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THE ATMOSPHERE OF MARS: A DERIVATION OF ENGINEERING AND DESIGN PARAMETERS

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ABSTRACT

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SUMMARY

Three model atmospheres have been derived for use in mission planning, aerospace lander design, and Martian orbiter and flyby studies. Atmospheric parameters for these three models have been calculated from the planetary surface to 10,000 kilometers. These three model atmospheres of differing atmospheric composition, surface pressure, and surface temperature are the upper density model (60 percent CO_2 and 40 percent N_2); the mean density model (100 percent CO_2); and the lower density model (80 percent CO_2 and 20 percent Ar). The general program of Kern and Schilling [9], with a few revisions, was used; this publication contains the details of the mathematical basis and program routines in considerable depth. The models chosen should provide values which will be of use as guidelines for the engineering and design of orbiting and landing vehicles.

I. INTRODUCTION

The occultation experiment on Mariner IV has provided data that have permitted the formulation of more credible self-consistent model atmospheres for Mars. This experiment indicated pressures ranging from four to ten millibars surface pressure and from 150° to 270° Kelvin in surface temperature.

Mars is an obvious objective for planetary studies and exploration, and should be a major goal in the future space program. The first mission to Mars has been successfully flown in Mariner IV. This probe yielded a wealth of new information on surface conditions, the atmosphere, the planetary magnetic field, and the planetary mass. From these data, more realistic evaluations of the planetary conditions may be made. These new

evaluations will, in turn, be used in the design of more sophisticated instruments to narrow the range of values even more. In addition, new missions will be planned to gather extensive data on areas as yet untouched. These new missions will be in the form of unmanned orbiters and landers. These craft require extensive data on the magnetic field, gravitational field, and especially the atmospheric conditions of the planet. This report deals primarily with the atmosphere of the planet Mars, but we also touch on the gravitational and magnetic fields of Mars.

Ideally, one atmospheric model for the planetary conditions should be given; however, even for Earth this is not feasible since the upper atmosphere is subject to diurnal, latitudinal, and solar cycle variations. As a result, three atmospheric models were generated with the suggestion that (1) the mean density model be used for design, and (2) the design should be critically tested to verify its survival in either of the other two atmospheric models.

We wish to thank Mr. C. L. Hasseltine for the suggestions he has made during the construction of these models. We also wish to thank Mrs. Jeanette Scissum for revisions made in the original computer program.

II. THE MARINER IV OCCULTATION EXPERIMENT

Probably the simplest experiment carried out by the recent Mariner IV probe has provided more data on the atmosphere of Mars than any other individual experiment. It consisted of observing the Doppler shift in signals from the probe as it was occulted by the planet Mars. This Doppler shift provided a direct indication of the atmospheric refractive index from which the surface pressure and temperature may be inferred. Johnson [2] interprets the low density near the surface of Mars as indicating that the atmosphere consists almost entirely of carbon dioxide.

Atmospheric composition from spectroscopic observations of Mars prior to Mariner IV had provided some data on the amount of carbon dioxide in the atmosphere. This was obtained from examining the pressure broadening of the weak CO_2 spectral absorption lines near 8700 A and broad CO_2 bands near 2μ. One of the prime candidates (before Mariner IV) for the major composition of the Martian atmosphere was thought to be molecular nitrogen. Nitrogen had not been observed in the spectral emissions of Mars; but since the spectral lines of nitrogen lie outside the earth's atmospheric windows, there was no problem in accounting for these missing data. Molecular nitrogen was selected because it was relatively heavy and would not readily escape from the planetary gravitational field. Also, molecular nitrogen does not have a high affinity for photochemical reaction. The large percentage of nitrogen in the terrestrial atmosphere undoubtedly played a role in the selection of this diatomic molecule as the primary gas of the Martian atmosphere.

Argon is now a primary candidate along with molecular nitrogen for a second constituent in the atmosphere of Mars. Argon results from the decay of potassium 40, and accounts for about 0.9 percent by volume of the earth's atmosphere. Owen [1] quotes a partial pressure of 2 millibars for argon on Mars using terrestrial analogy.

Polarization studies by Kaplan, Spinrad, and Münch [8] have indicated the presence of precipitable water vapor. But the amount of water vapor is almost indiscernible.

