 1300 knots. This is a very important reason why we feel the 1970 eclipse should be the target event and why we proposed in our feasibility study that it be used.

Now in 1972 there's an eclipse that occurs in Alaska and Canada, and it could be used very easily; but you note that the speed is 1600 knots minimum, and we certainly couldn't do as well there. The maximum elevation is 46°; so that if we use the same window we couldn't get the same usable aperture. It might drop to 8 inches or 6 inches and we would have to look through it at an angle even further off the normal. Certainly for polarization work that might be very difficult.

PASACHOFF: Your minimum velocity, of course, just depends on the latitude of observation. Because it depends on the component of the earth's rotational velocity subtracted from the eclipse speed, and is least when you're closest to the equator.

MERCER: That's right, and you see from Figures 9 and 10 that these are the better ones. In 1973 we will have one close to the equator; it's across the Sahara and is a good one because it's so slow. With a maximum elevation of 85°, however, we are going to have to look up through the window at an angle that we wouldn't like, because in the chine bay you can't get around undernearth the window unless you modify further out into the chine area. The modification could be done, if that's desired; without it you might still be limited to something with a 6 or 8 inch aperture. If you subtract 58° from the elevation angles required you will get the best look angles through the window.

The 1974 eclipse is a good eclipse. It's low speed; however, it's in Australia, and it would require that the left-hand side of the aircraft be modified rather than the right side. Both the 1974 and 1976 eclipses require left-hand modifications; so, if you already had the right-hand configuration, additional modifications would be necessary.

TABLE 3

TOTAL SOLAR ECLIPSE DATA FOR OBSERVATIONS FROM VEHICLES AT 70,000 FT. ALTITUDE FROM 1968 TO 1981

Date	Min. Vel. UT of $V_{min.}$	Solar Elevation Max. & at $V_{min.}$	Geog. Region Coords. at $V_{min.}$	Remarks
22 Sep. 1968	1675 Kts. 1126 Hrs.	19.2° 18.6°	Arctic-Russia-China 66.0°E, 52.0°N	Very low elevation, too soon for sci./diplom. arrngmts.
7 Mar. 1970	1300 Kts. 1127 Hrs.	63.3° 62.7°	Mexico-U.S.-Canada 97.4°W, 15.1°N	Excellent for North American observers.
10 July 1972	1590 Kts. 1950 Hrs.	46.5° 46.4°	Russia-Alaska-Canada 91.0°W, 62.2°N	Moderate elevation. Good for No. Amer. observers.
30 Jun. 1973	1170 Kts. 1136 Hrs.	85.5° 85.3°	Atlantic-Africa-Ind.Oc. 4.6°E, 19.0°N	Excellent but located in somewhat remote regions.
20 Jun. 1974	1220 Kts. 0446 Hrs.	34.5° 34.5°	Ind. Oc.-S. Austr. 103.1°E, 31.8°S	Low elevation over water. Remote but near Australia.
23 Oct. 1976	1280 Kts. 0511 Hrs.	70.8° 70.8°	Africa-Ind. Oc.-Australia 91.5°E, 29.6°S	Excellent and mostly over water but remote.
12 Oct. 1977	1125 Kts. 2034 Hrs.	67.4° 67.2°	North Pacific-South America 121.6°W, 12.9°N	Excellent and mostly over water; mainland & Hawaii nearby.
26 Feb. 1979	1505 Kts. 1649 Hrs.	26.1° 25.9°	U.S.-Canada-Greenland 97.2°W, 50.5°N	Low elevation. Useful for vehicles already modified.
16 Feb. 1980	1135 Kts. 0849 Hrs.	77.2° 76.9°	Africa-India-China 45.8°E, 0.7°S	Excellent but located in somewhat remote regions.
31 July 1981	1390 Kts. 0349 Hrs.	54.5° 54.4°	Russia-North Pacific 135.7°E, 52.7°N	Moderate elevation but long sci./diplom. arrngmts.

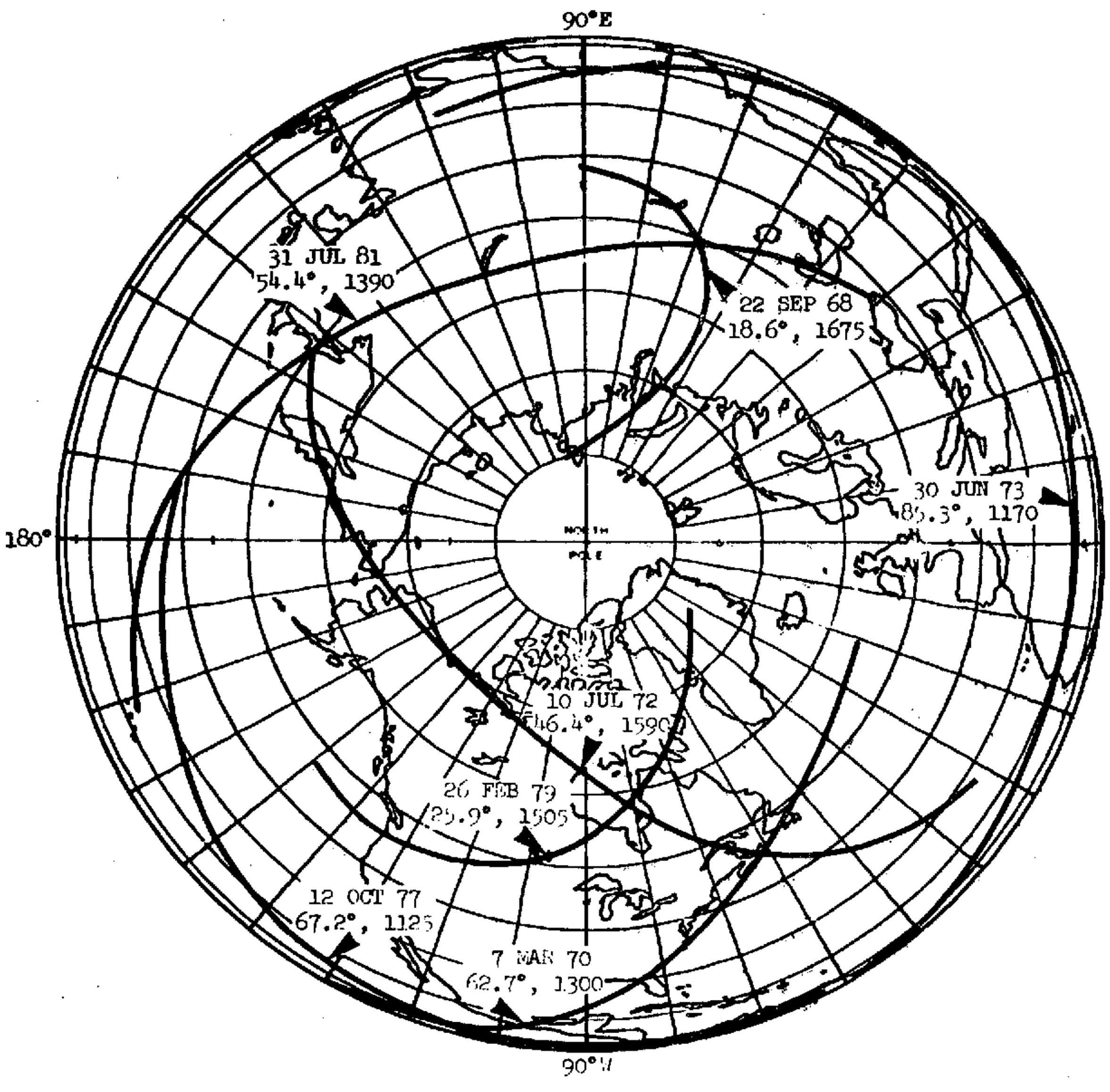


Fig. 9. — Polar plot of total solar eclipse paths in Northern Hemisphere during 1968-1981. Arrowheads touch tracks at points where velocity is minimum.

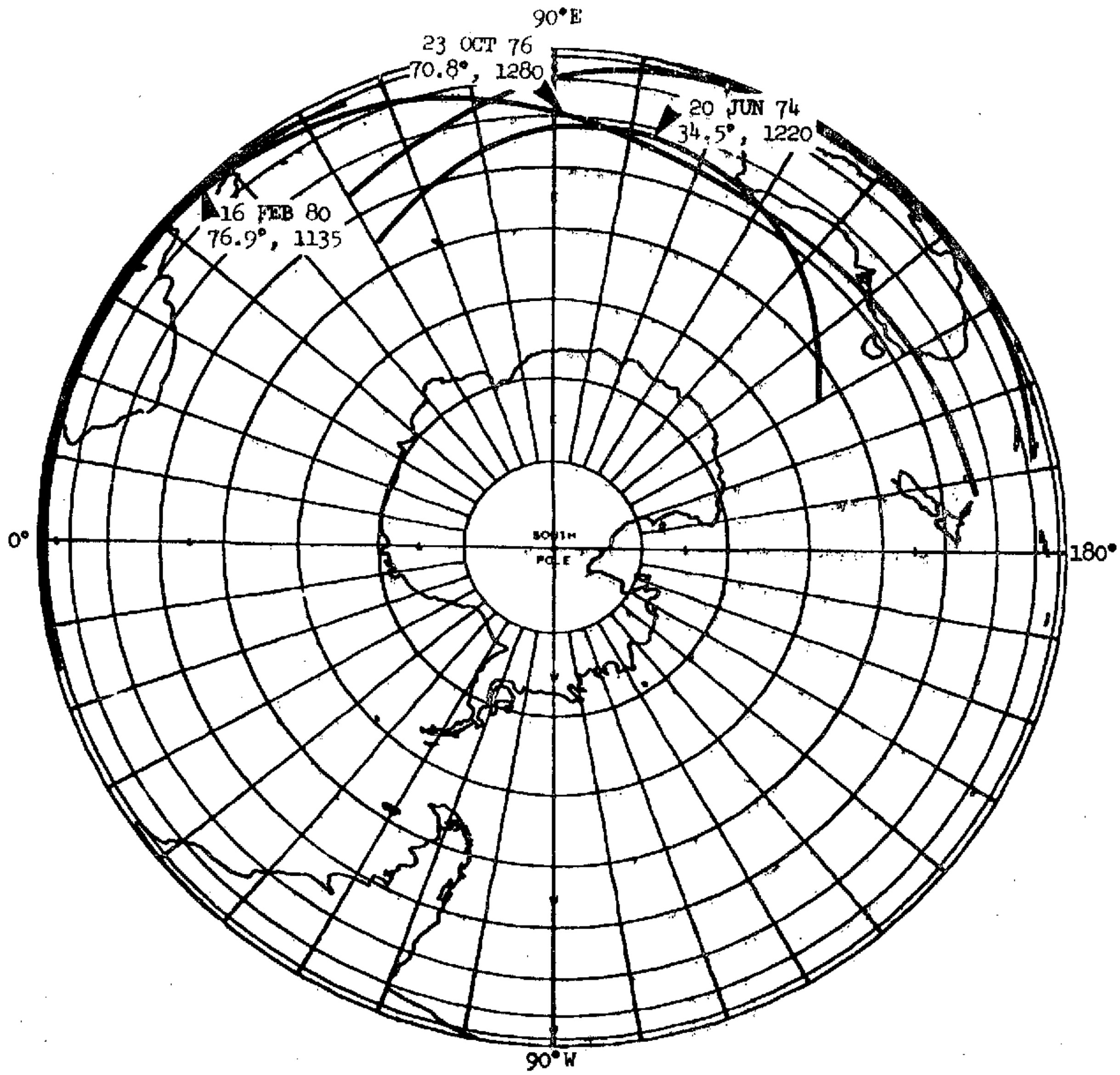


Fig. 10. — Polar plot of total solar eclipse paths in Southern Hemisphere during 1968-1981. Arrowheads touch tracks at points where velocity is minimum.

BADER: I think the 1973 eclipse is, too.

MERCER: No, the 1973 eclipse is in the Northern Hemisphere and cuts across the Sahara. The eclipse path on the earth starts in the Atlantic, goes across the Sahara, and into the Indian Ocean.

BADER: But the sun is way up north; so, if you fly from west to east, you have to have left side windows.

MERCER: Well, it's 85° elevation, Mike, but it's still off the right side.

BADER: The declination of the sun may be 23°, and the latitude of observation may be 15° or so.

MERCER: No. The Sahara is up 20° and more in latitude—30° even—so you're still north of the sun's declination, but not by much, of course.

In 1977 there's a good eclipse at very low speed, at very good elevation angles, similar to 1970, and it goes down the Pacific between the Hawaiian Islands and the U.S. west coast. The 1979 eclipse is a quick, highly curved path that starts in the Pacific, cuts through Washington state and goes up into Canada. It's high speed and similar in that regard to the one in 1972. In 1980 there's a good one, but it's quite a distance away from the U.S. Like the 1973 eclipse, it would require a long, long staging operation for the airplane. By then, though, we should know what we are up against. By 1981 we're back to Russia again as in the 1968 eclipse.

Obviously, the Northern Hemisphere is the most profitable place to be for eclipses over the next decade or so. The little arrows on Figures 9 and 10 touch the umbral paths at the minimum speed points.

Figure 11 shows a tentative schedule for attempting the 1970 eclipse, and it gives the key points in time. We would try to shoot for completing our feasibility study by July 1, 1968. If NASA or NSF or the Air Force is going to decide to do something with this airplane on the 1970 eclipse as a project it should be decided by about October 1, 1968. It's possible this can slide, but we will be cutting into the time needed to prepare. It depends on what experiments are worth doing and how complicated they are on this first attempt. If a box is used for the bay, as we here at Dudley

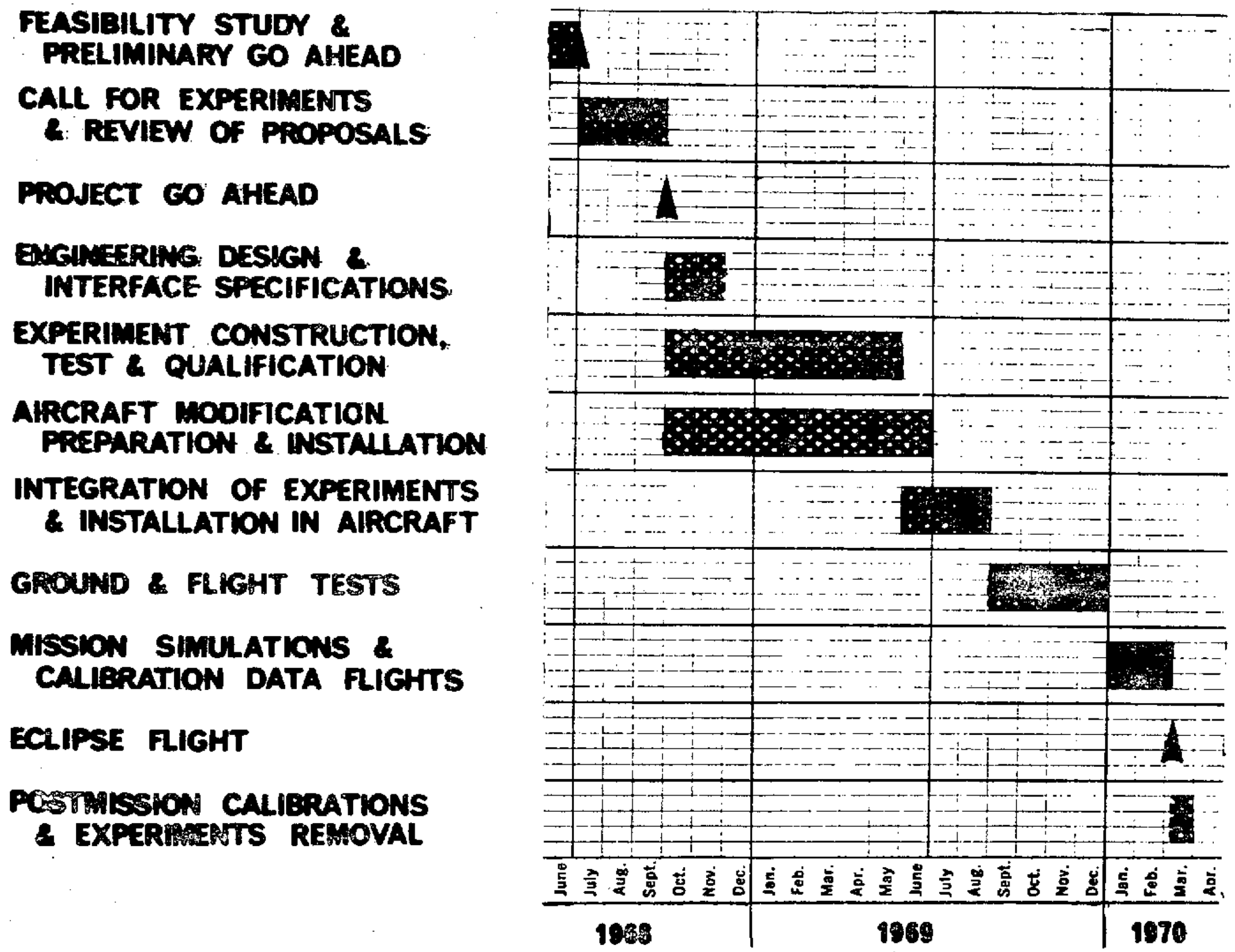


Fig. 11. — Most desirable scheduling to prepare supersonic aircraft for participation in March 7, 1970 eclipse.

have talked about, equipment work for the box, testing, and checkout could be done separately while the contractor is modifying the aircraft, installing the external window and equipment box hanger-type connection points. This would require a minimum of interface work which always takes lots of the time and coordination that can be horrendous. Then there will be some ground testing and flight testing time to check out some of these problems that we have already talked about, some practice runs prior to the eclipse flight, and so forth. After the eclipse, the box would be removed and the aircraft returned to use on other projects. If there are no other projects, perhaps we could continue with some non-eclipse work; it would depend on the situation. But after modification it would be possible to ask for the aircraft when it's not scheduled for other work.

LIEBENBERG: The initiation day of the project is dependent very much on the total funding available.

MERCER: It most certainly is.

LIEBENBERG: Under what assumption did you set the length of time for modification and instrument construction? Under the minimum cost expended, or what?

MERCER: Well, this, again, is a problem. Let's say somebody already has an experiment or has equipment already built up, then it would be largely a matter of modifications.

LIEBENBERG: The aircraft modification is longer than the experiment construction; so, never mind the equipment. Let's just look at the aircraft.

MERCER: OK.

LIEBENBERG: How firm is that number that you have obtained?

MERCER: The Air Force actually feels that they could do it in less time than this. Modifications for the test nose section, which is not now being used, could commence immediately and would not affect the aircraft's flight schedule.

LIEBENBERG: So for nose experiments, the lead time could be as little as six months?

MERCER: Perhaps so, perhaps longer; it would depend on the extent of those modifications. We would like to have the nose ready to go on the airplane by the middle of 1969, at least for some ground testing. But it might be that one could use dummy loads or their equivalents for such tests. So you might not have to have the experiments ready by that time if you could show that the interface tests faithfully reproduce the characteristics of the experimental gear.

LIEBENBERG: I'm just trying to develop how this schedule in Figure 11 is related to the use of the nose section versus the chine area or to the number of dollars that you have to spend.

MERCER: Until we get this answer from the aircraft contractor on what it's going to cost and the man hours, it's very difficult to answer the second part of your question. For the first part of your question, let me answer it this way. We feel that if the chine area modifications are as we have talked about them here with a window put in, hanger points installed, the flight recorder moved and its electrical lines extended, then, they can build a kit for these modifications. The aircraft can remain flying on other projects during all this time. The aircraft probably wouldn't be pulled out of the inventory until mid-1969 and quite probably several months later than that. The Air Force is talking about delaying the pull-out until about September or October of 1969, at which time the kit could be installed. So the aircraft might only be involved, not flying, that is, for about a month or two.

LIEBENBERG: What would be the last possible date that you could start a modification in the aircraft and make the eclipse date? That isn't the number you have on the slide, is it?

MERCER: No, but do you mean the last, possible date for touching the aircraft?

LIEBENBERG: No, starting with project go-ahead, what is the last date?

MERCER: Well, once you can define something, they could begin to design and build kits.

LIEBENBERG: No, no, you missed my point. Since these numbers are variable, presume I can talk you down to January 1969 for project go-ahead. Then you could still have an experiment in the chine area ready to fly in the eclipse, is that right?

