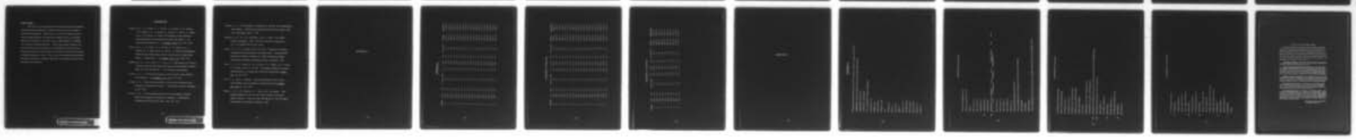
AD-A054 341 AEROSPACE CORP EL SEGUNDO CALIF IVAN A GETTING LABS F/G 22/3
THE CONSTRUCTION OF THERMOSPHERIC DENSITY CORRECTION TABLES FOR--ETC(U)
APR 78 L R SHARP, A B PRAG F04701-77-C-0078
UNCLASSIFIED TR-0078(3960-04)-4 SAMSO-TR-78-87 NL

1 OF 1
ADA
054341



END
DATE
FILMED
6-78
DDC

REPORT SAMSO-TR-78-87

②

The Construction of Thermospheric Density Correction Tables for Use in Satellite Trajectory and Lifetime Predictions

L. R. SHARP and A. B. PRAG
Space Sciences Laboratory
The Ivan A. Getting Laboratories
The Aerospace Corporation
El Segundo, Calif. 90245

26 April 1978

Interim Report

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED

Prepared for

SPACE AND MISSILE SYSTEMS ORGANIZATION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
P.O. Box 92960, Worldway Postal Center
Los Angeles, Calif. 90009

This interim report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract No. F04701-77-C-0078 with the Space and Missile Systems Organization, Deputy for Advanced Space Programs, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009. It was reviewed and approved for The Aerospace Corporation by G. A. Paulikas, Director, Space Sciences Laboratory. Lieutenant Dara Batki, SAMSO/YCPT, was the project officer for Advanced Space Programs.

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Dara Batki

Dara Batki, Lt, USAF
Project Officer

Robert W. Lindemuth

Robert W. Lindemuth, Lt Col, USAF
Chief, Technology Plans Division

FOR THE COMMANDER

Floyd R. Stuart

FLOYD R. STUART, Col, USAF
Deputy for Advanced Space Programs

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(19) **REPORT DOCUMENTATION PAGE**	**READ INSTRUCTIONS BEFORE COMPLETING FORM**
1. REPORT NUMBER (18) SAMSO-TR-78-87	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) THE CONSTRUCTION OF THERMOSPHERIC DENSITY CORRECTION TABLES FOR USE IN SATELLITE TRAJECTORY AND LIFETIME PREDICTIONS.	5. TYPE OF REPORT & PERIOD COVERED (9) Interim repto
	6. PERFORMING ORG. REPORT NUMBER (14) TR-0078(3960-04)-4
7. AUTHOR(s) (10) Lawrence R. Sharp and Arthur B. Prag	8. CONTRACT OR GRANT NUMBER(s) (15) F04701-77-C-0078
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Aerospace Corporation El Segundo, Calif. 90245	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Space and Missile Systems Organization Air Force Systems Command Los Angeles, Calif. 90009	12. REPORT DATE (11) 26 Apr[illegible]978
	13. NUMBER OF PAGES 25 (12) 25p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Thermospheric Models
Satellite Trajectories
Ephemeris Predictions
Thermospheric Density Variations

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In order to improve short-term ephemeris predictions and long-term satellite lifetime estimates, a set of correction tables has been provided. For the user, a ratio of a modified version of MSIS and DENSEL for a variety of input parameters is shown on these tables.