The molecular composition of the Martian atmosphere is now considered to be primarily carbon dioxide. For our mean atmospheric model of Mars, we chose a surface pressure of 8,000 dynes/cm^2 and a surface temperature of 210° K. An adiabatic lapse rate of 5°/km was chosen with the tropopause located at 14 kilometers. To this point, our model corresponds exactly to that given by Johnson [2]. However, at 60 kilometers, we assumed that our atmosphere would change from a purely mixed medium to a gas undergoing strong dissociation and diffusive equilibrium. When carbon dioxide is dissociated, the resulting atomic oxygen and carbon monoxide begin to undergo diffusive separation. The rate of change of mean molecular mass should be rather rapid since we assume that the predominant ion at the ionization peak is atomic oxygen, O^+. The mean molecular mass at 120 kilometers is then assumed to be 22, composed primarily of 60 percent oxygen atoms, 30 percent carbon monoxide, and 10 percent carbon dioxide.

A second point which we consider in developing the mean molecular mass curve has to do with the very low magnetic field which must surround Mars. It has been estimated that the surface magnetic field of Mars will not exceed about 500 gammas (5×10^{-3} gauss). J. A. Van Allen et al. [6] indicate, as a result of Mariner IV data obtained from the University of Iowa "package" of low-energy-particle detectors aboard, that the equatorial surface magnetic field of Mars is less than 200 gammas, and that these results suggest interaction of the solar wind with the Martian atmosphere. This interaction may be of primary importance in determining the physical state of the atmosphere. J. J. O'Gallagher and J. A. Simpson [5] and E. J. Smith et al. [4] also comment on the solar wind interaction with the Martian atmosphere. If this is so, then the upper atmosphere of that planet must be related very intimately with the interplanetary environment. The solar wind will penetrate deeply into the upper atmosphere and probably will become an actual part of the atmosphere itself. How deeply the solar wind particles can pervade the atmosphere is a subject for further consideration. We feel that the upper atmosphere of Mars will definitely be influenced by the solar wind and that this will be even more significant when the upper atmospheric temperature is discussed. Essentially at 1,000 kilometers above the surface of Mars, the solar wind is the primary source of the atmospheric composition.

ATMOSPHERIC TEMPERATURE

The temperature at the Martian surface probably varies from about 150° K to about 270° K. These two values make up our proposed temperature extremes. As we mentioned earlier, we have chosen an intermediate temperature of 210° K to represent our mean atmospheric surface temperature. On the other hand, once we exceed 150 kilometers, we have chosen to let our temperature vary by the equations

$$T = 85 \left(\frac{H}{150}\right)^{1.83635} \quad \text{for Model II and Model III}$$

and

$$T = 92 \left(\frac{H}{150}\right)^{1.8175} \quad \text{for Model I}$$

where H is the height in kilometers.

By this method, we reach the interplanetary temperature of about 190,000° K at 10,000 kilometers. This temperature distribution is based upon the supposition that the solar wind penetrates to low altitudes (relative to the earth) on Mars. The solar wind is cooled as it collides with the atmosphere, and in this manner becomes a part of the atmosphere. If one accepts this concept, then the atmospheric density and composition will be a direct function of solar activity. Also, there will be no isothermal exosphere on Mars, but rather a continuous increase in temperature until the kinetic gas temperature of interplanetary space is reached. We have chosen this altitude as 10,000 kilometers, although the solar wind predominates by 1,000 kilometers.

III. MODEL DESCRIPTIONS AND DATA OUTPUT TABLES

A. MODEL I (UPPER DENSITY MODEL)

Our upper density model supposes the atmosphere to be composed of 60 percent CO_2 and 40 percent N_2 by volume. We have chosen a surface temperature of 270° K which might well be a mean upper limit to the atmospheric surface temperature of the planet. Previous measurements of surface temperatures for the planet Mars undoubtedly were not indicators of atmospheric surface temperatures. Spectral measurements give the representative temperature of the planetary surface which may or may not be in equilibrium with the overlying atmosphere. This is especially true

on Mars where the tenuous atmosphere provides very poor thermal insulation. Planetary surface temperatures probably undergo a mean diurnal variation of as much as a factor of two greater than the mean diurnal variation of the atmospheric temperature immediately above the surface.

A dry adiabatic lapse rate of -4.55° K/km exists to an altitude of twenty-two kilometers after which a lapse rate of -1.0° K/km prevails to 100 kilometers. From 100 kilometers to 150 kilometers, the isothermal region exists; and from 150 kilometers to 10,000 kilometers, the temperature varies by the equation

$$T = 92 \left(\frac{H}{150}\right)^{1.8175}.$$

The mean molecular mass is assumed to be 37.6, which exists to an altitude of 71 kilometers. At this altitude, dissociation is assumed to begin with the resulting components undergoing diffusive equilibrium. At the height of 120 kilometers, the predominant ion is taken as atomic oxygen and an F_2-type peaking of the ionosphere results.

The initial surface gravity is assumed as 375 cm/sec^2 and varies with increasing altitude by the equation

$$g_z = 375 \left(\frac{r}{r + z}\right)^2,$$

where g_z is the acceleration due to gravity at height, z, above the surface.