MERCER: That's right, depending on the degree of complexity of the experiment and what the modifications are that are required for that experiment. For the numbers shown we used the case of more complex experiments. We assumed the maximum aperture that we could get; we based it on using the 14 x 29 inch window. If you do less with the airplane or don't require those things, then it will help to relieve the time constraint.

LIEBENBERG: Well, you see, the case I'm trying to make is that the likelihood of your getting a go-ahead by October 1968 is small. Your October start date really isn't the date which affects the science that is going to get done, should the project be approved later on.

MERCER: Well, obviously, there's planning and coordinating with what the airplane is going to be doing. If this isn't planned, if the Air Force isn't informed that we want the airplane at some particular date, if this is left wide open, then you take a chance that you may squeeze yourself too close. You may run up tremendous costs because they have to move faster than they thought to get the airplane ready. Things have to be set up in a permanent manner eventually but a target date for each phase of planning is essential.

LIEBENBERG: Presumably this is one of the parameters that you want to determine in a cost study.

MERCER: That's exactly right; because once we know the manhours it takes to do this work, then we would know in what order these manhours would have to be expended.

HEMENWAY: Bob, would it be fair to say that if you do simple experiments, not the optimum or maximum, that you could probably start about January 1, 1969?

MERCER: Sure, if you worked only in the nose, you could possibly get away with starting as late as March. Because the nose not now being on the airplane means that you could begin to do modification work very quickly and then plug it on the airplane.

PASACHOFF: What about the side bay, the chine area?

MERCER: The airplane wouldn't have to be pulled out to mate the nose and do the test flying until very late. Of course, how much flight testing they might feel would be necessary to prove out those windows, I couldn't say. It might mean a lot fewer hours with the nose modification as opposed to the big window in the chine, I just don't know.

PASACHOFF: May I ask Dr. Baker or Dr. Dunn what kind of glass or window might have to be put in to provide the stability and structure to take care of the heat transfer?

DUNN: It would have to be quartz with titanium frames around the windows.

MERCER: That's exactly what we were thinking. Of course, now, Lockheed said that for structural reasons they would have to have a minimum window thickness of five-eighths of an inch, but it would probably be pretty hard to work a flat that would be less than that and yet be that big, 14 x 29 inches.

BAKER: You can, but it gets pretty hard and costs a lot.

MERCER: I think they would want a minimum of five-eighths of an inch there for that big pane.

BAKER: For the heat transfer you might even need the double windows that we talked about. There's another thing to consider. There are materials other than quartz which have better stability when you include the change of index as well as shape. How bad and what they would be for various optical materials, I can't say right off hand. Quartz does have a dn/dT.

GEBBIE: So you have to monitor the temperatures.

BAKER: You have to know just how badly the windows are affected under these particular conditions.

deGASTON; That temperature effect may be worse than just the 250° on the glass, too, since the conductivity of titanium is probably considerably better than that of glass.

MERCER: Well, the air temperature doesn't get any hotter over the glass than over the titanium skin. The outside temperature should settle down to the 250°.

deGASTON: Then this cooling air that goes down the bays doesn't actually cool the titanium skin?

MERCER: No, as a matter of fact, in the bays there is insulation material around the walls. When I discussed the optical equipment box, I didn't mean to imply that it would be right up against that wall. The box is smaller than the bay, because there is insulation material in there.

PASACHOFF: Dr. Baker, do you know the transmission of a one inch or three-quarter inch thick quartz window?

BAKER: It's good down to about 2.6 microns; it depends on whether there is any water in the quartz. You can get materials with better transmissions further down from Corning.

PASACHOFF: How much further down?

BAKER: Several microns.

GEBBIE: You are referring to fused silica! People working in the infrared use "crystal quartz", which is much more transparent at 300 microns and completely essential at 100 microns. I doubt if we could live with even a quarter of an inch of fused quartz for infrared work.

DUNN: Down in the infrared you wouldn't use quartz at all.

SCHMALBERGER: We might use Cervit where you have a very good temperature coefficient. This is its main selling point.

BADER: The transmission is no good.

SCHMALBERGER: The transmission is good down to about 5 microns except for some water absorption at around 2.5 microns. With the latest compositions one can get down to about 4.5 microns with still usable transmission at 2.5 microns. I don't know about the optical quality going through it with this thermal problem. How does it compare to quartz?

BAKER: So far, I think, it's rather poor in its transmission optical quality. There's some Schott material developed for the infrared which goes down, I think, to 6 or 7 microns but I'm not sure beyond that.

GEBBIE: Generally speaking these things are not good for the very far infrared.

BAKER: Right.

GEBBIE: But polymers like PTFE (Polytetrafluoroethylene, "Teflon") possibly would do.

BAKER: What about temperature?

GEBBIE: PTFE would withstand that.

SCHMALBERGER: Bob will now take a minute to relate some relevant comments from the letters of Houtgast and Newkirk, neither of whom could come to the meeting.

MERCER: We had particularly hoped to have Drs. Houtgast and de Jager attend our meeting, although we realized that it would be unlikely due to the extreme distance and short notice. However, the group at Utrecht received the handout material and did discuss our proposed flight. Dr. Houtgast has conveyed some very useful remarks concerning worthwhile scientific tasks in a letter. I will quote the more important parts:

"We all agree that the planned observations are absolutely necessary for the needed progress in the investigation of the outer layers of the sun's atmosphere and related objectives.

I give you the following list of observations which we think are needed in this stage of solar research and for which the advantages of a very high speed, high altitude aircraft are clear, because of the relatively long observation time and the avoidance of disturbances by the lower atmospheric layers (scintillation, water vapour).

1. The intensity behaviour of interesting chromospheric emission lines in the infra-red; He lines at 10830 A and 2μ, the Paschen and Bracket lines of hydrogen.

2. The spectral region around the Balmer jump at λ 3640 A, at different heights in the high photosphere and low chromosphere; for this a spectrograph of high resolving power is needed.

3. The continuous spectrum of the chromosphere at different heights; one wants to know the intensity-λ curve over a wide range of λ.

4. Darkening at the outer limb of the sun at several wavelengths, from u.v. to i.r. Both methods, photoelectrically (T. de Groot) and photographically (H. Heintze), should be used.

5. Exposures of the corona, with filters and polarization optics, especially into the far outer corona in coronal streamers.

6. Fine structure photographs of the corona; comparison and changes in the structure over the maximum time during the flight, combined with

7. Spectra of the inner corona with high spatial resolution.

8. Every other spectral region, however small, for the determination of line profiles near the sun's limb, inside and outside; high spectral resolution with slit-spectrograph and therefore relatively long exposure times."

Dr. Gordon Newkirk, of the High Altitude Observatory at Boulder, Colorado, has also contributed very pertinent comments. In fact, his remarks are almost identical to some already made here, particularly Dr. Thomas' expressed concern for doing an experiment uniquely suited to the aircraft and doing that experiment well. Let me quote from Dr. Newkirk's letter which states in part:

"As you already mentioned, there are numerous research programs that could be carried out from this platform. Since I will not be able to attend your meeting myself, perhaps I could make a couple of comments regarding its utilization. If we learn from the experience of eclipse observation with conventional jets, there was a lapse of several years and a couple of eclipses before people really became convinced that these new-fangled gadgets were any good to the astronomers at all. I suspect that the same phenomenon will occur with this supersonic aircraft. It would appear that the best way to demonstrate its feasibility and usefulness would be to take as a first attempt an experiment which is both simple and which can be done only by such a vehicle. Observation of the corona or chromosphere in the infrared or extremely long duration observations of the corona or high angular resolution observations of the chromosphere all seem to fall in this class. It appears to me that the most important thing, however, is that the chosen experiment truly represent something which cannot be done as well from the ground or from conventional aircraft. Otherwise, your supersonic aircraft experiment takes on somewhat the character of going over Niagara Falls in a barrel."

MERCER: With that I would like to turn the meeting over to Dr. Schmalberger.

PASACHOFF: In summary, could you say a word about just where this stands with NASA?

MERCER: The only thing that now exists is a feasibility study; I am now working under a grant from NASA to look at the feasibility, originally, of using a YF-12A aircraft as an eclipse observing platform. We originally said the 1970 eclipse, but we have broadened it since then to include later eclipses and some non-eclipse work, and we have now moved to the SR-71A aircraft because we think we can get that. This study is about to draw to a close. We just about have the conclusions that we need except for these money figures which must come from the contractor. He knows the problems for this study, but we cannot provide these; they must be provided by the contractor. You have just heard the gist of what I will be sending to NASA. At that time we will be proposing to them that a project be instituted to use the aircraft, and at the present point, they have asked us to ascertain if possible, what significant scientific work we could do with the aircraft. We have called this meeting, therefore, to apprise you of what has been done and to elicit from each of you what further remarks you might like to make and which we would very much like to include (at your discretion, of course) as to the value of this new vehicle and what it could do well, what should be done, what should be emphasized, and so forth. Not only as regards the 1970 eclipse, which is certainly the first priority, but for all the work that we have discussed. I hope to close up and report to NASA by the middle of August. A digest of this meeting will be prepared and each of you will get a copy, as will the others who could not attend but who are corresponding with us.

At this point, then, it's up to NASA and other agencies who might wish to provide financial support for the science. In addition it's up to the Air Force to support the necessary aircraft operations. We've gotten encouragement from each of these groups separately and now we are trying to obtain joint agreement for project go-ahead. But for now it's just a feasibility study.

BAKER: Is it possible for us to get any cross-section drawings of the different stations?

MERCER: I have some which are more accurate than the sketches I have shown here that I may be able to supply you to work with.

BAKER: Would it be possible to have a nose cone of a different shape? Does it have to be that needle nose?

MERCER: Well, you do have to fair into those chines; and if you have to have that, you can't very well have a new shape for the nose cone. The needle nose is undoubtedly required to form the initial shock front ahead of the aircraft. I don't mean to discourage anyone, but, perhaps, if early flights prove successful, we could consider such types of changes for improving the aircraft's use in the far future. I do mean to discourage such changes for the immediate future, because I just don't think we will have the time for such things.

BADER: I have a feeling we don't have to be quite so vague about the costs. On the basis of my experience with the NASA 990, I would say that you're talking something like half a million dollars, outside of operations costs. What I'm thinking of is something like $150,000 for aircraft modifications and $250,000 for the experiments, and another $100,000 to buy the pilot a sandwich.

MERCER: Are you talking about a modification just in the chine area, just nose, or both?

BADER: I'm thinking of putting the window in the airplane chine and beefing up a couple of hard points to attach the instruments.

HEMENWAY: What are these numbers you're suggesting, Mike?

BADER: Well, obviously, I'm no expert on that airplane, but I'm thinking something like $150,000 to do the aircraft modifications and $250,000 to get a heliostat, a telescope, an attachment point beef-up to take 9 G loading, and, maybe, a little data reduction. Then you add another $100,000 to round it out to $500,000. This sounds like a good guess. For every experiment that you add on top of this--putting another small hole in someplace--you're probably adding another $100,000 per experiment beyond this. I think it's a reasonably good guess.

MERCER: I hesitate to hazard a guess, because it is just a guess on my part. I don't know how cleanly faired in with the external surfaces these installations will have to be, and things of this nature. It's certainly going to be different than the 990 in that regard, because it's supersonic and a titanium airplane.

LIEBENBERG: The factor probably goes up right along with the speed.

BADER: Three years ago the original 13 observation windows on the 990 cost, as I recall, about $80,000 or so. We did not have to take out any structural members.

MERCER: But you are not worried about external edges. Just a slight edge on one of these windows on the SR-71A is going to cause a shock wave for certain.

BADER: OK, so I'm saying that your one window installation, including the removal of one rib, is going to cost you something like $150,000, and maybe, you can throw in a couple of hard points with the window mount to save a little there. So, I don't think it's going to be very far off; it's a reasonable number.

HEMENWAY: Even for an airplane that is titanium, not aluminum?

MERCER: And remembering that external modifications must be flush?

BADER: Well, you see, we got 13 windows for $80,000.

MERCER: One point here, it might be possible—I haven't contacted anyone about this as yet—to get some NASA people at Ames or Langley, some aircraft structures people, to look at this and tell us what it would take to do the job. This would be one way to get estimates in-house, so to speak.

BADER: Let me put it another way: these are not estimates that you can propose as firm numbers to NASA, but I think they are useful numbers for Liebenberg and Goetz to get together on, because they should be very close. It's something they can start thinking about and take home with them.

HEMENWAY: It's obvious that the financial side of this needs to get very careful consideration and is, in fact, one of the reasons we wanted to get people together. I have a feeling that this might more appropriately come after we have explored more fully what actually is unique about this aircraft, if we are to justify going after the money for it.

JOHN C. BRANDT

NASA Goddard Spaceflight Center

As a first thing, I think I would disagree as a matter of philosophy. I think if you are going to talk about something which costs like an OSO satellite you certainly wouldn't want to run it for one experiment. I agree that, on the other hand, one should not go the other way and attempt to put too many experiments on board. I think that for the people who will be picking up the operational costs for this thing one had better have more than one experiment.

Now Dick Thomas as you know is interested in the chromosphere, but I would like to point out that there is another part of the sun which actually requires an eclipse study called the corona, and this "new and novel" piece of the sun is, I think, far more worthy of discussion than one might ordinarily have inferred from Dick's remarks. If one wanted to be "anti-Thomas", and I am not, it could be pointed out that one doesn't even need an eclipse to do those studies; and it seems to me that the point of this airplane is that you can prolong an eclipse ....

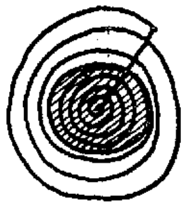
DUNN: That's not true at all, and I'll get to that; but you've got to have an eclipse to do the chromosphere.

BRANDT: Well he so stated.

WEART: I think that he was merely pointing out that one can do some of it outside of eclipse.

BRANDT: Well, anyway, ninety minutes is as much eclipse time as we have had in the history of astronomy. And my own interest on this is that I have always wanted to know the structure of the corona, and I'm afraid we still don't know this yet. If you go through the literature you can't find any photoelectric wide-band photometry of the corona that has an accuracy greater than about five per cent. With Livingston and Trumbo, a few years ago, I attempted to alleviate the situation but the weather over the eclipse site would not co-operate even though we had a nice long eclipse (this was the 1965 eclipse in the South Pacific) which lasted for four minutes. And that was great to have an eclipse that long.

Just as one possible thing that one could do for the corona that hasn't been done and which I think needs to be done would be



a simple—here is the moon—spiral scan out to about five solar radii. We have done this once and find that this accumulates something like 5,000 points along this scan; and by using reflection and transmission optics one can get ultraviolet, blue, and infrared (about 6800A) points simultaneously. This is the kind of measurement one can use to infer any sort of velocity and temperature structure in the corona. I think it would be a shame to devote the entire experiment to the chromosphere regardless of how valuable the data on the chromosphere are. It still isn't immediately clear to me that you need the eclipse.

HEMENWAY: John, isn't it possible to build something like this which would be largely automated?

BRANDT: Yes, sure. The only thing the observer would have to do would be to center this thing and tell it to go. Then after each scan he might have to re-center it.

HEMENWAY: Did you say this was a visual instrument? Narrow band?

BRANDT: Actually wide band—several hundred Angstroms wide, close to the B, V, R on the Kron system, but not exactly.

WEART: Couldn't you do this just as well using a balloon coronagraph of some sort?

BRANDT: Yeah, but you don't have ninety minutes!

HEMENWAY: How large an aperture would you need for this?

BRANDT: Well, we used a 16 inch aperture before, so a ten inch aperture will be only a factor two.

BADER: What was your comment with regard to "ninety minutes"? it certainly can't take ninety minutes to run a scan!

BRANDT: Oh, no, ninety minutes is given as the maximum total time available. The best eclipse you can get on the ground is something like four minutes, and this allows you one or two scans but with poor statistics. Give us ten scans, which we could pick up with a flat like this, and ....

BADER: You mean then that you're talking about something like two minutes per scan?

BRANDT: Yes, two minutes per scan—and there's nothing sacred in that, it just happens to be a convenient duration. We may have to scan slightly longer, however, to make up for the loss in aperture.

BAKER: What focal length do you think would be most useful for your scanner?

BRANDT: I don't have it here but when we did it, it was feet—many feet, twenty feet or something like that.

MANKIN: Is time the only advantage here, or do you also gain by being above the atmosphere?

BRANDT: You also gain from the altitude by knocking the sky background down as far as you can reasonably hope to get it.

LIEBENBERG: Between the ground and about 40,000 feet during an eclipse you get an improvement, that is to say a reduction, in the scattered light by something like a factor three.

BRANDT: Remember that anything you do with regard to the data with a view to determining temperatures or anything like that involves differentiating so you are really eager to get scattering down as low as you can possibly get.

DeGASTON: But what does this plane get you that a spacecraft won't get for you? Why not a coronagraph in space?

BRANDT: Well, I would hesitate to commit a whole spacecraft to something like this until I had proven that it was worthwhile, and....

LIEBENBERG: So far the coronagraphs that have been up there haven't done much external to five solar radii, have they?

BRANDT: Well, Tousey has said he's had a lot of trouble with those; and I have not looked into it in detail. But, again, I wouldn't do this on a satellite because this would involve you in a data processing problem that you wouldn't believe! And anyway, I'm looking for 10 scans and not 10^8 scans, which is what you'd get from a satellite.

At that altitude you can go almost twice as far from the disk. You should be able to get to eight solar radii, maybe ten.

GEBBIE: And what is the physics of what you are expecting to get?

BRANDT: The real physics is complicated but what you get is a two dimensional light distribution which you ascribe to the scattering of photospheric light by electrons, and this enables you to get the line-of-sight density of electrons. If you then make an assumption about spherical symmetry this give you the logarithmic gradient of the electron density which is proportional to the temperature.

BADER: There is some work, unfortunately unpublished, by Ed Ney and a graduate student at Minnesota which was something like this. They got some broad band pictures from our airplane at 40,000 feet with a band centered at about 8000A, and they were seeing out to fourteen radii.

BRANDT: That's interesting, and with a knowledge of the background at 40,000 feet I think we can make a reasonable extrapolation to higher altitudes. You recall that at five solar radii, give or take a little bit, you run into the F corona anyway. It isn't immediately clear that you are getting real coronal data beyond that point because then you have to subtract out the F corona, which is severe.

DeGASTON: I'm sure you must be familiar with Gordon Newkirk's experiment to go up on the ATM; and I'm curious: with the exception of the region within the first 1.6 solar radii, it seems you will be duplicating what he plans to do!

VOICE: But when do you think the ATM will go up?

DeGASTON: Well supposedly, as of now, I understand it's to be sometime during the first six months of 1971.

HEMENWAY: I think it can be startling how many times programs are forced to be postponed, and delayed, and so on. I wouldn't want you to hold your breath waiting for the ATM to go up.

BRANDT: Even if the time were not important, I would match this experiment with the cost of that one, any day. Let me emphasize that I do not think this is the only coronal experiment one should do—I am emphasizing that the corona is important. There are a lot of things to be done in the corona that have never been done properly. There is not extensive photoelectric photometry of the corona and this is the kind of thing that can be done on this eclipse plane.

BADER: It seems to me that you need a pretty long focal length for this experiment but you don't need a terribly large aperture, do you?

BRANDT: Not really—we would get into photon statistics trouble again.

HEMENWAY: Can you build your instrument such that it is able to take the vibrations and motion in the aircraft? Suppose, for example, that you had a time record of the motion; would this be adequate?

BRANDT: Yes. Even when we did this in the South Pacific we weren't sure that the program would correctly reproduce the spiral that we wanted. But we didn't care. All we wanted to know was: when the measurement was made, where was it pointing? In principle we don't care—as long as the frequency is not too high.

HEMENWAY: In other words the guiding problem on this experiment is a relatively easy one.

BRANDT: Yes, it's a relatively easy thing--just so we have a recording of ....

BADER: It's possible the Air Force may not wish to release that data.

HEMENWAY: But he might even have a recorder built into his instrument!

BRANDT: No, no, no. You don't have to tell me where my experiment is pointing relative to the airplane!

MENZEL: But you have to know where you are relative to the sun!

LIEBENBERG: In this particular experiment, you are integrating over time to get your data points and so the average effect may be the relevant datum and hence not classified.