DD FORM 1473 (FACSIMILE)

409 944

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

JOB

CONTENTS

INTRODUCTION

The requirement to predict satellite trajectories accurately depends very critically on detailed knowledge of upper atmospheric density. The atmospheric model currently being used at the Satellite Control Facility (SCF) in Sunnyvale has errors in it which can lead to corresponding position errors which are unacceptably large at the end of a one-day period. In addition, the long-term lifetime predictions based on this model have little validity. The situation is most critical for high inclination orbits at low altitudes. The errors are expected to become more severe as solar maximum is approached around 1980.

The model currently in use at SCF is called 'DENSEL. This model is essentially a juxtaposition of the ARDC 1959 (Air Research and Defense Command) model (Mizner et al., 1959) and the first thermospheric density model produced by Jacchia (1960). The simplicity of the 'DENSEL model makes it useful for production-type calculations such as orbit determinations. However, since it doesn't include any of the known atmospheric variations other than the diurnal and solar cycle effects, its accuracy is rather poor. In addition, recent studies by Sharp et al. (1978) have shown that the diurnal variation in 'DENSEL and other models derived from satellite drag data is incorrectly modeled, especially at low altitudes. Also, since there is no provision for K_p input to the model, the density predictions of 'DENSEL are too low during a magnetic storm. As a consequence of these errors in 'DENSEL, the right combination of K_p, month of the year, and local time could lead to a situation where 'DENSEL would predict a density that was too low by more than a factor of 2.

DISCUSSION

In the last 18 years enough progress has been made in thermospheric physics and upper atmospheric modeling to justify replacing 'DENSEL with a more accurate model. In order to select a replacement model for 'DENSEL, extensive tests were run on five current upper atmospheric density models and 'DENSEL using the neutral density data base compiled at the Space Sciences Laboratory of The Aerospace Corporation. This data base currently consists of over 40,000 measurements of neutral atmospheric density at 5 km intervals in the range 130-400 km. The data were obtained from three different types of instruments: cold cathode ion gauges, capacitance manometers and calorimeters. The former two instruments are described by Rice et al. (1973). The data reduction procedures for constructing the data base have been described by Rice and Sharp (1977).

The five other models tested were MDAC (Olson et al., 1975) MSIS (Hedin et al., 1977a, b), J-65 (Jacchia, 1965), J-71 (Jacchia, 1971) and J-77 (Jacchia 1977). A comprehensive description of all these models with the relative advantages and limitations of each has been provided by Hickman et al., (1978). Two measures of a model's effectiveness were employed in this evaluation, the average percentage error and the RMS error. The average absolute precentage error is simply:

$$E_A = \frac{100}{N} \sum_{i=1}^{N} \left| \frac{\rho_i - m_i}{m_i} \right|$$

Where: ρ = Measured Density

m = Density Predicted by the Model

N = Number of Points

The RMS error is defined as:

$$E_R = \left[\frac{1}{N} \sum_{i=1}^{N} \left(\log \frac{\rho_i}{m_i} \right)^2 - \frac{1}{N} \left(\sum_{i=1}^{N} \log \left(\frac{\rho_i}{m_i} \right) \right)^2 \right]^{1/2}$$

In the RMS error calculation any offset between the model and the data base is removed and the larger amplitude errors are weighted more heavily.

In Table 1 is presented the results of this test divided into 2 altitude regimes, 130-195 and 200-400 km. Since MSIS performed the best in the low altitude regime where density predictions are most critical,it was selected as the model to replace 'DENSEL.