The planetary radius r is taken as 3,381 kilometers. This equation for the acceleration due to gravity was used in all models discussed in this report.

The surface pressure, p, for this model was chosen as 10,000 dynes/cm^2 resulting in a calculated surface density of 1.67×10^{-5} grams/cm^3. This mass density was derived through the equation

$$\rho = \frac{Mp}{RT},$$

where ρ is the atmospheric mass density, M is the mean molecular mass of the atmosphere, T is the atmospheric gas temperature, and R is the universal gas constant. This equation was used throughout to calculate the value of atmospheric density.

The geopotential pressure scale height was calculated to be 15.92 kilometers at the surface dropping to 10.02 kilometers by 22 kilometers. The lowest calculated value of the potential pressure scale height was 7.13 kilometers at 71 kilometers.

The upper density model should also be used in total heating studies of vehicles entering into the Martian atmosphere. Apparently, a high argon content in the atmosphere will not increase heating significantly [11], which should be expected since argon is an inert gas and is not easily ionized.

We have found that the pressure and density curves for this model stabilize at relatively large values. The density at 1,000 kilometers is just over 10^{-17} grams per cubic centimeter, whereas the pressure is reasonably stable at 10^{-6} dynes per square centimeter which is the pressure at 700 kilometers on Earth.

Use of this model will result in atmospheric drag on aerospace vehicles; this drag is correspondingly less on Mars than on Earth below 700 kilometers and correspondingly greater on Mars than on Earth for altitudes greater than 700 kilometers.

At any rate, it is apparent in all models given here that the absence of an extensive isothermal region results in large scale heights above about 200 kilometers. This tends to stabilize the atmosphere of Mars more rapidly than on Earth.

Extensive data on the physical properties of the atmosphere may be found in Table I. In addition to the previously discussed parameters, we have calculated the speed of sound (cm/sec), columnar mass (grams/cm^2), number density (cm^{-3}), viscosity of the mixture (poise, or grams/(cm-sec) and kinematic viscosity (cm^2/sec).

B. MODEL II (MEAN DENSITY MODEL)

The mean density model was covered in Section II, but will be repeated here for continuity. An atmospheric temperature of 210° K was chosen as a mean at the surface of Mars. The pressure with this model is taken as 8,000 dynes/cm^2. A temperature lapse rate of -5°/km was chosen to obtain an altitude of fourteen kilometers after which a lapse rate of -0.64°/km obtains to 100 kilometers. Above 100 kilometers the atmosphere is isothermal to an altitude of 150 kilometers after which the temperature varies by

$$T = 85 \left(\frac{H}{150}\right)^{1.83635}.$$

As in Model I, this temperature is a result of the interaction of the solar wind with the planetary atmosphere.

The mean molecular mass of the atmosphere was taken to be 44 at the surface. At an altitude of 60 kilometers, dissociation and diffusion began. By 60 kilometers, the atmospheric pressure is 1.06 dynes/cm^2 on Mars, whereas this pressure is not reached until about 95 kilometers on Earth. Since the bonding strength for CO_2 is about the same as that for oxygen, we chose 60 kilometers as a reasonable mean altitude for photodissociation to begin. An interesting point here is that, if the mean molecular mass is not assumed to dissociate and the atmosphere is taken as isothermal above 100 kilometers, then interplanetary densities will be reached by 220 kilometers. This is not a reasonable model for the atmosphere of any terrestrial planet the size of Mars. Another subject for further consideration and possible interest might be the effect of the solar wind penetration of the atmosphere and the variations in the flux of the solar wind as a possible mechanism in accounting for the so-called "blue haze" phenomenon observed in the atmosphere of Mars.

The pressure scale height, using the initial parameters specified above, varies from 10.58 kilometers at the planetary surface to 6.5 kilometers at 30 kilometers. According to Mariner IV data, the pressure scale height should have been essentially a constant of about 9 kilometers in that region. For that to be true for any case, the temperature would have to be almost isothermal for the first 30 kilometers. An isothermal atmosphere here means that the atmosphere would be in radiative equilibrium. There is the possibility that the CO_2 abundance in the atmosphere maintains an isothermal balance by condensing out and revaporizing. A subadiabatic lapse rate could have been chosen assuming this or some similar mechanism acting in the lower atmosphere; however, we chose to go along with a near-dry adiabatic lapse rate because we need to know much more about the reactions taking place therein in order to construct better models. We may, indeed, speculate about these reactions but, without conclusive evidence, our speculations are only that.

In this model a density of about 4.4×10^{-22} is reached at 10,000 kilometers, which is on the order of the expected interplanetary density. The gravitational field of Mars at this point is still a strong influence on the atmospheric medium.