MERCER: I'm not so certain that the problem is that serious. In any event, we may be able to arrange for the preliminary reducations to be made within classification constraints and then the final data released unclassified to each investigator for the complete study.

BAKER: Are you proposing that the scanning be done at the image or by the heliostat mirror?

BRANDT: The way we did it was we had a nutating flat, but this is a point which will have to be looked into.

BAKER: Because it might fit the present configuration rather well--with the ten inch aperture and twenty foot focal length, say.

DUNN; The focal length, though, is just a mechanical problem, right? Because you don't really need the focal length if you can get the light onto the photomultiplier.

MENZEL: Yes, I think you could do with a much, much shorter instrument.

BRANDT: Yes, I agree.

DUNN: Have you considered multiple channel instruments for your experiment? I mean, this is a ten channel instrument and it comes out to forty minutes, right? That is, on the ground—while it's a one channel instrument working forty minutes in the air.

BRANDT: I don't understand.

DUNN: Well, you're using one collector. I was suggesting you use a multiplexer of some sort. Use ten photomultipliers, and ....

BRANDT: We already use different photomultipliers and reflection/transmission filters to measure three colors simultaneously.

DUNN: These are the three colors?

BRANDT: Yes.

DUNN: But I was thinking of taking care of the speed problem with multiple systems. Nowadays it seems like everyone's going to a Channeltron, or a ten-cell, or even hundred-cell, system to beat the speed. I think the scattered light might be a problem though.

BADER: I would point out that the room available on this aircraft is going to be rather limited. If one wishes to introduce an experiment using full aperture there isn't going to be a lot of space left for other experiments.

SCHMALBERGER: Unfortunately, the large focal length is desirable for some purposes. And in our trial systems we've found that when folded beams are needed, they very quickly eat up the available volume. Getting back to this experiment though, do you require a minimum of four minutes at a given point—at the center of the umbral shadow, for example?

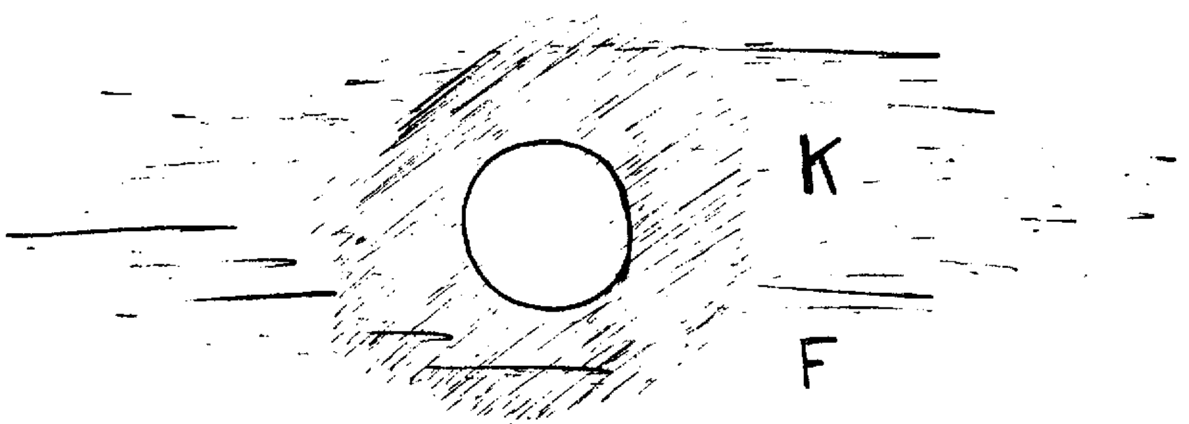
BRANDT: Yes, but it doesn't have to be precisely at the center.

DONALD H. MENZEL

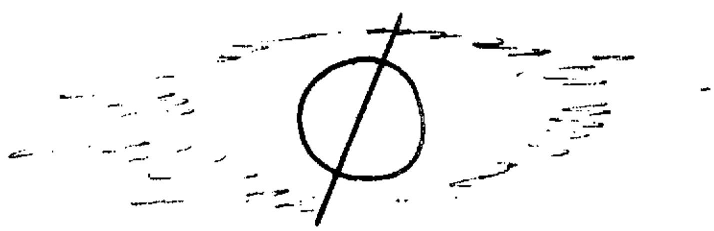
Harvard College Observatory

I think that John has given most of my talk for me! I do have a few additional points regarding this experiment which I think is one of the most outstanding problems and which I think is uniquely streamlined for this particular plane. It makes use of the height because of the darkness of the sky, and it makes use of the speed because we do get the longer eclipse—and I think that that's necessary since it gives us the longer duration. I think it's important, also, because working in the corona we don't have to have quite the accuracy of pointing that we need for some of the experiments.

There is one thing that John said with which I do disagree, at least in principle. He used the term "F corona". Now, there are two coronas. The K corona is supposed to arise from electron scattering and is the one which is supposed to have most of this structure and which contributes most of the corona that we think of



as corona when seen with the naked eye. But theoretically, if in the space between the earth and sun there are lots of scattering particles—dust particles, micrometeorites—then these should produce, in addition to this K corona, a corona which is called the F corona (for Fraunhofer corona because it shows the Fraunhofer spectrum) and it should be symmetrical. A model of this corona worked out some years ago by van der Hulst seems to have been just adopted by the whole solar community as the final corona. I have myself been making some observations, and I question on experimental grounds the accuracy of the van der Hulst model. I believe that he overestimates the amount of scattering in interplanetary space and that he overestimates the amount of the contribution from the F corona. Now I don't know what it is that is producing the Fraunhofer lines that have been recorded at so many eclipses from the ground. There have not been adequate checks in many cases; like putting the slit of the spectrograph across the center of the eclipsed moon to see whether you get the lines of the Fraunhofer spectrum in here, in which case it could be ascribed to scattered sky light, to which I think part of the phenomenon is due.



Now there are two ways, and I think only two ways, of separating these two coronas. One of them is tracing this corona out by some means, photographic or (preferably) by the electronic spiral scan technique that John has in mind, going out as far in radius as possible with a wide field instrument—out to at least eight or ten solar radii. Thus one can find out whether this ray structure persists out to these great distances. I've seen some of Tousey's photographs taken from rockets which have a portion of the field blocked out but you do see this ray structure extending out to distances of five to eight radii. I think that this in itself is evidence that my conclusions about the F corona are correct. Because otherwise this ray structure would not show up—it would be drowned out by the F corona according to van der Hulst's model. I don't think that van der Hulst considers his model sacred; for, after all, he had to put some numbers in so he made some guesses using imperfect eclipse data trying to fit something in at large distances with a forward scattering theory. So he did a nice piece of work, but I think this area needs to be studied and questioned. I think it is the most outstanding problem of the sun's outer envelope. I think that John has already made the point, but I agree with him, that the corona be the number one consideration. You can have the corona visible way out only with the dark sky available under these conditions of long duration and high altitude of the aircraft.

Now there is one further way of getting information in addition to the three colors—the gradients should be different in the three colors. But polarization is also an important characteristic, and

I should like very much to say that some additional filters ought to be made so that the polarization can be studied in the three colors: Red, Visual, and Blue. With two directions of polarization, and without polarization, that would make a total of nine different scans; and I think it would be quite possible to develop multiple channel scanners that would get this kind of information. I think it's far more important than the chromospheric experiment.

I'm sorry that Dick Thomas had to leave because I had a number of questions I wanted to raise. But I think that if his experiment does need high altitude it can be better done outside of eclipse, because I can see no advantage to the eclipse study except using the moon as a shutter. I think it is a tremendous waste of eclipse time. If the experiment is to be done I think it would be better done at a number of frequencies. This theory that he used, which I am quite familiar with, is a model atmosphere. It's very sensitive to changes in the model, and I think that the changes in limb darkening as a function of frequency are what are going to resolve the questions that he raised. It is a very legitimate problem, and all of us who have worked on the chromosphere have worried about it; but as an old chromospheric astrophysicist I would say that the corona rates great priority.

SCHMALBERGER: Are there any comments?

DeGASTON: It appears that Newkirk will be getting three polarizations to remove any degeneracy. Would you care to comment?

MENZEL: Three aren't necessary to remove degeneracy. You need either two or four. Two are adequate. I've just finished looking at some of the material on polarization from the 1966 eclipse. It helps to have four polarizations.

HEMENWAY: Do you disbelieve the measurements from the zodiacal light which seem to fit continuously to the F corona?

MENZEL: Depends on what you mean by "continuously"--it all depends on how you draw "that line".

BRANDT: Well, there's a gap in there, and if you draw on log paper anything will fit.

DeGASTON: Has anyone looked at the size of the F corona in various colors? You mentioned the earth sky scattering problem, and one would expect that the F corona would appear larger in blue light, then, than in the red.

MENZEL: No one's ever measured anything like this.

LIEBENBERG: People do measure scattered sky light at times of eclipse. Unfortunately, for example, the results of the 1963 and 1966 eclipses are miles apart!

MENZEL: All I'm saying is that I think that the contribution from the F corona has been greatly overestimated. And I think that all the discussion this question has raised typifies the current lack of understanding.

LIEBENBERG: One further point is that even if you put your slit across the moon you ought to see Fraunhofer spectrum still, because of scattering in the earth's sky. So you may not be able to resolve the problem immediately.

MENZEL: You can calculate that the earthshine is, I think, a considerably smaller contribution than the F corona. Of course, I'd like to see the spectrum of the corona done, too; especially, the spectrum of the outer corona.

BAKER: Over what range? The maximum?

MENZEL: The maximum! Just need one of those nice lenses you design that's complete flat from 12,000 to .... (Laughter).

HEMENWAY: Would Dr. Gebbie like to make a comment at this point?

GEBBIE: It does seem to me that if one goes into this new spectral region that there is a definite possibility one might somehow be able to answer the question about the chromosphere that Dick was raising. And let me say at this point, in agreeing with Dr. Menzel, that I don't think Dick excluded the possibility of a spectral analysis in anything he said. It's just simply that one wants to get both spatial and spectral resolution. The amount of information intake is finite and one is forced to apportion it spectrally and spatially. I don't think he in any way excluded that possibility.

MENZEL: Well, I wasn't really criticizing his proposal, I just said that I think that it isn't important for this particular vehicle.

GEBBIE: The only other thing I have to say about the possibilities for far infrared and submillimeter observations is that there may be some surprises. This is a point one can not afford to neglect. No observations at all have been made in this region; and, after all, science is a bit based on this: that we don't know exactly what we're looking for. If the amount of observation goes up in the way that the visible has since Newton, the surprises become fewer and fewer unless one does go to a new spectral region.

MENZEL: I think you have completely convinced us that this should be done from a high flying plane but outside eclipse. I think that there may well be some very interesting things come out of this, but it should come out of knowledge that we gain outside of eclipse first.

GEBBIE: I completely agree that some work should be done outside eclipse first.

HEMENWAY: Do you think that the operational costs for this project would be justified by the spiral scan study and the coronal work were they to amount to as much as ten million dollars?

BRANDT: Are you asking me that? The answer is, No.

MENZEL: I do, I say this because if this is going to be done at all; that is, if the plane is going to be flown at all, I think that this knowledge will have a tremendous bearing on solar physics in general. It's related to the solar wind problem, to problems of interest to NASA and others, and so on.

BRANDT: I agree, but I still think the price is high. NASA could put up nearly a whole OSO for that.

HEMENWAY: But, John, how do you feel about the fact that the plane could be used for a whole series of eclipses and that different experiments could be carried at the same time: Does this alter your opinion?

BRANDT: No. Because the total cost is in the airplane and the fuel.

PASACHOFF: On the other hand, if the plane was not engaged in carrying solar instruments it might simply be up flying for practice that day.

BRANDT: Well if you want to look at it that way it's a different problem.

BADER: I think that is a good point. There are various reasons why the planes might be flying at any given time. I think that the whole costs should not be ascribed to the experiments.

LIEBENBERG: I think the important point being overlooked is that the performance of this plane for an eclipse is simply not yet matched by a satellite, and particularly so for the far IR and good photoelectric photometry of this intermediate corona.

(There followed a near unintelligible exchange among several present concerning problems of coronagraphs in satellites and balloons. Liebenberg has reported that the exchange alluded to occulting disk and alignment difficulties, and local vehicle atmosphere problems, in satellites. These problems, he added, have been solved in the case of the natural eclipse. Eds.)

JAY M. PASACHOFF

Harvard College Observatory

I would like to say first that I think it would be a mistake to make a ninety minute scan from a fast plane at a total eclipse of the sun without devoting a major fraction of the time to a very sensitive outer coronal experiment. A couple of things: the polarizations are very important, and I would also stress that the rapid, extreme reduction in the background in the infrared means that it would be very important to get an infrared color in addition to the normal colors. If we could get one at two microns this would give a factor of five in wavelength compared to the blue, and this could be useful in discriminating among theories. There is a third method for disentangling, as you know, the F and K coronas, having to do with the depths of the lines observed. So it would be very important for this, and other reasons, to have a spectrograph taking spectra of the outer corona as far out as we can go and with the longest exposures we can make for this purpose. Then there is the Blackwell gap. Those of you who have seen the paper recall that there's a line here and a line there with a gap between about fifteen and fifty solar radii, between the outer corona and the inner zodiacal light, which still remains to be filled with observations and we certainly ought to do it.

Now let me say a word about the outer corona itself, the so-called F corona, which we've been saying let's strip off and throw away and see what's really around the sun. Let me just point out that what we are throwing away is itself a useful physical quantity, the result of scattering of sunlight from particles mainly between the orbits of Mercury and the earth. If we can get observations of the polarizations at very widely separated wavelengths (if we are using the spiral scan experiment, we can easily get an infrared photometer) then we can use these various differences to gain information about the scattering properties of these particles which fill interplanetary space.

The infrared is something that comes to the minds of us all. I know that at our observatory Drs. Goldberg, Noyes, and Dupree have been talking about getting spectra in the near infrared. This ties in with some discussions I had some years ago with Dr. Pollack and Dr. Menzel about observing the transition zone at the 1965 eclipse. The transition region ought to be about a couple of seconds of arc, if you want to have the corona extending down to the tops of the spicules. It is not satisfactory just to observe the transition zone with low spatial resolution; you want to find out what it actually looks like. Now there are various ions of intermediate stages in the transition zone, say FeVI and FeVII, which are just not observed because the volume in the transition zone is too small. With the capabilities of this experiment, with the long time for exposure and the dark sky, we could perhaps observe some lines and get some information about this layer of the sun about which literally nothing is known. I mention that this is certainly something that ought to be seriously considered.

We have spoken about using the moon as a shutter. I would also point out an additional use of the moon as a knife edge. If we can stay in the center of totality for a long time we can, of course, stay at the edge. And, although "chromosphere" has become a nasty word in this meeting--possibly because submillimeter is getting into radio astronomy, and most people here are optical astronomers, and ne'er the twain shall meet--there are a number of important things that can be done about the chromosphere and about the fine structure of the chromosphere with the unique capabilities of this experiment. If we can observe the so-called flash spectrum for a while we can get greatly improved height resolution. We can, for example, use a slit spectrograph if we like and know exactly where we are and not have to worry about the problems of integrating over slices from the moon upward that one always has to do with eclipse observations. One can take time series, because we can sit in the chromosphere for a long time. And let me mention that if we can get ninety minutes of corona and compare that with the four minutes that Dr. Brandt got at his eclipse (which sounds like a large ratio) let us remember that we get two or four seconds of flash spectrum on the ground at each eclipse. With proper guiding we could get ninety minutes of flash spectra! This is a remarkably exciting possibility. We could have problems in fine structure with seeing, and I'm particuarly interested in knowing what the seeing will be right outside this plane. This will have to do with the kinds of flow of air across the plane, whether we'll get a lot of eddies, whether laminar flow will develop around our window (we hope), and so forth.

We have one other great advantage of being at this height in that we can be above a lot of the scattering background and can get some continuum observations of spicules and can observe some fainter lines in spicules. In fact, very few lines have been observed in spicules--perhaps fewer than a dozen, including those of only one ion, calcium (strontium lines have been marginally "found" in some unpublished results but no others). It seems that the spicules are certainly linked to the magnetic fields, or are guided by magnetic fields, and it would be very interesting to see just how the ions are moving in the spicules and are linked to the magnetic fields. All these things are related to just seeing different elements in different ionization stages. We can see these new things only with this setup.

Lastly, we can make simultaneous observations over various levels. That is, we could look at things over a wide dynamic range. We could use film like EG&G's XR film with a dynamic range of a million, although there are then other problems with disentangling what's going on. At the very least, we could take a graded sequence with different kinds of film, perhaps different cameras, at least different exposures with short time periods, looking at the structure of the sun in one continuous swoop from the spicules up through the lower corona to the upper corona. And if we could do this with a little bit of time resolution, taking a time sequence, we could perhaps follow the entry of energy or matter into the corona from the chromosphere. Thus perhaps we could follow a disturbance coming up from the chromosphere into the corona and see exactly how these regions are dynamically linked. So some kind of motion pictures over a wide dynamic range of these kinds of phenomena could also be very useful. These are some things that I think ought to be considered for some of the rest of the time that's left after our coronal observations.

SCHMALBERGER: Do we have any comments on Jay's remarks?

MERCER: I have one I would really like to ask Dr. Baker. A lot of people have expressed interest in polarization, so I would like to ask you: What are the polarization problems we would have with the window? We would be looking anywhere from, say, zero to thirty degrees off the normal. What problems would you envision owing to heating and so forth?

BAKER: Well they may be rather severe because with heating there will be strains in the material. I think it could be a real problem.

MERCER: I have been thinking of polarization and ways to study this, and I was thinking of using the nose section. Some persons have asked: Could you have protrusions and openings? While we could never allow a continuously open window, short duration openings to change something around might be possible. Even if a shock wave forms during the changeover, when you get through things must be flush again. This may be possible but, on the other hand, there may be only a short time interval that such a window in the nose is aimed in a preferential direction.

PASACHOFF: If you measure intensities, even intensities without polarizations, and you are looking at something polarized through a polarizing window, then you are going to have lower values of intensity.

BRANDT: I should think you would have less.

LIEBENBERG: Well, the other point is that during the eclipse you're changing the angle by a significant amount due to the bearing of the sun with a heliostat inside that is guiding out the short-term fluctuations, and that is introducing changes in your polarization, as well. And if you are operating at these kind of angles, it looks like you are not only changing these angles but also you will be working in a region in which these things are pretty sensitive.

BAKER: Well, maybe the characteristics of the window could be calibrated against temperature and strain in some way. It may be also that the window might best be made of homogenized Ultrasil, which would give us the best change, I think, at least for polarization.

MERCER: I was considering possibly that something could be done in the nose area this way, although you might not use a heliostat behind it, because again we'd have all the problems Dr. Liebenberg brought up concerning reflecting angle polarization problems.

DUNN: Coelostats may not be as bad as they used to be. In the green, for example, OCLI has this very, very high reflection coating now which they claim has virtually no polarization even at high angles.

BAKER: Over what spectral range?

DUNN: This one was best at about 5,000A. It gave out going into the blue, unfortunately.

SCHMALBERGER: A point with regard to the XR film is that you get the dynamic range all right but you do so at the expense of spectral coverage. That is, there are three density ranges in the film which give you the latitude but these ranges are sensitive to different regions of the spectrum. So for continuum observations it will be valuable but with a source radiating lines it may cause some problems of interpretation.

MENZEL: But I was told that that is not the case, and that the film itself does not have separate sensitivities. I asked that question and was told, "No", but I may have misunderstood; although, I don't remember what the rest of the answer was.

BAKER: This would imply some photometric uncertainty in the pictures you've taken.

PASACHOFF: Perhaps one could do better with a small battery of cameras for different wavelengths.

MENZEL: Wouldn't there be some way of calibrating this by allowing your light to go through a beam splitter? You could measure both beams and that way tell whether there is a change of polarization or not.

BAKER: I think we could try something like that. And it had best be tried quite early!

MERCER: I've talked to people at the Visibility Laboratory in San Diego. They did an experiment where they were concerned with scattering of light off a window, and this brings up another question: What is the scattered light problem with that outer window? The same problem occurred on their experiments in the Gemini program. They measured the scattered light by photometrically viewing a light trap through the window on the outside of the spacecraft. Another thing we might ask is: How constant do you think it might be? Say you made a measurement of the polarization—although I guess, it would really be a study of the gradients across the window—and see edge effects and how deep into the center of the window these things go. Tests like that might tell us which times on the flight profile we'd be looking through the most constant region of the glass. That time might dictate the mission phases, so to speak.