The MSIS (Mass Spectrometer and Incoherent Scatter) model makes use of measurements of upper-atmospheric compositions from Mass Spectrometers on five satellites (AE-B, OGO-6, San Marco-3, Aeros-A and AE-C) and neutral temperatures inferred from incoherent scatter measurements at four ground stations (Arecibo, Jicamarca, Millstone Hill, and St. Santin). The data set covers the time period from 1965 to 1975, essentially a complete 11 year solar cycle. There are two limitations in MSIS which should be corrected to enhance the accuracy of the model predictions. The first is the fact that MSIS has no K_p input. It models the corpuscular heat source simply by using the daily Ap index. Since the

TABLE 1

	All Data	130-195 km	200-400km
Number of Points	40,261	25,639	14,622
Average Absolute Percentage Error			
'DENSEL	22.3	28.9	26.2
MSIS	13.5	12.6	15.8
J-71	14.2	13.5	16.3
J-77	15.4	15.1	17.0
J-65	18.0	14.7	30.4
MDAC	28.8	23.8	30.6
Average RMS Percentage Error			
'DENSEL	23.4	17.0	28.7
MSIS	16.9	14.2	18.2
J-71	16.7	15.7	18.8
J-77	17.8	17.5	18.8
J-65	18.3	16.1	18.9
MDAC	21.0	19.1	21.8

thermosphere is known to respond to changes in K_p with a delay time of about 6 hours; a K_p correction algorithm has been added in a form which best fits The Aerospace Data Base. For $K_p \leq 4.3$ the correction is given by

$$D\ (6) = D\ (6) \times \left[(K_p + 1.0)^{0.05} \right]$$

where D (6) is the output density of the basic model. For $K_p > 4.3$ the correction is given by

$$D\ (6) = D\ (6) \times \left[\left(\frac{K_p}{3.5} \right)^{0.4} \right] \quad .$$

For $K_p = 4.0$ the correction factor from the first equation is 1.083 and for $K_p = 4.3$ the correction factor from second equation is 1.085; for $K_p = 8$ the correction factor is 1.391. The application of this correction algorithm yields a model known as MSIS (MOD 1).

The second correction is applicable to the altitude dependence of the model output. MSIS in general predicts densities which are too low at low altitudes and too high at high altitudes when compared with The Aerospace Data Base and the Jacchia Models. The following correction algorithm compensates for this effect

$$D\ (6) = D\ (6) \times \left[.98 + \left(\frac{185-H}{1200} \right) \right]$$

where H is the altitude in km.

At 130 km the correction factor is 1.025 and at 300 km the correction factor is .884. The addition of this correction algorithm to MSIS (MOD 1) yields a model known as MSIS (MOD 2). The accuracy analysis for these two modifications is presented in Table 2 along with the original results for MSIS and 'DENSEL repeated for convenience.

As can be seen from Table 2, the accuracy difference between 'DENSEL and MSIS (MOD 2) is significant but not overwhelming, so an expensive systems software change was deemed inappropriate. Consequently, a set of correction tables was generated which provide the ratio of MSIS (MOD 2) to 'DENSEL for a number of input parameters designed for wide coverage, good resultion and ease of use. The computer Fortran Code is contained in Appendix A and a portion of the printout is contained in Appendix B. Copies of subroutines 'DENSEL and MSIS are available upon request.

The format of the computer printout is set up in such a way so the user can rapidly enter the appropriate input parameters and find the necessary density correction. The first column gives the month of the year. All 12 months are provided since 'DENSEL has no semiannual variation. The day of the month is assumed to be the 15th. The next column is the altitude in nautical miles. The tables have been provided in two sets, one from 65 to 95 NM and the second set from 100 to 150 NM, both in 10 NM steps. The third column is latitude with four values provided (0°, 20°, 40°, 60°N). The fourth column is local time with six values provided (2.0, 6.0, 10.0, 14.0, 18.0, 22.0). The fifth column is the 10.7 cm flux for the day prior to the day the prediction is to be made with four values provided (80, 120, 160, 200). The sixth column is the

TABLE 2

Average Absolute Percentage Error	
'DENSEL	22.3
MSIS	13.5
MSIS (MOD 1)	13.1
MSIS (MOD 2)	12.1

Average RMS Percentage Error	
'DENSEL	23.4
MSIS	16.9
MSIS (MOD 1)	16.4
MSIS (MOD 2)	15.4

K_p value which occurred six hours prior to the time for which the prediction is to be made with five values provided (0, 2, 4, 6, 8). The eighth column is the ratio of the MSIS (MOD 2) density prediction to the 'DENSEL prediction. The next column is labeled B-Factor (which is short for "B-Factor Correction") since this ratio should be proportional to the B-Factor which is currently being generated from observation of orbit precession and knowledge of offsets and errors in 'DENSEL. The last two columns give the actual densities for both MSIS (MOD 2) and 'DENSEL in grams per cm^3 for reference. For best possible accuracy in using these tables, some interpolation will be necessary.