Table II is a tabulation of a number of parameters for the mean density model of the Martian atmosphere. All values are in cgs units.

C. MODEL III (LOWER DENSITY MODEL)

This lower density model considers the atmosphere on Mars to be made up of 80 percent CO_2 and 20 percent argon. J. J. O'Gallagher and J. A. Simpson [5] report an implication based on their conclusions drawn from Mariner IV data that virtually all of the secondary production of particles from high-energy interactions takes place below the surface of Mars instead of in the atmosphere, as on Earth. Fast neutrons from cosmic radiation and solar flare protrons of sufficient energy will penetrate to the surface of Mars; the resulting π mesons produced in the solid planet will interact with nuclei below the Martian surface producing radioactive and stable isotopes.

From the above mechanism, we infer that the gases possibly produced and released, such as argon, may be in sufficient quantities to qualify as secondary gases in the Martian atmosphere.

The inclusion of argon in this model and nitrogen in Model I provides output data of interest in the consideration of aerodynamic heating factors in the Martian atmosphere in addition to the factors contributed by the 100 percent CO_2 atmosphere considered in Model II.

The surface pressure with this model is taken as 4,000 dynes/cm^2. A temperature lapse rate of -5.15°/km was chosen to an altitude of ten kilometers after which a lapse rate of -0.15°/km obtains to 100 kilometers. Above 100 kilometers, the atmosphere is isothermal to an altitude of 150 kilometers, after which the temperature varies by

$$T = 85 \left(\frac{H}{150}\right)^{1.83635}.$$

This minimum density model provides a probable lower limit for the atmosphere of Mars. Parachute descent to the Mars surface should certainly consider the effects of such an atmosphere as this.

Orbiters of the planet will certainly not encounter excessive drag for this model, since the atmospheric density at 100 kilometers on Mars is about the same as that at 300 kilometers on Earth. Above this altitude, the atmospheric density for Mars falls off at a much faster rate than it does on Earth. This is due to the relatively low temperatures between 100 and 200 kilometers. Once again, this atmosphere is found to stabilize by about one thousand kilometers because of the large temperatures encountered.

Table I

Maximum Density Model

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 3.76000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 1.00000000E 04
TEMPERATURE= 2.70000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIM.)
0	1.00000000E 04	2.70000000E 02	1.67491854E-05
1.59211723E 06	2.66666667E 01	3.76000000E 01	3.75000000E 02
2.89112703E 04	2.68333771E 17	1.59211723E 06	1.98512356E 02
			1.18520604E 07
5.00000000E 05	7.20000000E 03	2.47300000E 02	1.31663633E-05
1.45826145E 06	1.92569142E 01	3.76000000E 01	3.73891681E 02
2.76692476E 04	2.10934432E 17	1.46258415E 06	2.07423218E 02
			1.57540252E 07
1.00000000E 06	5.03000000E 03	2.24500000E 02	1.01323246E-05
1.32381600E 06	1.34930321E 01	3.76000000E 01	3.72785002E 02
2.63629171E 04	1.62326991E 17	1.33168179E 06	2.17701416E 02
			2.14858313E 07
1.50000000E 06	3.38000000E 03	2.01800000E 02	7.57448293E-06
1.18996021E 06	9.09384507E 00	3.76000000E 01	3.71679963E 02
2.49945817E 04	1.21348563E 17	1.20058955E 06	2.29619542E 02
			3.03148801E 07
2.00000000E 06	2.16000000E 03	1.79000000E 02	5.45705302E-06
1.05551476E 06	5.82875499E 00	3.76000000E 01	3.70576965E 02
2.35402899E 04	8.74258408E 16	1.06811405E 06	2.43805170E 02
			4.46770756E 07
2.50000000E 06	1.32000000E 03	1.66900000E 02	3.57663850E-06
9.84164320E 05	3.57263872E 00	3.76000000E 01	3.69474807E 02
2.27307340E 04	5.73002731E 16	9.98881692E 05	2.52488300E 02
			7.05937431E 07

Parameter Units

Height	centimeters	Temperature	degrees Kelvin
Pressure scale height .	centimeters	Molecular mass . .	dimensionless
Speed of sound	centimeters/sec	Density scale height	centimeters
Pressure	dynes/cm^2	Density	grams/cm^3
Columnar mass	particles/cm^2	Gravity	cm/sec^2
Number density	particles/cm^3	Viscosity(mix) . .	poise
		Viscosity(kinematic)	cm^2/sec

Table I (continued)