BAKER: It isn't just the polarization either! It's the variation of the index of refraction; and this varies with material, too.

BRANDT: Perhaps someone here knows the answer to this: Just what is the expected polarization of the K corona at two solar radii?

LIEBENBERG: Well, polarization approaches roughly one for the free electron scattering component at large distances, right? What you're really asking is: What is the fraction of the total continuous spectrum that is scattered by the free electrons?

BRANDT: I think that is a useful number to know; for, after all, this is the number you're going to be shooting for when you ask whether the glass is, say, order-of-magnitude the same or, e.g., a factor of ten less.

MENZEL: We have van der Hulst's calculations for the K corona in Kuiper's book. From there, the K corona goes up to 65% at 2 1/2 solar radii.

LIEBENBERG: I think that's very suspect, isn't it?

MENZEL: Well, of course, that's for the K corona alone; and van der Hulst says it will be dropped about 27% due to the F corona. I have found, in general, that the corona shows higher polarization than he predicts.

PASACHOFF: This is a seventeen year old datum—has it been updated?

MENZEL: No, I don't think so substantially. This is regarded as if it came from Heaven.....(Laughter).

DUNN: Wasn't he at Harvard at that time.....(More laughter).

MENZEL: I don't know—it says here words to the effect of: Courtesy of photographs taken by R. Dunn at Harvard Observatory. So even if it did come from Heaven.....(More laughter).

BAKER: If you wish to get both high resolution and high efficiency on your flash spectrum I think you are striving for something very worthwhile; but some of the equipment problems may be formidable.

LIEBENBERG: I think a point that might be made is that the guidance for a slit spectrograph is required to be of the same order as the resolution that you can produce by using the moon as a shutter.

BAKER: I think the appropriate thing is to think in terms of a moving film spectrograph.

MENZEL: I haven't devoted too much time to the chromosphere, because the chromosphere is pretty thin and the guiding ....

PASACHOFF: But everything that goes out has to go through it!

MENZEL: Agreed, I'm simply noting that as things open up one may be swamped by even a little patch of photosphere.

MERCER: Well, of course, we can slide into the proper position, and with a minimal positional change, we could hold on some level very accurately.

MENZEL: Of course, you've got the problem here of the way in which the moon covers the atmosphere. A mountain on the moon can make a difference of two to three seconds in the actual time that the flash would appear.

WEART: We know what the edge of the moon would look like for a given eclipse.

MENZEL: All right, but you can't go up there and shave it down to make it smoother!

WEART: No, but you can deconvolve the influence of the lunar limb after the fact.

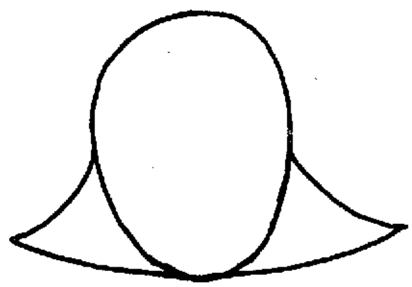
PASACHOFF: I think that this exchange overlooks the solar atmosphere itself—at least if one is interested in a region as high as 6,000 km above the limb—for, then, the few seconds you might be off are unimportant.

MERCER: Remember that we will know pretty well what the periphery of the moon will look like in advance so that we can be careful to choose a region of maria rather than a mountainous area, at least to the degree that that will be possible for any given eclipse.

We could arrange that a slit spectrograph look at a region above a pretty flat area chosen in advance.

BAKER: Is it possible to join the two chines by a tube through the central portion of the fuselage?

MERCER: That was one of the first things we looked at. The fuselage extends completely below the chines in cross section. We can describe this as a sort of oval for the main part of the fuselage with



the chines flared out on either side. The oval portion contains fuel, and insulation material to separate it from the chines.

BAKER: What I'm really asking is: Can we put, say, a ten or twelve inch diameter hole through the central area to get high dispersion with less folding?

MERCER: Just to put a tube through would not sacrifice much fuel so that this might be possible on future flights with the type aircraft. At this stage it would be what is termed a "major modification" but it is definitely something which we hoped for in the future.

BAKER: Another point. There's a question in my mind of whether or not it might be desirable to have a type of photography on the corona which would be like a spectroheliogram covering about three degrees, maybe four. This way one could get, say, five, six, or ten lines and simultaneously build up images in selected coronal emission lines.

PASACHOFF: With interference filters?

BAKER: No, done by spectroheliographic techniques but with wide field optics instead of the optics one is usually restricted to.

MENZEL: I think it would be interesting but I think I would give priority to the coronal spectrum. I'd like to get the spectrum with some short, medium, and long exposures. I'd like to get spectra showing the continuous part of the inner corona for a comparison with the kind of distribution in the outer corona. That has never been done. And it's quite important, because, theoretically at least, there's a difference between the two.

VOICE: Of course, the line intensities fall off rapidly as you go out.

DUNN: I took some pictures at, oh, just a half a radius or so, at about 36A/mm.

MENZEL: What lines?

DUNN: Well, all we really got were coronal continuum and scattered light in the H and K lines, which also showed some absorption.

RICHARD B. DUNN

AFCRL Sacramento Peak Observatory

I want to stress the chromosphere problem again, a little bit, to give you some idea what might be done there. This is a bit bold, I guess, because as Gebbie says when you get wrapped up in Dick Thomas's problems you really get wrapped up.

This experiment goes back to the 1958 eclipse, then the Canary Islands' eclipse in 1959, and then finally with success in 1962. Basically we used two large spectrographs; although originally we had three, with the third intended for line profiles. First I'll talk generally about the two spectrographs which were successful. Here we were trying to measure integrated brightness above the limb of the sun using what Jay called the knife-edge effect of the moon moving across the sun. The characteristics of that system are given in Table 1, where I include some of the numbers for the profile spectrograph which, recall, was not used at the 1962 eclipse.

In the integrated brightness experiment there were two cameras you will note. There was a grating flip between exposures on alternate cameras so that film was being transported in one camera while being exposed in the other. This resulted in a height resolution equivalent to time intervals of about three tenths of a second, with about two tenths of a second exposures.

A point on the film size, too. It is pessimistic, because we actually had three exposures on each frame in order to cover the full anticipated brightness range; but we only used the center one because the cameras weren't quite fast enough to really burn in the second and third exposures, although the second exposure did show lines like H and K, and H_α quite nicely. Finally, the image sizes are elliptical since we used some of Jack Evans's optical techniques to compress the image. This was done by coming onto the grating at one angle and coming off at another.

Now the speed of the eclipse is of the order 200 to 300 km/sec. So with three tenths of a second between exposures, we get something like 60 to 80 km intervals for data points. Of course, we are interested in the low chromosphere, which is all over in 500 km; and in 1500 km or so you've gotten just about all the curve you're going to get, so you can see that 1500 km divided by an average of, say, 75 km per point will give you something like twenty points.

TABLE 1

ECLIPSE SPECTROGRAPH DATA

	Integrated	Profile
Aperture	9 in	12 in
Focal ratio	f/18	f/12
Focal length	75 cm	200 cm
Dispersion	6 mm/A (UV camera)	2-3 A/mm
Resolution	80,000	250,000
Spectral Range	UV 3500-7000 A IR 3600-8800 A	4000-6000 A
Exposure	0.22 sec	0.5 sec
Ht resolution	0.3 sec	100 km
Film size	6 in x 24 in	6 in x 24 in
Image axes	2 in (major) 0.66 in (minor)	2 in (major) 0.2 in (minor)

Now I don't think there's any point to doing this experiment again from an airplane. The wavelength region is perfectly accessible from the ground. Menzel did it back in the thirties and it was done at the 1952 eclipse quite beautifully, with a lot of theses coming out of that one. The 1962 experiment was successful; the data is coming out, and the information is there. So I think one would have to put moderately low weight on this.

The thing we were not successful with was the experiment for the line profiles as a function of height. You see, in this one you just take a part of the sun, and as the moon goes across the sun you integrate over all above the exposure layer. This is the jumping film technique. (Menzel's original experiment used a moving plate, and there's advantages to using that, too.) You, then, have to take this curve of integrated brightness versus time and put it in the form of an integrated brightness versus height, and finally differentiate this to get back to intensity versus height; and then, presumably, you can draw your conclusions from that.

WEART: What was the lateral scale in the image?

DUNN: It wasn't too bad. You see, this dimension--major axis of monochromatic image ellipse--was two inches; and so, we felt that we had a chance of seeing what, at that time, people were calling spicules. In other words, if you took a spectrogram with a small coronograph and you got these "blobs", and you were pretty sure you were well above the top of the chromosphere, you would resolve some spicules, and that was one of the parameters we wanted--to be able to get down into what one was calling spicules--then.

VOICE: But you don't think you saw them?

DUNN: Yes, I think we saw them--at least we saw what they were then calling spicules. What I call spicules are the things that you take on a nice ten or fifteen inch image, working off the slit jaws with the slit right in the spicule. This would be more convincing, but you're probably getting the same thing if you take the eclipse and catch the moon when it is definitely at the top of the chromosphere--you're undoubtedly getting nothing but spicules there after about 10,000 kms. They are just a little more smeared out than one would like.

So that's the basic problem. Now, if you want to extend this to line profiles, then you've got to get enough dispersion to resolve the lines; and most of these lines in the low chromosphere are very narrow—on the order of a tenth of an Angstrom— so we hoped to do something with the helium lines which are somewhat wider. We, therefore, designed a spectrograph with a system that had the characteristics given in the second column of Table 1.

Here, Jack Evans ran the aperture up to twelve inches. Incidentally, all three of these instruments were fed by a single sixteen inch mirror. The spectral resolution is based on the length of the grating. The spectrograph image quality was not as good owing to troubles with the correcting plate and other problems related to transmitting Schmidt optics. The free spectral range was cut short of covering the full Balmer series because the Schmidt wasn't wide-field enough; so it was aimed, then, at the wealth of helium lines in about the 5,000A region. For this spectrograph, the image was compressed in the ratio ten-to-one; and the idea here was to run the whole chromosphere through the slit and have it be only twenty microns on the plate, you see. This is because it's very difficult to guide anything well. You've got seeing working against you on the ground even during the eclipse. The only way you can really get the height resolution is to take the whole blob in and then try to differentiate the curve. So we ran the entire chromosphere through this slot about 0.2 mm wide, and it was then compressed by the ten-to-one factor to twenty microns on the final image. In this way the whole chromosphere was supposed to be on the same order of, or less than, the instrumental profile of the spectrograph. Here, again, the number of points that you can hope for is approximately—well, for 1500 kms—about fifteen points. And you've got to remember that you're going to differentiate this thing later, so you need high accuracy to do this. Now, this experiment, I would say, was unsuccessful. It was slow—as I recall we needed another factor two or three in speed—and we didn't have as many points as we really would have liked. You see, you could get another factor of almost two with the other spectrograph. You didn't really have as much resolution as you'd like to have in order to get the tenth Angstrom lines, so that you were sort of limited to wider lines of, say, a half Angstrom wide. And this particular spectrograph was very soft.

This instrument could be improved immensely for an airborne version like you're talking about—only because of the long observing time involved. For instance, if you want to talk of a ninety minute eclipse and say we're stretching a four minute one to ninety minutes then we have a factor of something on the order of twenty or so in time. Back here at 200 to 300 km/sec we went through the whole region we are interested in in something like fifteen to twenty seconds, including spicules and everything. Up here now, we could devote twenty times that to each limb so that now we're talking about 300 seconds. The only time that we really need to run this thing during eclipse would be for this 300 seconds unless you want to re-start. If there is some way you could start the eclipse over and over again you could get more and more pictures all the way through. But I'm not familiar enough with the relationship of the plane to the eclipse shadow, and so forth.

MERCER: We can weave back and forth across the chromosphere for, say, several minutes, making several cuts back and forth through it. This could be done very slowly, and one could almost set the rate at which you slide over.

DUNN: You'd have to know exactly where you are on this whole thing because we are using the moon as a knife edge to know what the height is. So you have to know where you are in order for us to go back and do that. I don't know but what, when you stretch an eclipse that is four minutes long and originally had fifteen or thirty seconds of chromosphere time, that it's simply scaled up to a longer eclipse. I just guess we get something like 300 seconds.

MERCER: You get an advantage because, as I mentioned, you can stay right on the edge so that, in fact, when you match the speed of the eclipse you can have, relatively, an infinity of time. You can get a factor of at least a hundred in time on the chromosphere.

DUNN: On a ground based eclipse the problem is that if you have a very long eclipse then the moon is very large with respect to the sun and you only get a very short crescent. Is it possible to stay for the whole ninety minutes on the chromosphere? (Facetiously.) (Laughter.)

MERCER: No, it's not; but we could stay in the chromosphere for about 60 minutes.

DUNN: Well, I don't know how many factors of ten I could get but I assume we could get about 300 seconds. So, let's say I have that factor of twenty, and of course if that could be 200 we'd be that much better off. Then, if the aperture is about the same, one could work up the following system for the 1970 eclipse:

Aperture	12 in
Focal ratio	f/12
Resolution	500,000 max
Dispersion	0.5 to 1 A
Exposure	1 to 5 sec
Ht resolution	10 km
Data points	150

We assume that the motion of the moon is only about ten to fifteen km/sec. Note that with the higher dispersion there would be a factor of about two to four loss; and, also, that there is a factor ten in the exposure. The ten kilometer height resolution then gives us about 150 points in the 1500 km. Of course if you could get more time on it you could do even better.

Now there are two aspects of this. This is what I would call a very sophisticated experiment to hang on an airplane and do right. You'll get some pictures maybe but about half the work is calibration and trying to see what you've got. The other thing one would have to review on this is: What are the line profiles going to do for you? Back in 1958 people seemed to think they would help some; nowadays, people who have been looking this over haven't been demanding: Look, we've got to have this thing done! So I think that before one would enter this you'd have to talk to people like Don, here, Athay, and Jefferies, and see what we're going to get (especially in the light of the H and K profiles the latter are working on). Also, you're still integrating over the line of sight. A lot of these things are optically thick, and there are a lot of blobs that you are integrating over.

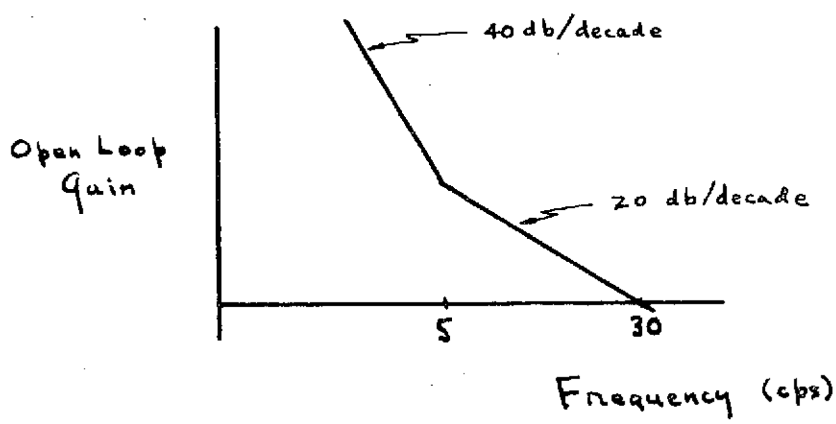
MENZEL: You also have relative motions with lots of Doppler shifts.

DUNN: Yes, I think that will all have to be reviewed. Now, I could picture the instrument but it would not be a trivial job. You are driven to an echelle right off the bat because you want this high dispersion. So you're going to have to take a small part of the limb and use this echelle. You'll still need this compression to get the entire chromosphere into the thing. So I think you'll need thirteen feet of optics before you get a reasonably sized image for the available area. You'll be working with square plates or square film; but you'll be better off on film transport since you won't have to transport as fast, and so on. I really don't think it ought to be the first experiment to go into an aircraft like this, and I think it would all have to be reviewed from the scientific aspect. But if you want line profiles in the chromosphere it's the only way that I can think of for getting the height resolution at the same time that you get the large dispersion.

I did take a look at those vibration numbers. Take the 3 1/2 milliradians per second maximum, and assume a sign wave for it at that particular frequency, and it does look like you could make a reasonable circle for it but just barely. It's not as nice as the 990 because the 990 had a Dutch roll frequency of 0.2 sec^{-1} which is another factor of about ten that you could track better with, you see. I realize, of course, that these are preliminary numbers. If one could make a recording such as Whittaker used to make on the 990, then you'd know exactly what you had to take out.

MERCER: But the maximum is supposed to occur only about three percent of the time.

DUNN: You can't tell from those numbers. What you need are three strapped gyros and a recording coming off. With that you could tell whether you could guide this way. You can't beat the torque motor servos and things, which are just great, and you've got that heliostat to move around; but if you plot the open loop response versus frequency, about the best that Whittaker and that group could do—and



that's about the best that I've seen—is something like a twenty db per decade slope at around thirty cycles. On the original heliostat (the one in the 1965 eclipse), they actually came up with sixty db which is a very tough one to stabilize; and so they back off on that at the 1966 experiment and came down to forty db. Now the accuracy with which you'll guide is just proportional to this open loop gain at the frequency that you are interested in. So if you have a lot of chaff up at thirty cycles you're not going to take it out at all. While the further you get down here the better you are. For example, at 0.2 cycles I think Liebenberg had a gain of 200 there; so that he could take a 200 (arc) second peak-to-peak sine wave and knock it down to one second, you see. But as you move out in frequency you can't get enough gain, and you find you have a big fight just to get factors of two. Going from 30 cycles to 60 cycles with a big heliostat mirror, even a ten or fifteen inch one, is rough. So I think you can probably expect a curve like this with about a 30 cycle crossover and a gain of about ten at 5 cycles. I sure wouldn't expect more than that.

LIEBENBERG: Dick, was the heliostat on the 990 anchored solidly into the aircraft?

MERCER: I thought they were shock-mounted?

BADER: Some of the experiments were shock-mounted but not because of heliostats. The shock mountings were for interferometers and things of that nature.

DUNN: You've got to have something for gyros to act against.

LIEBENBERG: Well, the question comes up when you begin to look at the points at which you begin to tie a box into the aircraft.

MERCER: I think the key here is that if the gyros are stabilized on the base of the heliostat which is inside the box it senses only the changes it sees inside the box. And if the box is itself isolating some of the aircraft frequencies then the heliostat doesn't have to work as hard.

LIEBENBERG: In that case the gyros have only to work against the box. That may be sufficient if the box is massive enough.

DUNN: I think that before you get finished with this thing you're going to have it bolted down solidly to the aircraft. For example, if you work up this instrument to take up in a 990 and go through only one landing!!! It's like taking your instrument and hitting it with about the biggest mallet you can buy. Now don't get me wrong—they never seem to get out of focus—I just don't understand it (we had more trouble with the ground based one actually).

You make it a part of the airplane up to 9 g's and even then you find yourself wondering how it held together, you see. I had another, small spectrograph we flew in the 990; and although we chipped a few optics we never seemed to go out of focus or adjustment.

MERCER: Well the box can be strengthened for landings and takeoffs.

DUNN: I know—but this is another complication; and when the chips are down they'll want that thing bolted to the aircraft. That's really what it comes to. On the high frequency vibration—I don't know. I imagine you'll have a ball trying to stabilize a spectrograph like this. I think you've got to do a lot of calculating and a lot of experimenting, find the node points, etc. I think that the very first thing you want to do if this thing is to run is to see if the Air Force will fly a test run with some strapped gyros and get this sort of thing to see if you can get the vibration out. And you might do this at your three tie points. If those chines are lift elements I think you're liable to get quite a bit of motion out of them.

MERCER: Well they don't go out very far, and we won't be in outermost tips of them—we'll be tied to the roots pretty well. And they get only about 15% lift out of them compared to what would be gotten with just the oval fuselage.

DUNN: Well that's all I wanted to say about this. I don't think there is any point to doing an old jumping film experiment. I think you could extend the line profile measurements significantly here providing people like Jefferies, and Don, and other people who have worked on these things can show you that if they get line profiles they can do something with them.

SPENCER R. WEART

California Institute of Technology

I'm all for a spectrograph, although it may be that we should think seriously about this as something for 1972. If I read the proposed schedule right we have about three months to a "go-no go" decision, and then about eight months in which to get things ready for a trial on the airplane. It does seem a little tight, so I would like to suggest one simple experiment that could be put on. I know if Thomas were still here he would say: Let's decide on what we want to see and they try to build something to see it.