CONCLUSION

Two sets of correction tables have been provided to the Satellite Control Facility in Sunnyvale, California which will aid in satellite tracking and navigation. These tables, one for low altitudes and the other for high altitudes, incorporate a modified version of the MSIS Model and provide the user with a ratio of MSIS (MOD 2) to 'DENSEL for a variety of input parameters. These tables shall eliminate the need to make ad hoc corrections to the 'DENSEL-derived B-Factors since these systematic corrections are derived from the best currently available atmospheric model. Thus, short-term ephemeris predictions and long-term lifetime estimates should be considerably more accurate than they are at present.

REFERENCES

Hedin, A. E., J. E. Salah, J. V. Evans, C. A. Reber, G. P. Newton, N. W. Spencer, D. C. Kayser, D. Alcayde, P. Bauer, L. Cogger, and J. P. McClure, "A Global Thermospheric Model Based on Mass Spectrometer and Incoherent Scatter Data MSIS 1. N_2 Density and Temperature," J. Geophys. Res., 82, 2139, 1977.

Hedin, A. E., C. A. Reber, G. P. Newton, N. W. Spencer, H. C. Brinton, H. G. Mayr and W. E. Potter, "A Global Thermospheric Model Based on Mass Spectrometer and Incoherent Scatter Data MSIS 2. Composition," J. Geophys. Res., 82, 2148, 1977.

Hickman, D. R., B. K. Ching, C. J. Rice, L. R. Sharp and J. M. Straus, "A Survey of Currently Important Empirical Thermospheric Models," Rept. No. SSL-78(3960-04) The Aerospace Corporation.

Jacchia, L. G., "A Variable Atmospheric Density Model From Satellite Accelerations," J. Geophys. Res., 65, 2775, 1960.

Jacchia, L. G., "Static Diffusion Models of the Upper Atmosphere with Empirical Temperature Profiles," Smithsonian Contrib. Astrophys., 8, 215, 1965.

Jacchia, L. G., "Revised Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles," Smithsonian Astrophysical Observatory, Spec. Rep. 332, 1971.

Jacchia, L. G., "Thermospheric Temperature, Density, and Composition: New Models," Smithsonian Astrophysical Observatory Spec. Rep. 375, Cambridge, Mass., 1977.

Minzner, R. A., K. S. W. Champion and H. L. Pond, "The ARDC Model Atmosphere, 1959" Air Force Surveys in Geophysics No. 115, ARCRC-TR-59-267, 1959.

Olson, W. P., K. A. Pfitzer, and O. K. Moe, "Response of the Magnetosphere and Atmosphere to the Solar Wind," Final Scientific Report for Contract F44620-72-C-0084, McDonnell Douglas Astronautics Company, Huntington Beach, California, 1975.

Rice, C. J., V. L. Carter, S. R. La Valle, W. T. Chater, D. A. Jones, C. G. King, and D. F. Nelson, "Atmosphere Explorer Pressure Measurements: Ion Gauge and Capacitance Manometer," Radio Sci., 8, 305, 1973.

Rice, C. J., and L. R. Sharp, "Neutral Atmospheric Waves in the Thermosphere and Tropospheric Weather Systems," Geophys. Res. Let., 4, 315, 1977.

Sharp, L. R., D. R. Hickman, C. J. Rice, and J. M. Straus, "The Altitude Dependence of the Local Time Variation of Thermospheric Density," Rept. No. SSL-78(3960-04)-2, The Aerospace Corporation, El Segundo, California, 1978.