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 3.76000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 1.00000000E 04
TEMPERATURE= 2.70000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIM.)
3.00000000E 06	7.85000000E 02	1.61900000E 02	2.19270527E-06
9.54680667E 05	2.13098246E 00	3.76000000E 01	3.68374689E 02
2.23876607E 04	3.51286860E 16	9.71850839E 05	2.56357485E 02
			1.16913790E 08
3.50000000E 06	4.61000000E 02	1.56900000E 02	1.32872600E-06
9.25197015E 05	1.25518611E 00	3.76000000E 01	3.67276211E 02
2.20392476E 04	2.12871284E 16	9.44653833E 05	2.60410178E 02
			1.95984858E 08
4.00000000E 06	2.66000000E 02	1.51900000E 02	7.91920008E-07
8.95713362E 05	7.26419944E-01	3.76000000E 01	3.66179374E 02
2.16852373E 04	1.26871175E 16	9.17289545E 05	2.64661360E 02
			3.34202138E 08
4.50000000E 06	1.51000000E 02	1.46900000E 02	4.64849753E-07
8.66229710E 05	4.13603245E-01	3.76000000E 01	3.65084176E 02
2.13253511E 04	7.44722112E 15	8.89756835E 05	2.69127780E 02
			5.78956487E 08
5.00000000E 06	8.39000000E 01	1.41900000E 02	2.67384987E-07
8.36746057E 05	2.30500446E-01	3.76000000E 01	3.63990620E 02
2.09592863E 04	4.28369620E 15	8.62054555E 05	2.73828236E 02
			1.02409727E 09
6.00000000E 06	2.43000000E 01	1.31900000E 02	8.33141813E-08
7.77778752E 05	6.71626148E-02	3.76000000E 01	3.61808427E 02
2.02072721E 04	1.33475199E 15	8.06136648E 05	2.84018762E 02
			3.40900861E 09
7.00000000E 06	6.38000000E 00	1.21900000E 02	2.36687011E-08
7.18811448E 05	1.77403176E-02	3.76000000E 01	3.59632795E 02
1.94261682E 04	3.79189297E 14	7.49526453E 05	2.95438830E 02
			1.24822578E 10
8.00000000E 06	1.60000000E 00	1.11900000E 02	5.84707172E-09
7.29709993E 05	4.47597867E-03	3.40000000E 01	3.57463724E 02
1.95728829E 04	1.03592662E 14	7.65507741E 05	3.08357406E 02
			5.27370658E 10
9.00000000E 06	4.16000000E-01	1.01900000E 02	1.50248513E-09
7.38337323E 05	1.17083754E-03	3.06000000E 01	3.55301213E 02
1.96881810E 04	2.95772808E 13	7.79267311E 05	3.24133760E 02
			2.19066196E 11

Table I (continued)

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 3.76000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 1.00000000E 04
TEMPERATURE= 2.70000000E 02

HEIGHT	PRESSURE	TEMPERATURE	DENSITY
PRESSURE SCALE HEIGHT	COLUMNAR MASS	MOLECULAR MASS	GRAVITY
SPEED OF SOUND	NUMBER DENSITY	DENSITY SCALE HEIGHT	VISCOSITY(MIX.)
			VISCOSITY(KIM.)
1.00000000E 07	1.08000000E-01	9.19000000E 01	3.94350191E-10
7.30315356E 05	3.05823158E-04	2.79000000E 01	3.53145265E 02
1.95810000E 04	8.51426850E 12	7.75511626E 05	3.40260606E 02
			8.62838699E 11
1.10000000E 07	3.18000000E-02	9.19000000E 01	1.03628823E-10
8.18305158E 05	9.05993549E-05	2.49000000E 01	3.50995877E 02
2.07278405E 04	2.50697906E 12	8.74267918E 05	3.40260606E 02
			3.28345529E 12
1.20000000E 07	1.08000000E-02	9.19000000E 01	3.09543698E-11
9.30401755E 05	3.09585942E-05	2.19000000E 01	3.48853050E 02
2.21011520E 04	8.51426850E 11	1.00013647E 06	3.40260606E 02
			1.09923286E 13
1.30000000E 07	4.09000000E-03	9.19000000E 01	1.06519834E-11
1.02309947E 06	1.17963715E-05	1.99000000E 01	3.46716784E 02
2.31851778E 04	3.22438502E 11	1.10743428E 06	3.40260606E 02
			3.19434037E 13
1.40000000E 07	1.66000000E-03	9.19000000E 01	3.99742209E-12
1.10738035E 06	4.81735997E-06	1.84000000E 01	3.44587079E 02
2.41117126E 04	1.30867460E 11	1.20511666E 06	3.40260606E 02
			8.51200094E 13
1.50000000E 07	7.22000000E-04	9.19000000E 01	1.59690102E-12
1.20566855E 06	2.10825120E-06	1.69000000E 01	3.42463935E 02
2.51590140E 04	5.69194617E 10	1.32021407E 06	3.40260606E 02
			2.13075576E 14
1.60000000E 07	3.31000000E-04	1.03400000E 02	6.12173023E-13
1.44185816E 06	9.72535847E-07	1.59000000E 01	3.40347352E 02
2.75131883E 04	2.31924459E 10	1.58866172E 06	3.20781384E 02
			5.24004443E 14
1.70000000E 07	1.73000000E-04	1.15500000E 02	2.68423167E-13
1.71867928E 06	5.11475182E-07	1.49000000E 01	3.38237330E 02
3.00384191E 04	1.08518359E 10	1.90548077E 06	3.03513794E 02
			1.13072876E 15
1.80000000E 07	1.00000000E-04	1.28000000E 02	1.30609401E-13
2.04171112E 06	2.97500517E-07	1.39000000E 01	3.36133669E 02
3.27398585E 04	5.66016548E 09	2.27778793E 06	2.88313144E 02
			2.20744956E 15