I would like to see the continuous intensities in the chromosphere and the photosphere; this could be done with filters and photomultipliers. I ought to take just a minute to repeat something some of you already know; namely, why it is really valuable to have these things.

Thomas mentioned yesterday this temperature minimum region in the atmosphere. I think this region tends to be overlooked in importance simply because good data on it don't exist. Nevertheless, this is the place where the spicules start and unquestionably this is the place where important energy transactions are taking place. So it would be very nice to know what the temperature, pressure, etc. are in this region. You have the temperature minimum from the upper end of the photosphere to about 500 km and then a homogeneous region out to 1,000 to 1,500 km, and the real inhomogeneities don't start till you get above this layer. So that it's possible to do something which only requires the assumption of spherical symmetry. Of course another question that can be answered is: How homogeneous is it? That can be done by looking at different points around the sun.

The emission one sees in the continuum is a function of the electron, proton, and hydrogen densities, non-LTE departure coefficients, temperature (as a function of height), and wavelength. Height and wavelength, of course, are the parameters that we put in. For densities there exist theories; e.g. if it's hot enough you can say n_p equals n_e. There exists a theory for the departure coefficients. So there remain only the two parameters, n_e and T_e, and if I measure the intensity of radiation at two wavelengths I can find them. That is, if I measure the continuum intensities versus height at two wavelengths I can, in principle, extract the electron density and temperature as functions of height. While it is in principle possible to do this at any two wavelengths it is in fact done more easily by picking the best wavelengths—above and below the Balmer continuum, say, as Thomas and Athey did in their book for their model of the chromosphere, although above and below the Paschen continuum might be a lot easier to do. Then if one could get one more wavelength, say out in the infrared, this would provide a check on the whole thing and, in particular, a check on the proton density and the departure coefficients. So, in order to establish a model for this part of the upper photosphere and chromosphere, including both sides of the temperature minimum, all we need is continuum intensities in three wavelengths as functions of height.

It doesn't seem like a very hard thing to do. Let's assume that we have available a telescope that could also feed another experiment, Dr. Brandt's for example. All we need to do is to drop a little mirror down into the beam and work the image down into a slit so we can get the integrated intensity. Then we would pass this through dichroic mirrors and onto three photomultipliers. Beam splitters certainly exist now and, in fact, by 1970 we may be able to get 1/4A solid Fabry-Perots. Photomultipliers and pulse height analyzers are now available in very small boxes. And the only thing which couldn't be ready to go next month, say, would be the things behind the pulse height analyzers—the digitizers and data recorders. It's possible, however, that these problems are already solved because of the aircraft's own problems of instrumentation. It may be that this problem may be reduced to simply plugging in to the right module.

That is about all I'd care to say, but perhaps I should point out why this experiment should be done by this plane. One would like about five minutes of time and try for something like a ten km height resolution, assuming we can find the position of the plane, from ground telemetry or assuming the pilot has a black box of some sort.

Consideration of the height of the plane comes in at two places here. First, in the IR one can go to the 1.6 or 2.2 micron windows without getting into too many problems with the airplane window. The second thing, which may not have occurred to you since we haven't really thought seriously about the problem of obtaining ten km resolution from the ground, is the matter of the shadow bands. These are the alternate light and dark bands seen moving along the ground during an eclipse at frequencies up to at least thirty Hz. So if you try to do it from the ground you simply have to know exactly what the shadow bands are doing, and then take this extra signal out of your data to know what the chromospheric intensities were actually doing.

MENZEL: It's impossible to take them out because they're just not that regular.

WEART: Sometimes they are. At the Bolivian eclipse they were as regular as a venetian blind.

MENZEL: We're not talking about the same thing. These are like the patterns at the bottom of a swimming pool on a sunny day. The rays are semi-focused by patterns of denser or more rarefied air passing over you.

WEART: There are some results, unpublished as yet (Faller and Healy), which show that shadow bands are wavelength dependent so they are not strictly density effects alone, there is ....

MENZEL: Wavelengths may be involved all right.

WEART: In any event the point here is that since they are an atmospheric effect we should be above that at 70,000 feet and we don't have this problem. Why not a conventional plane, then? Because you simply need this duration--you need five minutes.

SCHMALBERGER: Thank you Spencer. We are open for comments.

LIEBENBERG: I'd like to make several comments. One is, that in order to know where you are looking at to within ten km you've got to know not only where the plane is on the earth but also where the moon is relative to the earth-sun line. And it's not clear to me that one has that information coming directly out of the Naval Observatory, for example.

MERCER: The program I'm using right now for analysis of the speeds and so forth uses the JPL positions of the earth and moon with respect to the sun. I'm not familiar with all the details but in any case these are being revised. However, these are the data I am using for calculating these ellipses and to get this limb work ....

BADER: It's not satisfactory.

MERCER: It may not be.

WEART: We don't need exactly ten kilometers. We must have 100 kilometers and fifty would be very useful. This would give us about a half a scale height. And, anyway, 100 kilometers with five percent accuracy is better than anything we now have.

LIEBENBERG: The second point I want to make is that with regard to these modules we've talked about I think you might be falling into an error which was alluded to yesterday. In the chines, the pressure is that of the ambient atmosphere at 70,000 feet; and I suggest that you won't find modules off the shelf providing high voltages for your photomultiplier tubes that you can take up to these altitudes and have operate without arcing over. I don't think you can build up the instrument you're talking about in the trivial length of time you might expect.

WEART: I'm evidently overemphasizing the triviality. As far as the voltage program goes, it's chiefly the basic photomultiplier, you would say? One could pot it.

LIEBENBERG: Yes, you can do that. But at the present time it's done by each individual and requires fairly careful heating to assure zero leakage.

WEART: Oh, OK. I'm not really talking about buying them off the shelf, I'm speaking with respect to the relative ease of these problems compared to other possible experiments.

MENZEL: I really can't see much advantage to doing this on the plane. In fact in the continuous spectrum the problem is to separate the contribution of the chromosphere from that of the corona, with the corona the dominating thing. So if you're wandering in and out of the ....

WEART: I'm not proposing to get into the spicular chromosphere. By the time you get up above about 1,000 to 1,500 kilometers all you get is Thomson scattering and it's not temperature dependent, anyway. I'm talking about the very low chromosphere; and here the chromospheric continuum is extremely bright, and you don't have to worry about ...

MENZEL: Are you talking about the continuum beyond the Balmer limit or beyond the Paschen limit? Because, in my opinion, it is not as bright as you have indicated. I think the coronal continuum, even at these low levels, tends to dominate.

WEART: Even at the photosphere?

MENZEL: Of course not.

WEART: But this experiment is supposed to run from the photosphere on out. I agree that there is a point where the coronal contribution can be large, and it seems we disagree on where this point is. In visible wavelengths, or at least in the Paschen continuum, this point is pretty far out.

LIEBENBERG: It's not clear to me where we stand with work from the ground with a large, say fifty foot, spectrograph.

DUNN: Do you mean what can we do to get 100 kilometers, let alone ten, from the ground? Well that's still a seventh of a second of arc, and you're just not going to do it. You just can't get this sort of resolution internally—even with a space vehicle. You simply have to use the relationship of the sun to the moon.

WEART: Furthermore, remember that in trying to look at the temperature minimum you have a tremendous scattered light problem.

SCHMALBERGER: On the other hand, if you could get something significantly under 75 km resolution over an extended period this would be quite an achievement.

WEART: Well, in conclusion, let me say that I think we all want a spectrograph. And maybe this can't be built in eight months, but we ought to start on something. If anyone can come up with something simple that can get line profiles I'd really be delighted. Especially if it can get absolute intensities, too.

SCHMALBERGER: Next we have Dr. Baker. Jim?

(Liebenberg notes he has worked on profiles using an instrument which could be built and tested in a relatively short time. Eds.)

JAMES G. BAKER

Harvard College Observatory

I would say that we have quite a few practical problems with this geometry, not the least of which, really, is overcoming the temperature. As we discussed yesterday on the Littrow problem, there is a possibility of using different materials. Offhand I'd say that Heraeus homogenized Ultrasil, perhaps, would be a good candidate for the first window, at least if we only put in one window. If we had a double window, there's a possibility that we could combine materials—of the inner window with respect to the Heraeus quartz of the external window—in such a way as to maintain a constant optical path through the two of them in spite of temperature change. With the Heraeus quartz you have a dn/dT, where T is the temperature, of something like 3×10^{-6} per degree C. This gets to be significant when we're talking about delta T's of, maybe, 100 degrees or more. There are several optical glasses that have negative dn/dT's so that it is possible to combine the two if you can get adequate thermal susceptivity along with radiation, sharing the temperature gradient to achieve this total constancy of optical path. Thus, one may get good optical resolution through the window in spite of the difference in temperatures.

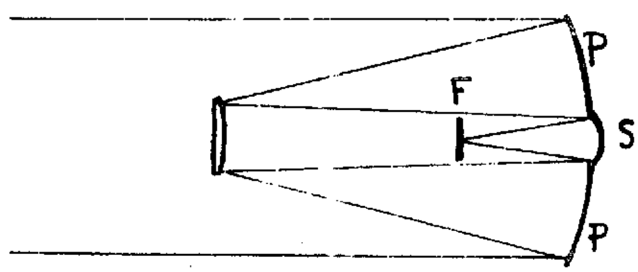
It would be nice to evacuate the equipment; but maybe this isn't possible? But it at least ought to be considered. We're not at very high pressure anyway, to be sure. But if you're talking about a 26 foot total optical path and you're near walls that are hot, it might be desirable to evacuate. That would get rid of some of the problems of the residual air. Or, perhaps in the absence of that, you might possibly have a helium-filled instrument, although this isn't as simple or trivial as it sounds. I've had a lot of practical problems with trying to use helium. You either have to have complete purity or do without; because helium that is mixed with ordinary air takes a very long time to settle down, and you simply can't have an instrumental atmosphere which isn't either altogether helium or no helium.

I think we're in really very fine shape with respect to mirrors, at least. As most of you know, we have the Owens-Illinois Cer-vit material which has perhaps some variation in quality but, in spite of that, you can get mirrors which will maintain their optical shape reliably over a wide range of temperatures. This is particularly important with respect to maintaining focus under adverse conditions of the aircraft. We also have the Corning ULE material which is nearly as good with respect to thermal expansion and, I think, better with respect to homogeneity, surface quality, and surface polishing. So, we should surely want to take a close look at that. Beyond that, of course, we have the ordinary fused silica and the Heraeus quartz, which is apparently extremely good. The shop people are also introducing two types of titanium glass with very low thermal expansions that will also be usable for mirrors. So, I think that as far as our needs with mirrors are concerned we're in excellent shape. We're limited, unfortunately, to this 10 inch diameter more or less but there are no problems whatever in that size.

With respect to fitting the queer geometry of the chines, this would probably take some work with the drawings in front of me. With these I could see just what we can put into such queer spaces in view of the tracking problem. I would like to mention that there are a number of possibilities for getting direct imaging systems that are very compact. With respect to Dr. Brandt's scanning problems, the ordinary Cassegrain is compact enough. But if we wanted to, we could also use an off-center, off-axis Cassegrain to clear the pupil of an echelle secondary. This would be all right if we had, say, a 10 inch aperture, at f/20. This would be very easy for an off-center Cassegrain. Or, we can even use what is called a Schiefspiegel, which is simply two on-axis mirrors that are tilted in such a way as to cancel the astigmatism, so that you can give it a sharp stigmatic point at least with a modest size pupil around it. A 200 inch focal length, for instance, could be gotten into a space of less than 5 feet, without undue difficulty.

There are other ways of folding optics. I have, for instance, a three-mirror system with an off-center correcting plate that has a scanner covering an unusually large field. For example, you can have a 10 inch f/20 system--which is hardly more than 50 inches long and which will cover an 18 inch wide film--but it is a scanner. Otherwise, you get a great deal of stray light. And you have to build up a picture by scanning techniques--the film synchronized with the motion of the heliostat mirror--in order to obtain a complete picture of the intensity variation near the sun. But already, then, this is about a 6 degree total field, about 12 solar diameters more or less, when the sun is centered in the field of view. So you could get a high resolution, long focal length scan of that kind with such a system involving three mirrors.

There is another, smaller, three-mirror system that might have some utility for the outer corona. We're again limited by the 10 inch aperture pretty badly, and so this becomes practically a baby instrument. In principle, it could be as large as 30 or 40 inches in diameter, but where we are limited to 10 inches this three-mirror system is only f/1. At f/1 it is a 10 inch focal length, and this means you have a very small scale; but it's a high precision thing. For photographic purposes you could use finer grained materials. It has a three degree coverage at f/1, so that you could consider the possibility of using this with interference filters for a set of solar diameter scans of different monochromatic lines, or you could use it as a direct viewing camera without filters; or with wide band filters for studying the outer coronal structure but, as I say, only to 7 solar diameters. This is a very compact little instrument. If it's 10 inches in diameter, it's only about 7 inches long. It starts out with a paraboloid (P) with a sphere at its very



limit (S). It has a single secondary mirror, and it has to have some baffling. The focal plane lies at the point F. In spite of simplicity, it is extremely highly corrected at f/1 on a flat surface so that by calculation it can be as large as 50 inches in diameter and still be diffraction limited at f/1. It will resolve, say, 1200 or more line pairs per mm ....

LIEBENBERG: Fifty inches diameter did you say?

BAKER: Yes, but not for this project. It could be as large as 50 inches, but here it's 10 inches. I'm just saying that in principle it is a highly corrected system. What you would have to do would be to thread film; and, in this case of the 10 inch, it would be only about 16 mm film because of the small scale. That's already sufficiently narrow to go ahead with the film right on across the aperture without losing too much light. You can also have the film go through the fins which hold the focal surface edgewise, over 45 degree rollers, over the image surface, and then over 45 degree rollers again to go out the other fin. You would have your spools on the outside and could take hundreds of pictures with this f/1 system. With some loss of light, there is also a possibility of putting a filter in this region behind the primary, but I think it is really quite inefficeint to do so.

SCHMALBERGER: What is the field of this system, again?

BAKER: This is three degrees at f/1.

DUNN: Could you draw the optical path; what's the sphere for?

BAKER: It's a Cassegrain. The light after the secondary is fairly collimated, and if there's room at all for a filter there you'd want an annular type of illumination. You can work with an interference filter in this parallel beam. Mathematically, the field is larger than 3 degrees, but the baffling problem of keeping stray light off the film limits it to 3 degrees. That's all that can be recommended; but here we have seven solar diameters, and that really isn't so bad. This camera in a 10 inch is not very spectacular; as a 30 inch it would be, of course. But you can't use more than 10 inches here. On the other hand, you could tuck this off into a corner, it's so tiny. It could be completely automatically operated, of course. With time exposures, it gives a very faint form of background and, of course, you don't need to center it on the sun. You could also move it around. You wouldn't need to feed this with a flat. It's so small that you could direct it through a window. If made of Cer-vit or ULE, of course, the focus would be highly stable. And you simply could direct it around the whole eclipse region, three degrees at a time, covering almost everything with this very wide vision photographically.

SCHMALBERGER: Have you built one of them?

BAKER: No, I've calculated a number of different applications and I've been toying with the idea of having one built for high resolution photography because with very finely grained film it should be able to do 500 to 600 line pairs per millimeter photography in spite of the small field. For solar work, I mention it here as a fact that it can be done. It's not an easy thing to make this paraboloid because it's f/0.7. But there are automatic machines available for making paraboloids, and with good testing methods, coating procedures, and good opticians, I think that it could be managed. We counted on getting 100 lines per mm without undue difficulty. Well, anyway, it's a possibility.

For large scale photography--if I stay off spectrographs, because we have already covered it, and it might require much more study, anyway, because of the geometry--it is possible now to build an apochromatic objective, but perhaps one shouldn't tie down such an expensive airplane with direct large scale photography when it takes up all the room. But I just mention it as being possible that you can now obtain glasses, certainly in 10 inch diameter, which will give wide field, so-called apochromatic results. You can have a 200 inch focal length extending from 3500 to 4500 A in one section diffraction limited. You can have another such lens from, say, 4500 to 8000 A, diffraction limited, which means that with a 10 inch aperture that you could count on getting something around a half second of arc which, however, is in cross product with the vibration problems and with the exposure time. I mentioned to Dick Thomas at lunch yesterday before I knew that we were limited to 10 inches, that with a thousandth of a second exposure and a 30 inch aperture, and with everything completely optimized with the best techniques available, that it is possible to get below 1/3 second of arc and, perhaps, to toy with 1/5 second. You can see we are far from that here, however, because we are restricted from 30 down to 10 inches and something more than a thousandth of a second. Perhaps we can use that but we won't have enough quanta, enough light intensity. So we are probably restricted to things on the order of a hundredth of a second or slower with work where resolution is concerned. This means, perhaps, that we would be lucky to get something around a second of arc in actual practice. I didn't get to tell Dick that it wasn't as good as I told him earlier before he left. We have these practical problems, of course.

One other, minor, point. It is possible to choose optical glass in some cases that could be athermal with respect to focus, quite apart from mirror systems that you have, in your refractive elements. According to the application, it might be possible to design simple elements with the proper glass so that we will not change focus when the temperature changes. This might be important; for you have no control inside the aircraft with some thermal gradients.

I think this is about all that I want to comment on other than saying, again, that it will require knowing exactly what the geometry of the space is and what the actual targets are for the scientific problems in order for one to come up with some recommended systems involving these principles.

OERTEL: What might be the time scale for doing something like that?

BAKER: I'm not so much worried that it can't be done quickly as to think that the people who can do it are tied up with other equally important projects. The experimental equipments would not be limited by the time it takes to construct them, but more by the availability of personnel and priority of the work versus present projects at three or four different, large companies. So, that's the problem. Where it's in conflict with some classified work, you never really know how the priorities are going to come out. But of itself, I think if it were simply one problem without conflict, it could be done by several different groups in a matter of a few months, I'm sure.

MICHEL BADER

NASA Ames Research Center

These will be comments about what the NASA CV-990 might do, rather then a contribution to the list of possible solar physics experimental studies. Don Liebenberg felt that a few words about what the 990 is likely to do may be useful for comparison so I'll just put a few figures on the board. The 990 operates at a maximum altitude of 40,000 ft. and that in itself is an important figure. Totality on the ground is 208 seconds. For this particular eclipse, the 990 happens to have the windows cut on the wrong side; so, instead of increasing totality, we will diminish totality. Preliminary calculations show that on the 990 we would get 165 seconds.

I have a few numbers here which are about to be published in the Journal of Meteorological Research. These refer to overhead water vapor content in microns of precipitable overhead water vapor at various altitudes. And for comparison purposes I've dug up a few related figures. At Mt. Wilson on a good day you have something like 7,000 microns; and at the Catalina Observatory in Arizona, I was quoted a figure of 750. At 30,000 feet we're down to 80 microns. On the days that we were taking data, the tropopause was in the general region of 36,000 to 38,000 feet. For these conditions we found that at 40,000 feet we were down to 8 microns overhead water. We also operated the Lear Jet which is capable of going to 50,000 feet, so we have a little more data. At 45,000 feet, we had something like 2.5 microns; and at 50,000 feet the data becomes a little less precise but it's somewhat between 1.5 and 2.5 microns of overhead water.

LIEBENBERG: How does that agree with the Canadians?

BADER: I don't know. I'm not familiar with their data. But I might say that we have three different methods of measuring this and that they all agree within something like 10% to 15%. The three methods were these: First, looking at spectra of the moon in the region between 1 and 3 microns; the moon has no water atmosphere, so that the spectral features seen are due to telluric water vapor. The second method was to look at the sky temperature in the 6 to 7 micron band of water. The third method was to measure the sky temperature around one millimeter. And those three methods interestingly enough all agree. The sky temperature type of measurements at the 6.3 micron band are such that you can extrapolate and get agreement with the figures that were gotten from the Lear Jet around one millimeter. I don't know about the Canadian data. I would like to get a reference, if you have one.

Other figures that might be of interest on the 990 are that the amount of space available is about 80 feet long and the fuselage is 11.5 feet in diameter. We don't have any specific experiments in mind for the 1970 eclipse, yet. We normally carry about ten experiments, depending on the size and weight of the group of experiments. So this is open for anything you propose.