APPENDIX A

APPENDIX A

MONTH	ALT.	LAT.	LOCAL TIME	AP	F10.7	KP	B-FACTOR	DENSEL	MSIS(MOD2
8	100.0	0.0	2.0	5.0	80.0	0.0	1.14	.287E-12	.327E-12
8	100.0	0.0	2.0	5.0	80.0	2.0	1.22	.287E-12	.349E-12
8	100.0	0.0	2.0	5.0	80.0	4.0	1.25	.287E-12	.360E-12
8	100.0	0.0	2.0	5.0	80.0	6.0	1.41	.287E-12	.406E-12
8	100.0	0.0	2.0	5.0	80.0	8.0	1.58	.287E-12	.455E-12
8	100.0	0.0	2.0	5.0	120.0	0.0	1.01	.381E-12	.385E-12
8	100.0	0.0	2.0	5.0	120.0	2.0	1.08	.381E-12	.411E-12
8	100.0	0.0	2.0	5.0	120.0	4.0	1.11	.381E-12	.424E-12
8	100.0	0.0	2.0	5.0	120.0	6.0	1.25	.381E-12	.477E-12
8	100.0	0.0	2.0	5.0	120.0	8.0	1.41	.381E-12	.535E-12
8	100.0	0.0	2.0	5.0	160.0	0.0	.93	.474E-12	.439E-12
8	100.0	0.0	2.0	5.0	160.0	2.0	.99	.474E-12	.469E-12
8	100.0	0.0	2.0	5.0	160.0	4.0	1.02	.474E-12	.484E-12
8	100.0	0.0	2.0	5.0	160.0	6.0	1.15	.474E-12	.545E-12
8	100.0	0.0	2.0	5.0	160.0	8.0	1.29	.474E-12	.612E-12
8	100.0	0.0	2.0	5.0	200.0	0.0	.87	.567E-12	.491E-12
8	100.0	0.0	2.0	5.0	200.0	2.0	.92	.567E-12	.525E-12
8	100.0	0.0	2.0	5.0	200.0	4.0	.95	.567E-12	.541E-12
8	100.0	0.0	2.0	5.0	200.0	6.0	1.07	.567E-12	.609E-12

APPENDIX A (Continued)

MONTH	ALT.	LAT.	LOCAL TIME	AP	F10.7	KP	B-FACTOR	DENSEL	MSIS(MOD2)
8	100.0	0.0	2.0	5.0	200.0	8.0	1.20	.567E-12	.684E-12
8	100.0	0.0	2.0	20.0	80.0	0.0	1.18	.287E-12	.338E-12
8	100.0	0.0	2.0	20.0	80.0	2.0	1.26	.287E-12	.362E-12
8	100.0	0.0	2.0	20.0	80.0	4.0	1.30	.287E-12	.373E-12
8	100.0	0.0	2.0	20.0	80.0	6.0	1.46	.287E-12	.420E-12
8	100.0	0.0	2.0	20.0	80.0	8.0	1.64	.287E-12	.471E-12
8	100.0	0.0	2.0	20.0	120.0	0.0	1.04	.381E-12	.397E-12
8	100.0	0.0	2.0	20.0	120.0	2.0	1.11	.381E-12	.424E-12
8	100.0	0.0	2.0	20.0	120.0	4.0	1.15	.381E-12	.438E-12
8	100.0	0.0	2.0	20.0	120.0	6.0	1.29	.381E-12	.493E-12
8	100.0	0.0	2.0	20.0	120.0	8.0	1.45	.381E-12	.553E-12
8	100.0	0.0	2.0	20.0	160.0	0.0	.96	.474E-12	.453E-12
8	100.0	0.0	2.0	20.0	160.0	2.0	1.02	.474E-12	.484E-12
8	100.0	0.0	2.0	20.0	160.0	4.0	1.05	.474E-12	.499E-12
8	100.0	0.0	2.0	20.0	160.0	6.0	1.19	.474E-12	.562E-12
8	100.0	0.0	2.0	20.0	160.0	8.0	1.33	.474E-12	.631E-12
8	100.0	0.0	2.0	20.0	200.0	0.0	.89	.567E-12	.506E-12
8	100.0	0.0	2.0	20.0	200.0	2.0	.95	.567E-12	.540E-12
8	100.0	0.0	2.0	20.0	200.0	4.0	.98	.567E-12	.557E-12
8	100.0	0.0	2.0	20.0	200.0	6.0	1.11	.567E-12	.627E-12