Table I (continued)

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 3.76000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 1.00000000E 04
TEMPERATURE= 2.70000000E 02

HEIGHT	PRESSURE	TEMPERATURE	DENSITY
PRESSURE SCALE HEIGHT	COLUMNAR MASS	MOLECULAR MASS	GRAVITY
SPEED OF SOUND	NUMBER DENSITY	DENSITY SCALE HEIGHT	VISCOSITY(MIX.)
			VISCOSITY(KIN.)
1.90000000E 07	6.38000000E-05	1.41000000E 02	7.02038427E-14
2.42341910E 06	1.90996823E-07	1.29000000E 01	3.34036969E 02
3.56692448E 04	3.27823939E 09	2.72060355E 06	2.74700766E 02
			3.91290214E 15
2.00000000E 07	4.37000000E-05	1.55000000E 02	4.03521155E-14
2.88791137E 06	1.31647669E-07	1.19000000E 01	3.31946630E 02
3.89378154E 04	2.04262591E 09	3.26247254E 06	2.62001380E 02
			6.49287841E 15
2.50000000E 07	1.20000000E-05	2.33000000E 02	5.82267817E-15
5.49575282E 06	3.73142043E-08	9.40000000E 00	3.21593351E 02
5.37147115E 04	3.73133655E 08	6.40842636E 06	2.13693576E 02
			3.67002210E 16
3.00000000E 07	5.85000000E-06	3.24000000E 02	1.67213443E-15
9.32939345E 06	1.87858800E-08	7.70000000E 00	3.11404098E 02
6.99852239E 04	1.30812713E 08	1.12346709E 07	1.81216159E 02
			1.08374157E 17
3.50000000E 07	3.77000000E-06	4.29000000E 02	7.08155233E-16
1.41965107E 07	1.25091716E-08	6.70000000E 00	3.01378869E 02
8.63317329E 04	6.36682856E 07	1.76644485E 07	1.57485575E 02
			2.22388493E 17
4.00000000E 07	2.82000000E-06	5.47000000E 02	3.47231740E-16
2.16570063E 07	9.67351323E-09	5.60000000E 00	2.91517666E 02
1.06629866E 05	3.73508835E 07	2.78589544E 07	1.39468382E 02
			4.01657931E 17
4.50000000E 07	2.31000000E-06	6.77000000E 02	2.09297044E-16
2.94318538E 07	8.19670711E-09	5.10000000E 00	2.81820488E 02
1.24304961E 05	2.47207936E 07	3.91630333E 07	1.25364650E 02
			5.98979552E 17
5.00000000E 07	1.99000000E-06	8.20000000E 02	1.34266190E-16
3.99234771E 07	7.30845595E-09	4.60000000E 00	2.72287336E 02
1.44047997E 05	1.75824067E 07	5.44325863E 07	1.13910170E 02
			8.48390579E 17
6.00000000E 07	1.62000000E-06	1.14000000E 03	7.00790842E-17
6.16481600E 07	6.38516480E-09	4.10000000E 00	2.53713187E 02
1.79903541E 05	1.02955431E 07	9.11189030E 07	9.66088698E 01
			1.37864793E 18

Table I (continued)