VOICE: Since you are on the other side of the aircraft, how does this affect your windows? Could you take that many for this eclipse?

BADER: We're flying the other way.

VOICE: Oh, that's right.

BADER: I'm quite convinced that we wouldn't get funding to cut windows on the other side of the airplane.

VOICE: You can't fly upside down? (Laughter.)

MERCER: No, the engines fall off at a 45° bank angle on this airplane. It just wasn't stressed for it.

BADER: If we were able to fly the right way—this is a fictitious figure—but if we were able to fly the right way, I have calculated that we would get 336 seconds. But we just can't fly that way.

DUNN: If you had the money, could you get the windows put in by eclipse time?

BADER: Yes, there's enough time to get it done.

DUNN: Does it affect the other projects?

BADER: We have an extremely busy schedule, so, it would have to be worth the priority. But one reason why people would not look very favorably on cutting additional windows on the other side, is that we are about to modify the airplane to take a 36 inch telescope. So, people just don't want to put any money into modifications that will be useless after the 36 inch goes in.

DUNN: Is that true in terms of future eclipses, Mike? Or do you think the 36 inch will take up so much space that ....

BADER: Well, the 36 inch will be just ahead of the wing and will only take up about one-third of the room, but it takes about two-thirds of the available payload weight. The weight of this installation, including aircraft modifications and so forth, is going to be on the order of 10,000 pounds.

LIEBENBERG: Is that with or without instrumentation?

BADER: That's the whole thing. The aircraft modifications, the telescope with its own stabilization, and allowing for 400 pounds of experiments.

PASACHOFF: That still leaves 5,000 pounds, which is more than we're asking for this whole other plane.

BADER: That's right. It does leave about 5,000 pounds, but with a 15,000 pound payload, you begin to cut into the range of the airplane. There is another problem. The 36 inch telescope is going to be positioned approximately centrally, so that non-telescope related experiments are going to be using space starting about the center of the airplane and going on back. And, the farther back you go, the more the airplane shakes and vibrates and wobbles. The aft positions, though acceptable, present additional stabilization problems.

DUNN: Would you use the 36 inch on the eclipse?

BADER: After the 1970 eclipse, conceivably.

DUNN: Then it seems to me that you have to take into consideration all these calculations of how many right-handed eclipses. Which side is it set up for?

BADER: The 36 inch?

DUNN: Yes.

BADER: We are planning the 36 inch to look out the left side of the airplane. However, we foresee the possibility of making it ambidextrous. It's going to cost a few hundred thousand dollars more to get the 26 inch to look out both sides but we think we see a way of doing this. The proposals as they now stand have the telescope somewhat off center, but in at least one of the proposals it is only 10 inches off center.

DUNN: It would make an extremely powerful eclipse instrument to have the 36 inches. I think it would be a shame not to make it so that you could either reverse it, or so that it will work on the next ten years of eclipses. Because taking a 36 inch telescope to an eclipse even on the ground is formidable, you see.

BADER: Another problem is the elevation range obtainable. The aeronautical engineers and others keep telling me that you need some structure to keep the airplane together. The way we are looking at it now, the elevation range would be 35 to 75 degrees, which is suited for most astronomical objects. But, of course, we are ten degrees short of that 85 degree elevation for the 1973 eclipse. Still, that's not too bad. If you are willing to lose a little totality, you can catch it at the lower elevation part of the eclipse path.

One other thing I wish to mention relates more directly to this high altitude SR-71 airplane. In addition to the 990, the Ames Research Center is using a Lear Jet for astronomy, partly because it can fly up to 50,000 feet; and another reason is that it's much less expensive to operate. We are set up right now, working with Frank Low from Rice University, with a 12 inch telescope looking through an open port, observing in the sub-millimeter region. This is, of course, quite interesting. It's very similar to what could be done presumably in the future with the SR-71. Frank Low will start around 20 microns and go up to 1 millimeter. He wants to do a general sky survey to find out just where the infrared spots are in the sky. More particularly, he wants to look at Saturn and Jupiter (which are obviously of interest, especially around 20-25 microns), the galactic center, Eta Carina, the Orion nebula, and the Crab nebula

All these things could also be done from this higher altitude airplane, the SR-71, only presumably even better. From the ground to 30,000 feet, you get about a factor of 10 decrease in overhead water vapor; then, going across the tropopause gives you another factor of 10, and from there to 45,000 or 50,000 feet another factor of 2 or 3. With the SR-71, we're talking about an extra 20,000 to 30,000 feet, and maybe you get another factor of 10 improvement.

DUNN: Could you make any comments at all, Mike, on what the cost per flight is on both these aircraft, the 990 and the Lear Jet?

BADER: Yes. The 990 costs about $2,500 per flight hour. The Lear Jet is a factor of 10 less, $250 per flight hour.

DUNN: So there's just no comparison between them.

BADER: Well, the comparison is that you can put ten experiments on the 990 but only one experiment on the Lear Jet. So the cost per experiment is the same.

DUNN: There's no comparison to the SR-71.

BADER: Oh, no!

MERCER: As a matter of fact, I've been quoted prices on this. The Air Force quotes prices on what they say it costs them to operate this airplane as $25,000 per flight. So it's another factor of 10 above the 990.

SCHMALBERGER: That seems to bring the comments on Mike's talk to an end, and I think we would all appreciate a short break.

* * *

SCHMALBERGER: I think we're all together now and Mike Bader has a comment he'd like to append to his talk. I, perhaps, interrupted, and he didn't get a chance to make it.

BADER: No, I was going to mention it but forgot. These are the figures on the stability of the 990:

Period (sec)	Roll (arcmin)	Pitch (arcmin)	Yaw (arcmin)
5	±12	±3	± 6
100	±42	±6	±12

I would like to say, also, that we have available for loan to any experimenters (on a first-come-first-served-basis, essentially) three gyro-stabilized mirrors, and those mirrors will give us better than 10 arcseconds stability in this kind of environment. And, this is 10 arcseconds almost indefinitely. For short exposures you can do better; maybe 3 to 5 arcseconds under some conditions. The size of our window (12 x 14 inches) and the size of the mirrors are such that you can accommodate a 10-to-12 inch telescope without vignetting. We also have access to a couple of other heliostats that are a little bit smaller and would only accommodate an 8 inch telescope. Of these other two, one belongs to the Air Force, Ken Kissel at Wright-Patterson; the other one belongs to Douglas Aircraft. We are able to borrow those. I thought of this because somebody asked me the question, "What is the cost of putting an experiment on board?" We do have other equipment available on loan, such as stands and mounting brackets. A stand that will take the heliostat and the experimenter's telescope might cost one to two thousand dollars by the time it is stress analyzed, but here it is already available.

BAKER: What window temperatures do you find at that altitude on the 990? Are the windows heated?

BADER: The windows are cold. The boundary layer really doesn't heat them up very much. The outside air temperature is -50°C, and the window may be a little warmer than that. Actually, we blow some warm dry air on the inside to prevent condensation from the cabin air.

BAKER: It's below the compartment temperature, then?

BADER: Yes, that's right. We bleed air from the air conditioner onto the windows, and keep them free of cabin moisture condensation.

BAKER: How much trouble do you have with turbulence when you do that? Do you detect any problems?

BADER: We haven't been bothered by it.

DUNN: Anyway, you don't have any air pollution problems up there. (Laughter)

BAKER: Turbulence can be a problem. If you test it in the laboratory, it scares you.

BADER: Using these heliostats we've taken pictures with resolutions in the 1 to 3 seconds of arc range. So the boundary layer and the turbulence in the past have not bothered us down to about 2 to 3 seconds of arc. And, we're going to try for better. We don't know for sure how much better we can do.

BAKER: You could use double windows with circulation between them, I suppose.

BADER: It could be done.

A. NEAL DE GASTON

Bellcomm, Inc.

I've had a chance to sit back here, and hear everybody else's comments. Perhaps I have an unfair advantage in talking for the experiment that I have in mind. But as the talks progressed. I found that, in general, it seems that my experiment could take advantage of this unique method of eclipse observation.

If we take a look at an externally occulted photograph we note that the further away we put the occulting disk, the smaller the angle subtended by the objective lens of the disk becomes. Now, the moon is 230,000 miles or so away from us, and so it makes the angle very small, and it will be a long time before the state-of-the-art arrives when we're in the position of building this kind of coronagraph. So by staying on the edge of the shadow, we can use this flight to see in a region, where we can observe down into the chromosphere for long periods of time, as has been pointed out, many orders of magnitude longer than is possible on the ground. So, it must be done at an eclipse to get the 100 km or better resolution at the sun, which is possible with this 100 foot positional accuracy, provided this JPL matrix works out right.

Some of the other experiments that are suggested, for instance looking at the corona, could be done from inside the shadow. From the middle of the shadow, in fact, you're still going to see down to at least 0.3 of a solar radius above the limb of the sun. Furthermore, the argument of there being less scattering from the sky by using an airplane such as this to look at the corona is made even better if one uses a satellite. I haven't been talking to people to get exactly what the cost of launching is but I understand it is approximately 15 million dollars for an OSO launching, including the launching, the experiment package, and all that goes with it. Just what the launch may cost, I can't remember—what AT&T paid to put up COMSAT and TELSTAR satellites. But it seems to me the figure is around $2 million. We're comparing this with about $7 million as the cost to the Air Force. So these things can be done in space with better avoidance of scattering and comparable cost, and apparently Gordon Newkirk has already begun this on the OSO program. Certainly excellent data is expected from the Apollo Telescope Mount program. So the necessity for an eclipse is not a unique requirement for looking at these regions of the corona.

As for height, one can look to the 990 to achieve 40,000 feet in elevation and compare this with 60,000 to 70,000 which would give a person the opportunity, if the windows were on the right side anyway, of up to maybe 4 minutes during the eclipse. Several channels would considerably increase the time. However, since the order-of-magnitude increase for looking at the lower layers of the chromosphere and, say, the reversing layer is such a higher order of magnitude, it would require that many more—some order of magnitude—number of channels to do this type of work on the lower chromosphere.

What I'm proposing then is that we cash in on the uniqueness of a plane that can stay with the shadow and fly at this high an altitude. That is, we have to take advantage of the fact that we do need the eclipse to do chromosphere work, and second of all, we will be able to get a reasonable amount of time—15 minutes or so out of the 90 minutes. Twenty minutes is fantastic compared to anything else which is possible. And, in the words of the first speaker, Dr. Thomas, we ought to see if we can't satisfy some theoretical question or questions in doing this.

I have one that I'd like to propose. It has already been stated that one may possibly obtain line profiles stepped up through the chromosphere. Dick Dunn has made this argument, or asked the question, "Maybe people aren't really that interested in these lines anymore?" Some work that I did on my doctoral thesis gives me another reason I'd like to look at chromospheric lines. If we go back to the time that Adams was at Mt. Wilson Observatory, and Hale also, Adams wrote a paper in which he and Hale inspected some of the plates that they had at Mt. Wilson. They had observed the lines of the reversing layer, and had other plates that they had taken with the spectrograph of the chromospheric hydrogen lines (H_α, H_β, and H_γ) and they compared these. They got Doppler shifts, and compared one limb with the other. This could be redone on this high flying experiment. They found out that the chromosphere was apparently rotating at 0.14 km/sec faster than the reversing layer which indicates, then, that there is a differential rotation. In fact, as high as one could go above the surface of the sun apparently, in the direction of rotation the velocity of the chromosphere was greater than that of the reversing layer.

Despite the fact that some of us might hold other beliefs or prejudices to the opposite, if we examine some of the other evidence in the chromosphere, it leads us to say, "Well, this certainly seems to provide a good explanation for these phenomena". For instance, there's an 8 degree mean lean in the direction of rotation of the filaments. One explanation of the east-west asymmetry in sunspot occurrence is that they're tilted in the direction of rotation so that as they come up over the east limb, they give us an apparently larger diameter; that is, they are more face-on to us, according to the cosine law, than when they go over the west limb. This can be explained by the fact that the layers of the photosphere at the top are moving forward faster than if they were in the, say, root of the magnetic field, i.e., the spot its magnetic field is tied into. So that there's a shear exerted on the spot which causes a tilt. If this were the case, one would expect to tilt the spot so far, and then the magnetic tension would resist further tilt, and it turns out that the recurrent spot tends to reach about a maximum of 7.6 degrees. Also, older spots seem to have a slower rotation rate than newer spots. The newer spot would still be moving more with the surface of the photosphere. So, we have this spectroscopic evidence. We have the fact that the filaments lean, the sunspots tilt, the filament rotation rate, according to the d'Azambujas, is greater than that of the sunspots as determined by Newton and Nunn, and one can argue that the difference is in the proper motions of the filaments and spots. The difference does show, however, that even with the careful work and within the limits put on their results, the filaments did come out rotating faster.

What could be done then, or what I'm proposing, is to study lines. Dick Dunn has emphasized that the wider the lines, the less elaborate the spectrograph has to be to get the resolution. One can step up through the chromosphere near one side of the equator, on a path, say, like Bob has drawn in his eclipse shadows. I would like to get a little bit above and below the equator on both sides. As one steps up through here at some point, maybe 100 km intervals, one can not only get at the line profiles, but by comparing the shift at one limb with that at the other limb, we can also determine what the rotation rate is—from the reversing layer right up through the chromosphere. This would be definite spectroscopic evidence on the rotation rate of the sun at these latitudes. Then we would not have to continually rely on statistical derivations done by observing spots and filaments. We actually would have tied it down; not only meridionally, but also with height. This is the type of experiment I am proposing.

Some of the technical problems are, "How do we want to measure that 0.14 km/sec?". I figured, well, a good way to get a handle on that would be to measure to .01 km/sec. This requires a dispersion of about .03 A or better. I was thinking of something like the hydrogen lines, and that seemed to give me a fine spectroscopist's design figure—a resolving power of about 1,000,000. If it appears that we can do something with a resolving power of about 500,000, it might give something to us. We won't need to worry about a polarization problem in this due to the window, and it doesn't seem as if the vibration should be too much of a problem in this unless the exposure turns out to be fairly long.

Dick Dunn's spectrograph seems like it's already designed to pretty much accomplish this. This sort of equipment is available. It might be expensive; cost about $100,000 to $200,000.

Before concluding, I want to bring out one other thing. While one is on the limb, this light path would allow for other experiments. There's certainly room for others to be done. Perhaps there's a way the light path could be shared with somebody else—certainly the aperture could—and one could have a mirror or something to shift the window from one experiment to the other. It would seem that we would want several experiments on a flight like this to justify the expense of it. So then, in conclusion, I would say that the unique advantage that the flight could capitalize on is the fact that you have an eclipse and you're able to travel with it. Second of all, it appears to be technically feasible; and third, it will serve to answer certain theoretical considerations and provide valuable data for future reference.

LIEBENBERG: I assume it has been quite recently possible to pick off hunks of the upper chromosphere.

DE GASTON: I haven't heard of anything stepped up through the chromosphere. For instance, the reversing layer didn't seem to ....

LIEBENBERG: With spicules you ought to be able to use spicules on one side or the other of the average.

DE GASTON: If you're up in spicule area, then you're liable to get quite a broad line.

PASACHOFF: One should look at rare earth lines of which a number are visible in scientific photographic spectra taken outside of eclipse. They are very narrow lines.

DE GASTON: Are you able to get this within 100 or so km?

MENZEL: Let me say that the Adams and Hale height scale was based on Mitchell's chromospheric heights and is absolutely meaningless. The second thing is that the data were statistical. There was a good chance for systematic error, and I long ago was familiar with it. I remember having gone through this 40 years ago, and more or less dismissing it as not being a real phenomenon.

LIEBENBERG: This would seem to be an experiment that could be tested on the ground, for example at Kitt Peak.

MENZEL: I think that the large solar telescope at Kitt Peak is perfectly adequate to at least test this and see what the order of magnitudes are.

LIEBENBERG: One ought to examine the limits, at least, that you could carry the experiment to by doing some of this from the ground.

DE GASTON: In principle, I agree; but that's what Hale did, or rather, I should say that he wrote up what Adams did at that time. It could be tested to see if we come out with the same result. But this flight would do it right; and do the higher requirement to get the line profiles, just as before, locating the reversing layer.

LIEBENBERG: It falls under the category of experiments that are nice to do from the airplane; but it is, perhaps, something for which the information could be gathered in other ways.

DE GASTON: Well, though, the seeing resolution on the ground is at best, say from Kitt Peak, about 1.5 arcseconds.

SCHMALBERGER: Oh, you can get it better than that.

PASACHOFF: You can get it, if you wait to get it. Dr. Dunn is the expert on specific numbers, but one would think that if you sit around and wait for long enough, you could get it at a fraction of the cost of the airplane.

SCHMALBERGER: As a matter of fact, at Kitt Peak, Keith Pierce has been getting chromospheric plates in a continuing program that's been running for, I would guess, about 5 years now. Perhaps, one could look at these, particularly for the rare earth lines around H and K.

PASACHOFF: Canfield has just completed a study of Cerium II. His thesis was for Boulder.

SCHMALBERGER: Actually some of your data might be available already. You can check and see.

LIEBENBERG: At Kitt Peak you get resolving powers of up to 1,000,000. So maybe you can do this experiment on the ground.

SCHMALBERGER: Well, at least one can get a preliminary estimate of what the observable effects might be.

MENZEL: I think what is really indicated here, with the new kinds of spectroscopic equipment, is to repeat the type of spectra that Hale took with much inferior equipment many, many years ago, and in doing so, seeing now whether the effect really still persists. I'd be willing to bet that it doesn't.

DE GASTON: I'm willing to change my mind on it.

VOICE: One could go back to Hale's first plates and try to measure it.

DUNN: I'd like to do it on my plates. Just to keep the record straight, the eclipse spectrograph was pretty much a disaster, the one that did line profiles. I thought someone asked me how much money it would cost to do a spectrograph that might be airborne, and I would have guessed $200,000. Nowadays, it might cost more than that.

BADER: Only about a factor of two or four. (Laughter)

MENZEL: There's one further point to these chromospheric detectors. I've worked so much with the chromosphere that I'm going to try to project myself on this plane and see what is essentially a slowed-down picture of the sun going into an eclipse. And, I don't see the tremendous advantage of it, except the--perhaps, the improved seeing. The height resolution doesn't seem to me to be very much greater because of the tremendous irregularities on the moon itself. And, I don't think you know where you are that accurately.

DE GASTON: Well, if you know where the plane is within 100 feet, especially on the smothest part of the maria, we've got enough.

MENZEL: I'm sorry. I've never seen the smooth part of a mare. It's always rough and rugged.

WEART: Two points. First, the moon's limb can really occult the sun with at least 100 km accuracy because the convolution integral can be evaluated. The second point is whether one really needs good seeing from the airplane. Just gathering the light intensity may be enough. In the infrared for example, you just can't do any kind of experiment in an ordinary eclipse because you don't have time to gather enough photons.

MENZEL: That's true.

PASACHOFF: But you can with this plane.

WEART: Yes, sure. You have 5 minutes instead of 5 seconds, and you can sit there and gather them up. It depends on the wavelength region you're interested in.

MENZEL: Yes, but that's a different problem. The problem that one deals with—the high resolution of the spectrum— I'm interested, I'd love to see it, but I just have a feeling that it's beyond the art—right now, at least. It's nice to talk about, but I'd hate to be given the responsibility of trying to design and build the equipment which would do it. And, I don't think that it would perform.

GEBBIE: I'd like to comment that if you've got time—the extra time these speeds would allow—you could trade this for resolution with interferometric techniques. Now, I would be the last to suggest that you put a refined interferometric spectrometer on this aircraft, but I think it is not fully without substance to think in terms of gaining spectral resolution by observation time, and it should be kept in mind.

SCHMALBERGER: Perhaps on a subsequent flight.

BRANDT: Another thing; actually two things. First of all, if you do an experiment, or a series of experiments that cost this much, you don't attempt anything that hasn't already been tried and are reasonably certain is going to work. A lot of these experiments that have been suggested are great experiments, but if we were doing something like this on OSO, for example, you would start out by trying a rocket flight or two to see if anything happened at all. If the equipment worked, if your ideas were sound, you would then contemplate putting this on a satellite. You would not make this first step going to the state-of-the-art limit which I hear in almost every field we have taken.