APPENDIX A (Continued)

MONTH	ALT.	LAT.	LOCAL TIME	AP	F10.7	KP	B-FACTOR	DENSEL	MSIS(MOD2)
8	100.0	0.0	2.0	20.0	200.0	8.0	1.24	.567E-12	.704E-12
8	100.0	0.0	2.0	35.0	80.0	0.0	1.22	.287E-12	.349E-12
8	100.0	0.0	2.0	35.0	80.0	2.0	1.30	.287E-12	.373E-12
8	100.0	0.0	2.0	35.0	80.0	4.0	1.34	.287E-12	.385E-12
8	100.0	0.0	2.0	35.0	80.0	6.0	1.51	.287E-12	.433E-12
8	100.0	0.0	2.0	35.0	80.0	8.0	1.69	.287E-12	.486E-12
8	100.0	0.0	2.0	35.0	120.0	0.0	1.08	.381E-12	.409E-12
8	100.0	0.0	2.0	35.0	120.0	2.0	1.15	.381E-12	.437E-12
8	100.0	0.0	2.0	35.0	120.0	4.0	1.18	.381E-12	.451E-12
8	100.0	0.0	2.0	35.0	120.0	6.0	1.33	.381E-12	.508E-12

APPENDIX B

APPENDIX B

```
PROGRAM DENJAC(INPUT,OUTPUT, TAPE 5=INPUT, TAPE 6=OUTPUT)
DIMENSION GXO(3), SUN(4), SAT(4), T(2), F(2), CD(6), CG(6)
DIMENSION D(8), TE(2)
EXTERNAL USERDMP
CALL NABLE(174602B, USERDMP)
PI=ACOS(-1.0)
MASS=48.0
D2R=PI/180.
TWOPI=2.*PI
N=0
FBAR=80.0
AP=5.0
TLOC=2.0
IMON=1
ADAY=15.0
CLONG=240.0
ZALT=185.2
XALT=100.0
ALAT=0.0
GEO=0.0
```

```
      UT=TLOC-CLONG/15.0
      IF(UT.LT.0)UT=UT +24
      ICT=0
      DO 10 II=1,5
      DO 15 KK=1,6
      WRITE(6,99)
99    FORMAT(1H1)
      WRITE(6,98)
98    FORMAT(// 9X,*MONTH      ALT.      LAT.      LOCAL TIME      AP      F10.
     +7      KP      B-FACTOR      DENSEL      MSIS(MOD2)*/)
      DO 20 JJ=1,4
      DO 30 LL=1,6
      DO 35 NN=1,3
      DO 40 MM=1,4
      DO 50 I=1,5
      AMJD=ADAY+42048.0+(UT/24.0)
      CALL DENSEL(ZALT,FBAR,ALAT,TLOC,ADAY,DENSE)
      SAV3=FBAR
      S1=FBAR
      JDAY=ADAY
      CALL GTS3(JDAY,UT,ZALT,ALAT,CLONG,TLOC,SAV3,S1,AP,MASS,D,TE)
```