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 3.76000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 1.00000000E 04
TEMPERATURE= 2.70000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIN.)
7.00000000E 07	1.42000000E-06	1.51000000E 03	3.95866772E-17
9.56550773E 07	6.02218080E-09	3.50000000E 00	2.35794980E 02
2.24095773E 05	6.81318991E 06	1.52126453E 08	8.39423170E 01
			2.12046688E 18
8.00000000E 07	1.30000000E-06	1.93000000E 03	2.67343476E-17
1.29670890E 08	5.94875958E-09	3.30000000E 00	2.18532953E 02
2.60916112E 05	4.88005977E 06	2.22513736E 08	7.42490278E 01
			2.77728968E 18
9.00000000E 07	1.22000000E-06	2.40000000E 03	1.89530841E-17
1.71651923E 08	6.04178652E-09	3.10000000E 00	2.01927029E 02
3.00195369E 05	3.68288100E 06	3.18775903E 08	6.65830686E 01
			3.51304664E 18
1.00000000E 08	1.15000000E-06	2.90000000E 03	1.38314416E-17
2.21717067E 08	6.18355351E-09	2.90000000E 00	1.85977205E 02
3.41176582E 05	2.87302192E 06	4.47065004E 08	6.05717927E 01
			4.37928267E 18
2.00000000E 08	8.85000000E-07	1.02000000E 04	2.81758140E-18
8.37597807E 08	1.41453920E-08	2.70000000E 00	6.25645440E 01
6.63128079E 05	6.28611319E 05	5.02040226E 09	3.22975322E 01
			1.14628569E 19
3.00000000E 08	8.11000000E-07	2.10000000E 04	1.20765954E-18
1.79079169E 09	1.70306011E-07	2.60000000E 00	4.76201630E 00
9.69621389E 05	2.79795456E 05	1.41021543E 11	2.25091855E 01
			1.86386848E 19
4.00000000E 08	7.77000000E-07	3.60000000E 04	6.23016240E-19
3.32575600E 09	6.18157004E-08	2.40000000E 00	1.25696222E 01
1.32137122E 06	1.56371505E 05	9.92200466E 10	1.71916744E 01
			2.75942636E 19
5.00000000E 08	7.58000000E-07	5.40000000E 04	3.71422094E-19
5.44214618E 09	8.81524896E-09	2.20000000E 00	8.59873617E 01
1.69030374E 06	1.01698499E 05	2.37337764E 10	1.40369434E 01
			3.77924296E 19
6.00000000E 08	7.46000000E-07	7.50000000E 04	2.51227089E-19
7.91846667E 09	3.31533108E-09	2.10000000E 00	2.25015235E 02
2.03892006E 06	7.20637175E 04	1.31965509E 10	1.19107414E 01
			4.74102590E 19

Table I (continued)

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PLANET RADIUS= 3.38100000E 08     SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 3.76000000E 01

    INITIAL CONDITIONS

HEIGHT=              0      PRESSURE= 1.00000000E 04
TEMPERATURE= 2.70000000E 02
```

HEIGHT	PRESSURE	TEMPERATURE	DENSITY
PRESSURE SCALE HEIGHT	COLUMNAR MASS	MOLECULAR MASS	GRAVITY
SPEED OF SOUND	NUMBER DENSITY	DENSITY SCALE HEIGHT	VISCOSITY(MIX.)
			VISCOSITY(KIN.)
7.00000000E 08	7.39000000E-07	9.90000000E 04	1.70581706E-19
1.15526261E 10	1.71999168E-09	1.90080000E 00	4.29653241E 02
2.46274820E 06	5.40814518E 04	1.00830958E 10	1.03669697E 01
			6.07742176E 19
8.00000000E 08	7.33000000E-07	1.27000000E 05	1.18009993E-19
1.65635691E 10	1.04729040E-09	1.70000000E 00	6.99901381E 02
2.94887670E 06	4.18156981E 04	8.87459087E 09	9.15308650E 00
			7.75619615E 19
9.00000000E 08	7.29000000E-07	1.57000000E 05	8.93547135E-20
2.17559872E 10	7.03831238E-10	1.60000000E 00	1.03575966E 03
3.37962916E 06	3.36408510E 04	7.87682272E 09	8.23226991E 00
			9.21302255E 19
1.00000000E 09	7.26000000E-07	1.90000000E 05	6.43399418E-20
3.00901733E 10	5.05139037E-10	1.40000000E 00	1.43722806E 03
3.97458690E 06	2.76835714E 04	7.85109566E 09	7.48329086E 00
			1.16308636E 20