Also, on that same line, you have to be really sure that the results are capable of rather straightforward interpretation. Everybody says it would be nice to have this, or not to have that, but as several of the chromospheric people themselves pointed out, you have to rigorously go over the theoretical bases for interpreting these lines to be sure you're going to get anything, even if you do get the results.

These two points are the same as those I made on the corona: that it be simple, done before, and since it's optically thin, you don't have the complications in the interpretation which could ruin everything.

But—even as I think Dick Dunn has mentioned on interpretation of chromospheric observations—he, himself, is not sure. I think the person who proposes such a chromospheric experiment has to guarantee in his own mind to certain of us that he is certain he can get good results out of it.

WEART: Well, nobody can ever assert that. Let me point out, with respect to simply looking for the continuum, that this has been done by a number of people and defined completely. A lot of it not very good perhaps, but there are a number of people who've looked at the continuum including Faller and myself in 1966. As far as interpretation—in 1961, Thomas and Athay published a book in which they interpreted continuum observations. So we do know how to do it. Moreover, let me point out that for the corona you're going from 4 minutes of observing time to 15 minutes, gaining only a factor of four ...

MERCER: A half hour was what I was aiming for.

BRANDT: More time on the subject does not necessarily mean that you can interpret the data.

WEART: OK; let's say you go from 4 minutes to 40 minutes. In the chromosphere we are comparing 5 seconds to 40 minutes; this will surely yield extra information about the chromosphere.

SCHMALBERGER: I think that this topic Neal has brought up is interesting and that it's definitely worth looking at albeit, perhaps, one should make some preliminary studies on it.

Bill Mankin now has a few comments he would like to make.

WILLIAM MANKIN

University of Massachusetts

I'd like to mention first what Dr. Strong and I have been doing at Massachusetts. We flew a balloon this past March to measure limb darkening curves in the far infrared, 10 to 100 microns, for the same type of information that Dr. Thomas was talking about yesterday. Since the data are still being analyzed, I can't tell you what the results are. It looks as if the data refer only to the region below the temperature minimum, rather than above, so that you need to go to longer wavelengths than 100 microns to see above the minimum.

I don't want to get into the argument on chromosphere versus corona, because I think both are interesting. But I do think that for this sort of work the usefulness of the moon should not be discounted; and to do far infrared work, you do have to get altitude. To get altitude you're limited in the size of your telescope to something on the order of 10 to 20 inches. At 300 microns the resolution of a 10 inch telescope is only 5 minutes of arc which means that as far as the limb darkening curves go, you just don't get any! You can only go out to a cosine theta value of 0.73 compared to 1.0 at the center. So for practical purposes if you're going to do any limb measurements at very long wavelengths you have to use an eclipse. There has been one experiment at 25 microns using an eclipse, 1966, by Noyes, Beckers, and Low (Solar Physics, 3, 36, 1968). The other alternative for doing this is that you do absolute radiometry at long wavelengths which, with the accuracy you need, is extremely difficult to do. In principle, the data are equivalent to limb darkening data.

For work outside of an eclipse, I don't really see the advantage of an aircraft over a baloon. The balloon doesn't shake around like the aircraft does. You can have as large or larger apertures, and on the aircraft you might have to make everything automatic anyhow. So that, except for the eclipse, I don't see the great advantage for the aircraft.

The only other thing I want to mention is another possible experiment which can possibly be done with a balloon-borne coronagraph; that is, measurements of the thermal emission of the F corona; again, for the same purposes Dr. Menzel mentioned, namely, helping to separate the K corona and find out how much F there is. There have been balloon measurements made at one wavelength, and it would be nice to do the spectrum. The advantage of using the aircraft in an eclipse would then be avoiding all the difficulties of doing it with a coronagraph. The disadvantage of the aircraft would be the window. It would be a very serious problem for anything beyond the wavelength of a couple of microns.

MENZEL: Which way do you mean "beyond"?

MANKIN: Longer wavelengths.

MENZEL: OK, that's what I thought you meant.

BAKER: Do you happen to know how many U-2 flights Dr. Strong is involved with for other than limb work?

MANKIN: There was one flight with the U-2, several years ago. The limb work is balloon borne, not aircraft.

BAKER: I was just wondering whether you know the cost per hour of operation, among other things. As a guess, I would imagine it would be in the $2500 per hour category.

LIEBENBERG: That might be right, but the package weight is probably reduced, too, isn't it?

MANKIN: The package weight was about 100 pounds on the U-2, while the balloon package weighs just over a ton.

BAKER: Well, you'd have about 300 or 400 pounds. The compartment size is small, but it's a better shape than the SR-71, and one could do quite a few things with that. In fact, if it's not expensive, it might be a good idea to have that also in this eclipse, if it could be worked out with the proper Air Force people.

SCHMALBERGER: Two questions. One: What was the altitude? And the other: Is this the same instrument that was described in "Stars and Stellar Systems"—in John Strong's paper there?

MANKIN: The altitude was 90,000 feet (89,300). The instrument, the package, and the engineering inside the instrument was the same. The framework and the guidance system were roughly the same. The telescope and radiometer were different. The telescope was an 88 inch focal length, 15 inch aperture, Corning low expansion coefficient quartz, and the radiometer used broadband filters—half a dozen filters at different wavelengths.

One other point that I might mention. There was a French balloon flight from Meudon by Lequeux and Gay in January for the same purpose. Their method was different; they were measuring absolute intensities with an interferometer at the center of the disk. But they did high resolution from which they could get preliminary values for the water vapor, obtaining 0.077 $\pm$ 0.015 microns above 82,000 feet and 0.022 $\pm$ 0.007 microns above 93,000 feet; although, their balloon was descending during those observations and may have swept away some of the water vapor that might normally be observed due to contamination. So, these are two more points for the list that Dr. Bader had on the board.

BAKER: Can you give any idea of the total cost of your balloon flight to compare with these other things we've talked about?

MANKIN: On the order of $100,000 for everything. This is per flight and includes rebuilding the basic framework and building whatever special equipment is needed for that flight. It doesn't include the fact that we have two of the original platforms. I don't know how much we needed for the development of those, but they've been around for years. We've had something like 16 flights. The balloon-borne coronagraph I mentioned is also on the same platform and is returned with the system.

BRANDT: We ran a gamma ray program out at Palestine, Texas, and for all practical purposes it compares to the costs that you quoted as costs.

SCHMALBERGER: I'd now like to turn the meeting over to Dr. Liebenberg for his comments.

DONALD H. LIEBENBERG

National Science Foundation

Let me put on two hats for about three minutes each. The first subject is to look for a moment at another discipline of interest at an eclipse—namely, the airglow studies. There aren't people here to speak to that point so I'd just like to say a couple of words in their behalf. This particular eclipse goes for a long distance through part of the mid-latitude region of the upper atmosphere. In this region, you're not running into auroral problems; and won't be influenced by the equatorial electrojet. You are flying along the path that was described by Bob, that takes you through a pretty stable region of the upper atmosphere. That means that over this path length during this time, you could, indeed, do some spectral studies of airglow and sky scattering which, I think, would have some value. You would have an advantage because the aircraft can maintain a relative eclipse attitude in a region of relatively unchanging upper atmosphere and because it takes a long time to collect photons at an effective signal-to-noise ratio. The airglow lines are very faint. The sky background is still fairly bright, and so it takes some luck to get valid polarization effects in sky scattering experiments. In general, people have not had sufficient time at eclipses to take into account the changing features of the solar shadow relative to their own location. In this particular eclipse you could maintain your position relative to the shadow.

If the aircraft's path was chosen so that the plane could travel along the northern part of the eclipse path, experiments could search for the daytime aurora. This problem has provided a real challenge and the high altitude platform would give a decrease in the background light and hence a significant improvement in signal-to-noise ratio. The 1970 eclipse is a good one because you can anticipate a fair amount of remaining solar activity. You get up to an L value—and, for those unfamiliar with it, it's essentially a magnetic latitude—of 5. In fact, this particular eclipse has the interesting feature that a good fraction of the eclipse is at a fairly constant L value over the last part of the eclipse. While some field line angles are changing, the magnetic latitude that you observe from is actually pretty constant.

Next, I'd like to make just a couple comments on the corona because—now I'm not speaking from the NSF point of view at all, but from my own observations—I would like to remark that the difficulty in observing the coronal emission lines is that you are limited in the number of photons you can collect. You'd like to obtain line profiles, emission line profiles, so that you can write down some information about the ion velocity distribution. In order to do this with some degree of accuracy, you can attempt to reconstruct the curve from a certain number of observations made to give, say, 100 resolvable points in the profile. Or you can look at the problem from the standpoint of the frequency response of the system looking at a line with arbitrary shape difference—departure, say, from a Gaussian function. In either one of these methods, you need something like 100 points to detect the kinds of departures from a Gaussian velocity distribution function to an accuracy of perhaps 1%. Now, some valuable work has been done at the level of 20 points resolution of the line profile. In fact, that's what we have obtained in previous eclipses. So it's a question of really setting about collecting photons. In the focal plane of an instrument fitted with fiber optics, as we used in 1966, we were able to improve the rate of data collection by using three photomultipliers and one photographic experiment simultaneously. Yet, in order to build up any information from a point in the emission corona that's at, say, 1/2 solar radius or greater you still find that you're fairly time limited. You have to make a decision as to whether you're going to devote the entire eclipse of 4 minutes or 3 minutes to collecting data about one emission line per photomultiplier tube, or whether you stay interior to one-half solar radius and then collect information on a multiplicity of lines or positions. So up to the present there is no useful line profile data beyond one solar radius. The photographic measurements that we've made have been carried out, getting reasonably good signal-to-noise ratios, to about 0.8 of a solar radius from the limb. In this case, then, there's no question but what the 30 minutes or 90 minutes or some fraction of that time scales directly into pretty much the total amount of information you can collect about the radial change of the velocity distribution function of ions along the line-of-sight. This, of course, is a key piece of information in putting together a model of how energy gets pumped into the corona and how the solar wind formation occurs from the gravitationally bound coronal material—neither of which questions have been answered because of time.

SCHMALBERGER: Questions on this? I have one. I'm not sure I understand how it's formed.

LIEBENBERG: Well, this is the intensity of the profile versus wavelength.

SCHMALBERGER: Oh, this isn't velocity distribution—what you called f(v) as a function of v?

LIEBENBERG: No. But it's an analog of that.

SCHMALBERGER: For one line, at one position?

LIEBENBERG: Yes, at one position integrated along a line-of-sight similar to the limitations of most visual coronal information.

SCHMALBERGER: OK. So, in other words, you need profiles, and you need an instrumental half width of something like a fifth or a tenth the line profile?

LIEBENBERG: Yes.

SCHMALBERGER: I see; but your main point is that you want this as a distribution over the field!

LIEBENBERG: That's right. To do this photographically, you can superimpose an interferometric pattern here, as several people have done, including myself. That's fine, except that now you will need the photometric accuracy of better than 5 percent if you prefer to improve upon this—particularly when the information that you're looking for is out in the wings.

MANKIN: The aurora and airglow; could they use the other side of the airplane?

LIEBENBERG: Quite possibly.

MERCER: You did mention observing the aurora. If we want to get the maximum solar elevation and get the best speed for the eclipse, we would be at latitudes just about crossing Mexico, too far south on the 1970 eclipse track for good auroral work.

LIEBENBERG: But I was looking at it after you refuel.

MERCER: Oh, I see. Well, by the time you got down to refuel, you cannot again get on the eclipse track. You can't catch up; so, you couldn't go on beyond that time. The velocity would now be well beyond what the aircraft is capable of doing in acceleration, and so forth.

LIEBENBERG: Now, if I put on my NSF hat for a moment, I would remark that I think there are enough good experiments having to do with solar physics that, considering the kind of payload that is available and the time scale, it would be a mistake to try and include every interesting experiment on one aircraft.

MERCER: Actually I think the aurora and airglow experiments would be very excellent ones to look at for 1972 where we'll be up at very high latitudes. We'll be right there to see the daytime aurora.

BADER: Don, can you say a little more about this aurora experiment. What do you expect to see at such a low latitude?

LIEBENBERG: Remember, L = 5. Under the probable disturbed solar conditions this latitude is somewhat south of the auroral oval in the daytime.

MENZEL: What are your units?

LIEBENBERG: Well, OK. Let me give you a thumbnail sketch, if I can have another few minutes. The earth's magnetic field in the dipole representation, is such that a magnetic line of force which extends outward and crosses the equator at 5 earth radii defines a locus of points in intersection on the earth's surface that is the L = 5 line.

MENZEL: OK.

LIEBENBERG: At L values greater than 8 or 9--where this nomenclature begins to break down—the field lines become very distorted compared to the dipole approximation. Remember that this magnetic axis is at some angle relative to the rotational axis of the earth—and, now, if I look as the earth is rotating around, it is carrying the center of that magnetic dipole around with it, and this provides, I hope you see, an off center locus of points where I anticipate finding auroral-like behavior, that is, precipitation of electrons. In the evening sector I see this as the formation of an aurora, and

I see that in the midnight sector the aurora has gone about as far South as it's likely to get. On any given day this locus of points is called the auroral oval. The auroral zone is something different. That's the locus of points that define this oval rotated around on the earth so that this function becomes seasonal. The appearance of the aurora occurs over a wide band of geographic latitude. So what one can expect to see in the daytime is that there ought to be electron precipitation occurring on the front side (day or solar wind side), if you believe in the current model of the process, and <u>should</u> produce an aurora.

BRANDT: Can't satellites see the precipitation?

LIEBENBERG: Satellites see the precipitation of electrons but not the daytime aurora.

BADER: So that the question is, "Why don't aurorae occur at lower geographic latitude?"

LIEBENBERG: Well, I'm not sure that we have a good handle on the precipitation mechanisms such that we can describe the energy spectrum variation from day to night. We don't know that the energy spectrum of electrons precipitating in one region is the same as in others. That's a satellite experiment that I don't believe has been accomplished. You clearly could have nighttime auroral observations during an eclipse, and obtaining daytime auroral observations in several wavelengths would be valuable. Suppose we consider auroral brightness as a function of altitude. This can provide an analog of the energy distribution function of the excited electrons.

BRANDT: I have a funny feeling that if you asked Joe Chamberlain whether this was worth doing he would say, "No." Somebody should call him up and ask him.

LIEBENBERG: Yes, that may be right. However, the point I'm trying to make is that the electron precipitation problems are certainly important, and that some thought could be given to the use of this aircraft in looking at this problem. Joe Chamberlain and the auroral physicists should be contacted.

BRANDT: If you want to do auroral physics, it would be better just to go do the zone with actual measurements in the case of electrons. Assume that if you had electrons, you'll have an aurora, rather than simply, say, observe on the day side and look for the 5577 A line and say, "Aha, there's an aurora." I don't see our needing it.

LIEBENBERG: I think we could make an even stronger case for doing such experiments but that is belaboring this point at present. I don't see that the SR-71 is necessarily unique to the auroral problem. For the airglow problem, it may be a slightly different matter. In any case the experts in the field should be contacted.

PASACHOFF: On the other hand, the point is well taken that, perhaps, something can be done from the other side of the plane.

MERCER: For our other eclipses we'll have to examine where the L numbers arrive on the 1972 and 1973 events.

MENZEL: And presumably this experiment could use a very small window.

MERCER: That's right.

DONALD C. SCHMALBERGER

Dudley Observatory

There are at least two problems which we are interested in at Dudley. And in discussing them with you it appears we'll be faced with this chromosphere-or-corona problem again.

We tend to favor in importance the region of upper photosphere-low chromosphere which Dick Thomas spoke about yesterday. That is, in that region where we all assume the temperature to be essentially constant up to the location of the chromospheric rise. One question we would like to look at is the turbulence in this layer—or at least what passes for tubulence, the non-thermal velocity parameter you can insert into the theory when calculating line profiles and which, at least in lower photosphere calculations, purports to be turbulence. Now there are some very good observations gotten by Roddier on a very few lines which resulted in a model with very small, almost vanishing velocity in the low photosphere and increasing with height to about 3 1/2 km/sec in the uppermost layers. I'm speaking there of layers within the temperature minimum where the radial optical depth at 5,000 A is about 10^{-3} to 10^{-4}; thus, at or above the region of unit tangential optical depth at the same wavelength. A model I derived a few years ago is anisotropic in the lower photosphere with both components in excess of three km/sec; both components decrease with height, the field becoming isotropic and about one km/sec in the upper layers. The decrease in this model occurs at about the same optical depths at which Roddier's model is increasing with height. And I should point out that Roddier's model is not the only one with height increasing turbulence any more than the one I obtained is the only model with turbulence decreasing with height. This, it seems to me, is an unfortunate state of affairs which could be resolved relatively directly if we could get line profiles for the temperature minimum area and the layers immediately adjacent radially. For many problems, too, on the dynamics of both the chromosphere and corona, one is concerned about the nature of the underlying medium for providing the initial conditions in a boundary value problem. So you'd like to know the model for these layers as well as possible.

For the profile calculations within this isothermal region one can use LTE theory as a first approximation. In many cases, in fact, one is almost going to be forced to do something like this because the information you want will be from lines which originate largely within these layers alone. That is, they are not things like H and K, or H_α, and so forth, which are formed over very much greater, and far more complex, layers. It would be very nice, then, to get high resolution with good spectral purity to look at some lines formed in this region. I don't know which lines in particular, as yet, but, fortunately, weak and moderately strong lines most useful for the purpose are scattered all about the visible, and selection can be governed more by instrumental criteria.

Another type of work, and for the same region of the atmosphere, that I'd like to counsel is for limb darkening observations—and these in the most canonical way. They should be done in a number of wavelengths, not necessarily too far into the infrared, but with extremely high spatial resolution; again, to look at this same locale. Spencer Weart has described the method of analysis, which need not be repeated. I think it's very important to pin this region down—I don't think it can be overemphasized. There just isn't any observational detail on these layers and the diverse models of present theory reflect our lack of knowledge.

With these sorts of things in mind we have looked at some telescope-spectrograph designs, always with a view to keeping the system as simple as possible. The problem you face immediately, of course, is how does one get a large plate scale without a large focal length and still retain something which is achromatic, i.e., using simple reflecting elements throughout. The simultaneous requirements of high spatial resolution, high chromatic resolving power, and high dispersion pose no end of problems. It may be that a modified version of the small three element camera Jim Baker talked about may be useful in this connection. In any case, the numbers we need for a spectrograph are easily calculable and found to be very similar to the sort of things which Dick Dunn has already noted—with a ten inch aperture, comparable focal ratio, and chromatic resolution in excess of 300,000. For rough purposes we looked at a long focus telescope with the heliostat, telescope, and spectrograph in a long box to be suspended inside the right aircraft bays. The heliostat is aft in the aft bay and throws the beam forward to the telescope primary at the forward end of the aft bay. In one arrangement, the beam is then sent back toward the heliostat forming an image next to it; in an alternate configuration, the primary has a focal length twice as long with a flat swung into position at the earlier, nominal, focal plane. Or the second mirror could be a figured element. In this connection we considered the possibility of a Schiefspiegel which seems to combine structural simplicity with a high degree of correction built-in, or at least it so appears. There, one has two spheres and the spherical aberration vanishes; moreover it can be made aplanatic or stigmatic by a simple tilt of the secondary. Since we would be feeding a spectrograph we would prefer the latter, of course. When we looked at this at first we were considering an unfolded long focal length primary so our numbers were based on a slower system than now seems required but for that system, which was f/50, we had the choice of no spherical aberration, and either a comatic blur of about 0.2 secs of arc in the stigmatic configuration, or an astigmatic circle of least confusion of about 0.6 secs of arc in the coma-free arrangement. It would be ideal if we could chop this system in half so that only one bay would be occupied with the heliostat, telescope, and guiding equipment. The forward bay could then contain the line profile spectrograph, the coronal scan system of John Brandt, and a lower dispersion spectrograph.

How we go about fusing the various preferences expressed here into a functional experiment package I don't know yet; but I think that a justifiable system must include a study of line profiles to try to separate out dynamical effects from thermal effects in this isothermal region. If you have a local velocity field which is not macroscopic mass motion—the very problem with spicular regions and higher levels—if you can stick to microturbulence in your thinking, then the profiles in this region can be calculated; the theory's there. Even if the velocity field is anisotropic, for example (and I don't think it is), the temperature field is not; so that one could distinguish between the two, even if one had to go to a non-LTE analysis. I think it is crucial that an experiment be done on line profiles and that a portion of this flight be devoted to it—there is just no other way to get the spatial resolution and sufficient exposure time.