APPENDIX B (Continued)

```
          ALTCOR=(185-ZALT)/1200
          D(6)=(.98+ALTCOR)*D(6)
          G=(GEO/3.5)**.4
          F=(GEO+1.0)**.05
          IF(GEO.GT.4.3)D(6)=G*D(6)
          IF(GEO.LE.4.3)D(6)=F*D(6)
          USAF=D(6)/DENSE
          ICT=ICT+1
          IF(MOD(ICT,50).EQ.0 )WRITE(6,99)
          IF(MOD(ICT,50).EQ.0 )WRITE(6,98)
   200    WRITE(6,201)IMON,XALT,ALAT,TLOC,AP,S,GEO,USAF,DENSE,D(6)
   201    FORMAT( 9X,I3,6F10.1, F10.2,2E12.3)
          GEO=GEO+2.0
          IF(I.EQ.5 )GEO=0.0
    50    CONTINUE
          FBAR=FBAR+40.0
          IF (MM.EQ.4)FBAR=80.0
    40    CONTINUE
          AP=AP+15.0
```

APPENDIX B (Continued)

```
     IF (NN. EQ. 3) AP=5. 0
 35  CONTINUE
     TLOC=TLOC+4. 0
     IF(LL. EQ. 6) ICT=0
     IF(LL. EQ. 6) TLOC=2. 0
 30  CONTINUE
     ALAT=ALAT+20. 0
     IF(JJ. EQ. 4)ALAT=0. 0
 20  CONTINUE
     ZALT=ZALT+10*1. 852
     XALT=XALT+10
     IF(KK. EQ. 6)ZALT=100*1. 852
     IF(KK. EQ. 6)XALT=100. 0
 15  CONTINUE
     IMON=IMON+1
     ADAY=ADAY+30. 5
 10  CONTINUE
     END
```

THE IVAN A. GETTING LABORATORIES

The Laboratory Operations of The Aerospace Corporation is conducting experimental and theoretical investigations necessary for the evaluation and application of scientific advances to new military concepts and systems. Versatility and flexibility have been developed to a high degree by the laboratory personnel in dealing with the many problems encountered in the nation's rapidly developing space and missile systems. Expertise in the latest scientific developments is vital to the accomplishment of tasks related to these problems. The laboratories that contribute to this research are:

Aerophysics Laboratory: Launch and reentry aerodynamics, heat transfer, reentry physics, chemical kinetics, structural mechanics, flight dynamics, atmospheric pollution, and high-power gas lasers.

Chemistry and Physics Laboratory: Atmospheric reactions and atmospheric optics, chemical reactions in polluted atmospheres, chemical reactions of excited species in rocket plumes, chemical thermodynamics, plasma and laser-induced reactions, laser chemistry, propulsion chemistry, space vacuum and radiation effects on materials, lubrication and surface phenomena, photosensitive materials and sensors, high precision laser ranging, and the application of physics and chemistry to problems of law enforcement and biomedicine.

Electronics Research Laboratory: Electromagnetic theory, devices, and propagation phenomena, including plasma electromagnetics; quantum electronics, lasers, and electro-optics; communication sciences, applied electronics, semiconducting, superconducting, and crystal device physics, optical and acoustical imaging; atmospheric pollution; millimeter wave and far-infrared technology.

Materials Sciences Laboratory: Development of new materials; metal matrix composites and new forms of carbon; test and evaluation of graphite and ceramics in reentry; spacecraft materials and electronic components in nuclear weapons environment; application of fracture mechanics to stress corrosion and fatigue-induced fractures in structural metals.

Space Sciences Laboratory: Atmospheric and ionospheric physics, radiation from the atmosphere, density and composition of the atmosphere, aurorae and airglow; magnetospheric physics, cosmic rays, generation and propagation of plasma waves in the magnetosphere; solar physics, studies of solar magnetic fields; space astronomy, x-ray astronomy; the effects of nuclear explosions, magnetic storms, and solar activity on the earth's atmosphere, ionosphere, and magnetosphere; the effects of optical, electromagnetic, and particulate radiations in space on space systems.

THE AEROSPACE CORPORATION
El Segundo, California

• • •