Now with regard to some of the earlier comments. I think it was Dick Dunn who posed the question of who needs these line profiles. I think we all need them, and for these purposes I've just mentioned. You don't necessarily have to go through the non-LTE problems because we won't be dealing with lines like H and K, H_α, and so on, which I noted earlier and which are the only things that you can solve convincingly in non-LTE. If I have a two or three level atom, the odds are I can solve the problem in non-LTE; but if you take on a forty level atom it's going to take a little time! It's true that you can take the problem to a larger computer but you will still be forced to approximations on the radiation field, collision rates, etc. In short, I think that by a not unreasonable choice of lines one can use relatively unsophisticated theory to learn at least something about this presumably isothermal region.

Obviously, I concur heartily with Weart's preference for some continuum observations and I would hope that we can do something like this for the 1970 eclipse. Liebenberg's comments with regard to a possible experiment to look at the velocity distribution in the corona is a very important consideration. Perhaps this could be coupled with the wide field, high resolution camera which Jim Baker described. This instrument would seem ideal for some photography we would like to do ourselves.

I would emphasize that the higher layers which Don Menzel referred to as the source of Doppler shifting mass motions on a macroscopic scale are quite above the isothermal region I was discussing earlier. I don't see how they might cause serious problems in the analysis. We would be looking at lines which are optically thick in deeper layers. Should it be necessary to approximate the influence of the spicular region at the upper end this might be possible with a two, or three, component atmosphere in those layers--it's something to be looked at.

Two final comments. First, with regard to John Brandt's caution to adhere to experiments which admit of straightforward interpretations. This is clearly very sound advice--and consistent with our hope for isothermal region profiles. Second, an historical remark.

It was exactly one hundred years ago--indeed, in August 1868--that Janssen went to India to observe an eclipse and, during the course of the observing run, devised a new technique for continuing observations outside eclipse. Some of the lines he used were unidentified at the time but his work prompted a search that continued for almost thirty years and was not brought to a close until Ramsay finally identified the source as helium. One wonders what this aircraft might reveal!

I think that before we say farewell Don Menzel has a summary of experiments he would like to convey to you.

DONALD H. MENZEL

Harvard College Observatory

I've become aware of the fact that Dr. Baker, for example, has said, "How can we do it in 1970? We ought to be shooting for 1972." It seems to me that as things get more and more complicated, that's where we would wind up. So, I've been trying to think, "What would be a useful and attractive, minimal program that conceivably we might get off the ground in 1970?" I think that I have given the impression that I'm very much adverse to studies of the chromosphere. I'm not, at all. I think there are several, very good proposals, if we had time enough, and if the instrumentation was available. I'm not adverse to high resolution spectroscopy, but again, just to make this comment—I keep seeing in my mind's eye, sitting up there in the observer's seat looking at this eclipse of the sun, I see Bailey's Beads as the pilot weaves in and out. I see them getting bigger and smaller and then a big flash of the photosphere showing, and then I think that the advantages that you have—that you're thinking you have in terms of integration—because you're mentally trying to slow down the actual visual eclipse seen from the ground. I don't think that's what you're going to have here; and I think you'll find it very difficult to take a long exposure photograph here and have any of this high scale resolution in height that you consider so important. Maybe I'm wrong.

Maybe they can navigate that plane so accurately that they know precisely how this thing would look—just like the slow motion pictures of an eclipse either at the beginning or end of totality. But, even so, the profiles at high resolution are interesting and it is important. So, also, is the experiment for the continuous spectrum of the chromosphere. On the other hand, that, also, takes very high resolution, because there are lots of very fine lines. As they flow together, they look just like continuum and there's no way that I know of for distinguishing between the faint line background and the continuum. And, I still think that in the ordinary spectral ranges we can get enough resolution from the ground with high dispersion. You may have to wait a few eclipses, or have several ground based expeditions in order to get one which has the seeing that is necessary. I've been on a number of eclipse expeditions. Some of them had superb seeing, and some of them had "lousy" seeing—to use the technical term!

So, I'm going to propose several possible experiments, and I'm going to include one that is for those who are interested in the chromosphere as well. But I'm going to start with the problem of the corona! From the standpoints of understanding the darkness of the sky, the extent of the corona, the important nature of the problem, because this is the way of connecting the sun with the interplanetary medium. These are problems that are full of interest, a lot more interest than just to the group of some narrow specialists like myself, who happen to be interested in them from the theoretical standpoint. And so, I visualize here some instrument—maybe it was Jim Baker's f/1 camera system. I think probably that it is almost too small a scale. I think I'd like an f/1.5 or f/2 and it may well be a lens. I want something that will be, say, 6 inches in aperture. Then with a 12 inch focal length it's strictly an f/2. It would give a solar image about 1 mm in diameter, if I haven't made a mistake in a decimal point or something, and a scale of about 2 mm per degree. So that you can cover 30 degrees with 60 mm. It's the sort of thing that would go readily on a 70 mm film ....

DUNN: A focal length of 12 inches? That would be about 3 mm.

MENZEL: Just a second—that's right, a diameter of about 3 mm.

One must review my calculations. Then that's 6 mm per degree, so that we then have something on the order of only 10 degrees for 60 mm, although I would prefer having somewhat larger film than that. Cover something on the order of, say, 20 degrees. Ten degrees on each side of the sun would be adequate.

LIEBENBERG: Well, we should put the solar image to either side of the plate. Then you could use the 70 mm film to cover it.

MENZEL: Yes, yes; we could. But now this camera could be made to do the spiral scanning that John Brandt has been talking about. He was talking about something of extremely long focal length, but I don't think that the long focal length is critical. I would like to see this done in at least three colors, and maybe, also somewhere in the infrared, if it's possible to do it. Since you're going to take some fairly long exposures, you will get out a considerable distance. You may also want to try some polarization experiments. I think that we jumped a little bit fast in saying that the window would give us polarization problems. I have the feeling that that can be licked. It's not a question of the pressure of the air on the outside, it's simply the difference of temperature, and there must be some way of overcoming that or minimizing it, even it we just weaken the thickness of the glass. Some experimentation would be necessary there to see whether that is a hazard or not.

I would prefer the spiral scanning, if that can be worked in. On the other hand, the photography gives you more information over a given frame, because of the integration. You're integrating everything at the same time; so, you can carry through a bigger program, though with less accuracy.

Now, the next thing is the problem of the detection of new coronal lines, which we have not actually discussed. I think there are a good many, new coronal lines to be detected. Here again, this ties in with the work that a good many of the theorists are going at the present time—predicting the positions of new spectral lines, trying to identify old ones; and it's a definite advantage that we have here, because many of these lines, which I think are new lines, will lie out here in the infrared where there are some strong atmospheric absorption bands—water vapor and so on. If we can get above a significant portion of the atmosphere, this will greatly strengthen these lines relative to the absorption, enabling us to detect them. I would say this should be a slit spectrograph. And this is a multiple purpose spectrograph--this is one of the by-products. It should have dispersion of, let's say, 10 A/mm, and I'd say, it should go from about 3300 A to 9000 A, plus or minus, depending again on the availability of film. This would require that the detectable wavelengths be broken up into at least two spectral regions. I suggest, perhaps, a grating spectrograph in which we use a first order on one side, second order on the other, or something of that sort; but in any event a slit spectrograph, employing a camera or lens of, in this case, about 60 inches focal length. This could go into the designed box and will give you a good spectrum of the chromosphere as it comes out of the bright lines in the corona, and also of the coronal continuum. I would suggest that it may be desirable to put a beam splitter into this equipment—one like Dick Dunn used on some of his spectra—so that we can have not one intensity but 3 or 4 intensities, so that we can have sufficient gradations to tie in with standardization and identification. This spectrum would also help us answer one problem that Jay Pasachoff and I are particularly interested in.

In the 1930's, I think it was,—maybe it was in the late 1920's—Grotrian, observing the continuous spectrum of the inner corona which is extremely bright and which is generally ascribed to scattering by free electrons, said that he saw very highly broadened H and K lines. This is a slit spectrograph, incidentally. I've used a slitless spectrograph, which should have had adequate resolution for the purpose, for the same objective and have found no trace, whatever, of this supposed depression. That was for two eclipses; and Shayn, the Russian astrophysicist, in 1936 also found results that agreed with me. Van de Hulst accepts without question the determination of Grotrian because it fits with his concept of the F corona. And he makes some critical statement, that may, perhaps, have been justified, that perhaps it was missed by Menzel and Shayn because it required more precise photometry. Jay and I recently rephotometered the plates, and we still find no evidence of that depression (Publ. Astr. Soc. Pacific, in press). I think this observation may answer this question. Also, in the longer exposures of the H and K region, it would probably show emission lines and get a repetition of the experiment that Righini and Deutsch did from an airplane several years ago. The interesting point was, I think, that the K line seemed to show the bright line, but there was no evidence of this whatever in the H line. What is this, and why?

There's a third experiment which I think rates a higher priority than this one. This is a low dispersion spectrum of the F corona, with a dispersion, say, of 20 A/mm to 40 A/mm with a camera lens, say, of 6 inches diameter, 30 inches focal length—possibly 15 inches—and covering an area, so far as the spectrum is concerned, not only of the sun, but an area of about 3 degrees, say three and a half degrees or four degrees on either side of the sun. This probably also should be done so as to get the bright, strong regions, and then the weaker regions. In this way, we should be able to see the scattered light over the center where the moon is as a standardization, see what the distribution is, and finally the amounts of Fraunhofer lines that have been recorded. This is something that has, to my mind, never been adequately done. It's difficult to do from an ordinary plane, difficult enough to do from the ground; and I have some doubts about how well it has been done from the ground, because of the difficulty of eliminating scattered light. Here with a dark sky you've got an unusual opportunity.

Now the fourth experiment that I'd like to see done is a distinctly chromospheric experiment, and I would suggest that the simplest thing is the jumping film—down in the 8000 to 11000 A range. Possibly this is the region which should be scanned. But, at least, you should record the flash spectrum down in this range as you come through with the chromosphere on the edge. Now this does not suffer seriously from any possible difficulty in guiding. You also have a chance to do some integration here. The old problem of the infrared corona was that you didn't have enough time, you were taking it from the ground, but you can now take an exposure readily of several seconds or more, if you want, without tremendously reducing your resolution.

So these are, I think, a minimum thing yet they all contain very important problems. Maybe they're not the most important problems, but I think that the equipment that is necessary to put these together would cost less than 10% of the funds that would be necessary to build some of the very highly specialized equipment which we have discussed here.

SCHMALBERGER: Are there any other final comments of a direct nature?

HEMENWAY: John, could you get good statistics with a 6 inch aperture?

BRANDT: I don't think that would be a serious problem. You'd get 10,000 points if you can't get 40,000.

SCHMALBERGER: Have the people who've done work with the high plate scale sort of problems tried to get high spatial resolution? You've done some of this, Dick. What do you think is practically realizable?

DUNN: I think you've got a small space there to work with. These last two experiments are certainly the sort of ones that I did on the NASA plane. We had a gyro-stabilized telescope with a 10 inch aperture and about a 40 inch focal length, and we covered the region from 2900 to 9000 A, at 36 and 18 A/mm. And these plates, I must say, are superb. The water vapor is essentially nonexistent. And we did pick up a number of new lines, very strong ones, in the middle of the A band; so the resolution is about 1 A.

SCHMALBERGER: When was this?

DUNN: Well, that was in 1965 and 1966. I guess we don't advertise around. The '65 airborne results are in Bader's initial publication. The '65 results from ground base with identical instruments is coming out.

For '66, now, I've given all the plates to Billings. He has a student who wants to work on them. I tried to get one of Lou House's students, but Lou had them loaded down. The plates are available. And I also traced the 18 A/mm spectrum, and sent a copy to Jay Pasachoff for this H and K thing. So, there is work going on, I think. You can argue about 10 A/mm ....

MENZEL: Did your spectrum show the Fraunhofer lines?

DUNN: It didn't really, no. And I can't visualize how you could get a cleaner looking spectrum.

MENZEL: Well, this shows that there is, at least, some evidence that one could go out further, and that the continuum is not a Fraunhofer continuum. But I've maintained that the Fraunhofer is something else--scattered light.

DUNN: There's no sign of the H and K emission on any of these plates, and I just don't know. I think Deutsch and Righini have not said anything further on this.

PASACHOFF: As far as I recall from reading whatever they published and reading the transactions of the IAU, they are not claiming any dip.

DUNN: They get the lines. There's no doubt about it. But they just don't understand why they get them.

PASACHOFF: The emission lines, but not the absorption. And, as far as the scattering, Grotrian's paper, when retranslated, reads a lot different from what people report it as being.

MENZEL: Dick, apart from the H and K absorption, did you find in the outer corona any evidence of a Fraunhofer spectrum?

DUNN: No. Well, when I got about a half of a diameter out it just looked like H and K absorption; that's about all. But no 400 A lines.

PASACHOFF: Grotrian didn't find it either. This is a real red herring. Grotrian said, "We looked, and the coronal and photospheric experiments agree to our accuracy, and our accuracy is a tenth of a magnitude." And then much later on he said, "Maybe we may see a small depression of a couple of hundred A around H and K." But he's already said that it's less than his error.

DUNN: Well, somebody ought to do it again photoelectrically. Jack Evans was interested in it. He did a paper on it years ago, I guess.

PASACHOFF: Well, Brandt did it, and he says he's thinking about reducing the data.

SCHMALBERGER: Well, I wonder if we couldn't wrap it up. One final question; more general but I don't think it was brought up yet. Addressed more to Jim Baker than anyone, I guess. This problem of windows in the nose cone--whether you get flat windows or curved windows; and what sort of things you can do with them?

MERCER: They can utilize flat windows. Within limits they don't have to be curved to match the cone shape. But right now the maximum is five inches between these ribs, and they'd prefer to stay that way. Maybe we can break through a rib and reenforce around it so we could get ten inches.

BAKER: What is the base diameter inside?

MERCER: Well, it goes from about 14 inches at the small end, to about 40 inches back where it connects onto the aircraft. We're talking about a length of seven and a half feet. Those are the outside dimensions but if you look in end-on at the thing, you would see these chine extensions which are dummy fairings, and you couldn't work into these. They've just added these on to fair in this chine as it comes forward along the fuselage. Every five inches there are ribs, ribs running all the way around, just like rings, really, and I have the dimensions on this at several stations. It's not exactly a straight cone--there's some longitudinal curvature to it. It's a very slow curvature over this long distance, you see, and almost straight for short distances. At intervals of 90° around its periphery (starting at 45° off the vertical) there are longerons which extend the whole length of the nose cone, so that the longerons and the ribs are the skeleton structure.

SCHMALBERGER: Yes, but what sort of configuration can you put on the outside of this thing that's form fitting to that contour but is still not an abomination optically?

BAKER: Well, if you're absolutely forced to do that, you probably could compensate it inside at some conjugate image. But it would be better, of course, to keep the window plane. I was just wondering: Is it conceivable that this thing could be made to rotate?

SCHMALBERGER: You mean the outer shell? I don't think so.

MERCER: No, but it may be possible, as I noted earlier, to build or to cut a round hole or a special shape that might have several windows in it. These windows might be stored inside, but could come out so that you could have several window types for one external opening if you're concerned, say, about going through several spectral regions with different type materials. You momentarily open a reenforced aperture to automatically slide one of several window materials in place and it quickly comes flush with the outer skin.

BAKER: Could we take out a section of the transverse stiffening member and strengthen the hole that's left with other members?

MERCER: By transverse, do you mean the longerons?

BAKER: No, I mean the ribs. And then reenforce in some other way?

MERCER: Yes. Just carry the structural load around.

BAKER: This would give us a larger window. What is the heating on flat windows, do you have any idea?

MERCER: Well, again, it would be pretty much the aerodynamic temperature at these speeds and it would still be around 250 °F. The stagnation point temperature at the end of the spike is 322 °F.

BAKER: Would it be higher than at the windows that are back in the chines?

MERCER: I don't know that that is necessarily the case.

BAKER: Well, maybe what you've got in this plane is not truly fair; it might be a higher temperature.

MERCER: This is true. It could be a little higher because of localized aerodynamic effects, I think, but I don't know what these are. We can get data on these depending on where we decide the windows ought to go.

BAKER: Otherwise it is essentially hollow?

MERCER: Yes, and, in fact, the Lockheed people mentioned that, perhaps, the equipment could be put in here by mounting on a big pallet that slides out or comes out on rails. Then, of course, we'd have to put the windows in the nose cone shell separately. But if the experimental apparatus must be tied directly in with the windows, it may be more complex because you would not be able to work back in the nose cone once the instrument pallet is in place if you have to tie the window into the front end of your instrument. It may be that you could slide the pallet in and then make some other connections from the outside by a rotation of an external window flange to lock it in place, so that the window would actually be more tightly tied to the experiment. There would be some mechanical problems here.

BAKER: Well, I think by all means, we should use that space although I'm not sure what experiment we can do from there.

MERCER: Well, anytime they use this lightweight nose, because of center-of-gravity problems, they have to put about 400 pounds of weight in it for ballast or something on that order, anyway.

BAKER: Well, normally, the radar.

PASACHOFF: What about flying without radar?

MERCER: Well, we would take off the normal nose which contains the radar and other things.

PASACHOFF: They don't need the radar for piloting?

MERCER: No, the radar is not needed for our tracking purposes. We could use the inertial navigation system. Basically the aircraft uses a stellar-inertial navigator with stellar sensors.

MENZEL: I'd be very cheap ballast. (Laughter)

LIEBENBERG: Is there a difference in the availability of power up in the nose area?

MERCER: No, because if you took the normal nose off at the bulkhead you'd have all the power for the radar available at that point.

LIEBENBERG: Yes, but does that include the 115 volt power?

MERCER: Yes, they use all that power in the equipment up here, and there's cooling up here available also. So you can get cooling. Now, normally, there's a layer of insulation around the inside of the nose cone shell structure, but you can cut it away if you have to. You just put up with whatever additional temperatures you get as a result of this. Just blowing air into this nose bay you can get the internal temperature down to 160 °F; that is, if you just dumped air into the nose cone and let it bleed out through small ports.

MANKIN: How long before flight would you be able to get to the equipment to do thing like put liquid helium in?

MERCER: This would just be a matter of designing your experimental equipment in such a way that you have a serviceable type of cryogenic container—one where you fill it and let it bleed off during the mission.

MANKIN: OK.

MERCER: We would set up the preflight operations in such a way for this special requirement that you could plug in with a cart and top off at the last possible minute—an hour or maybe 30 minutes prior to engine start.

MANKIN: Sort of through an external filler line.

MERCER: Yes. I think this could be arranged if such an experiment were done. After all, it was done just like this with Gemini spacecraft flights.

SCHMALBERGER: Certainly, if you had the small, three-element, camera that Jim Baker was talking about, you could simply pop one or more of those in the nose without much trouble. With any long focal length, you could fold the beam to get into the bay. I think it would be worth considering, however, with regard to your own plans, in which bay you'd be most effective scientifically and, at the same time, where you could occupy the least space.

BAKER: Well, on this nose cone again, they don't want to rotate it, apparently. But, can it be unbolted and moved in azimuth on the ground?

MERCER: Well, no; it can't because these two chines are not symmetrical. They're down a little bit below center, I believe.

BAKER: They join, I see.

MERCER: They join at the nose and must mate with the forward fuselage chines.

BAKER: It's welded to the nose cone?

MERCER: Yes, I think it's actually welded right to these nose cone longerons. The elevation is 45° to the longeron locations, so that if we're looking at 51° elevation as our minimum for the 1970 eclipse there wouldn't be interference. Of course, you have to reassess this problem for different eclipses.

BAKER: Do you have drawings of that nose cone, too?

MERCER: I have some very crude information.

SCHMALBERGER: A parting remark, then, before I turn it over to Curt Hemenway. And that is to say that we've been recording this meeting, as we pointed out at the beginning, and will make up a digest of the tape in, perhaps, the form of a report of the Dudley Observatory and may send some brief copy to Sky and Telescope.* In any case, if you have something that you have written up, and you'd like this to appear with some sort of inclusion such as a table or a picture, get it off to me at your earliest opportunity. With that, then, we'll turn it over to Curt.

HEMENWAY: I think we'll just adjourn. It's lunch time, and some of us have to leave in the early afternoon. Thank you, all, very much.

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