```
END OF PROBLEM
```

Table II

Mean Density Model

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.40000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 8.00000000E 03
TEMPERATURE= 2.10000000E 02

HEIGHT	PRESSURE	TEMPERATURE	DENSITY
PRESSURE SCALE HEIGHT	COLUMNAR MASS	MOLECULAR MASS	GRAVITY
SPEED OF SOUND	NUMBER DENSITY	DENSITY SCALE HEIGHT	VISCOSITY(MIX.)
			VISCOSITY(KIM.)
0	8.00000000E 03	2.10000000E 02	2.01601137E-05
1.05819509E 06	2.13333333E 01	4.40000000E 01	3.75000000E 02
2.35701596E 04	2.76000450E 17	1.05819509E 06	2.09866256E 02
			1.04099738E 07
5.00000000E 05	4.84000000E 03	1.85000000E 02	1.38450943E-05
9.32219485E 05	1.29449256E 01	4.40000000E 01	3.73891681E 02
2.21227311E 04	1.89545174E 17	9.34982843E 05	2.20104322E 02
			1.58976398E 07
1.00000000E 06	2.72000000E 03	1.60000000E 02	8.99645078E-06
8.06243879E 05	7.29643088E 00	4.40000000E 01	3.72785002E 02
2.05737220E 04	1.23165201E 17	8.11034384E 05	2.32656654E 02
			2.58609380E 07
1.50000000E 06	1.39000000E 03	1.39400000E 02	5.27684468E-06
7.02439979E 05	3.73977652E 00	4.40000000E 01	3.71679963E 02
1.92036712E 04	7.22422268E 16	7.08714535E 05	2.45446391E 02
			4.65138554E 07
2.00000000E 06	6.76000000E 02	1.36200000E 02	2.62658750E-06
6.86315102E 05	1.82418443E 00	4.40000000E 01	3.70576565E 02
1.89819764E 04	3.59590895E 16	6.94507391E 05	2.47689508E 02
			9.43008781E 07
2.50000000E 06	3.23000000E 02	1.33000000E 02	1.28520725E-06
6.70190224E 05	8.74213868E-01	4.40000000E 01	3.69474807E 02
1.87576616E 04	1.75950287E 16	6.80212371E 05	2.50013100E 02
			1.94531349E 08

Parameter Units

Height	centimeters	Temperature	degrees Kelvin
Pressure scale height	centimeters	Molecular mass	dimensionless
Speed of sound	centimeters/sec	Density scale height	centimeters
Pressure	dynes/cm^2	Density	grams/cm^3
Columnar mass	particles/cm^2	Gravity	cm/sec^2
Number density	particles/cm^3	Viscosity(mix)	poise
		Viscosity(kinematic)	cm^2/sec

Table II (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 06 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.40000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 8.00000000E 03
TEMPERATURE= 2.10000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIN.)
3.00000000E 06 6.54065347E 05 1.85306316E 04	1.52000000E 02 4.12623355E-01 8.48414326E 15	1.29800000E 02 4.40000000E 01 6.65828876E 05	6.19713818E-07 3.683746896 02 2.52422098E 02 4.07320428E 08
3.50000000E 06 6.37940469E 05 1.83007854E 04	7.00000000E 01 1.90592252E-01 4.00593070E 15	1.26600000E 02 4.40000000E 01 6.51356305E 05	2.92608285E-07 3.67276211E 02 2.54921864E 02 8.71205215E 08
4.00000000E 06 6.21815592E 05 1.80680155E 04	3.16000000E 01 8.62965046E-02 1.8552H665E 15	1.23400000E 02 4.40000000E 01 6.36794091E 05	1.35517134E-07 3.66179374E 02 2.57518246E 02 1.90026538E 09
4.50000000E 06 6.05489153E 05 1.78292402E 04	1.40000000E 01 3.834/3207E-02 8.44125877E 14	1.20160000E 02 4.40000000E 01 6.21934466E 05	6.16581373E-08 3.65084176E 02 2.60252056E 02 4.22088742E 09
5.00000000E 06 5.895658366 05 1.759323926 04	6.06000000E 00 1.66487807E-02 3.75254458E 14	1.17000000E 02 4.40000000E 01 6.073980396 05	2.74100007E-08 3.63990620E 02 2.63027020E 02 9.59602382E 09
6.00000000E 06 5.57316081E 05 1.71052899E 04	1.06000000E 00 2.92972723E-03 6.94368220E 13	1.10600000E 02 4.40000000E 01 5.77635884E 05	5.07192734E-09 3.61808427E 02 2.69007286E 02 5.30384739E 10
7.00000000E 06 6.06375810E 05 1.78422897E 04	1.94000000E-01 5.39439125E-04 1.34887936E 13	1.04200000E 02 3.81000000E 01 6.32286410E 05	8.53156285E-10 3.59632795E 02 2.75530382E 02 3.22954173E 11
8.00000000E 06 6.35892350E 05 1.82713843E 04	3.90000000E-02 1.09101980E-04 2.88911514E 12	9.78000000E 01 3.41000000E 01 6.670A7638E 05	1.63549695E-10 3.57463724E 02 2.82683736E 02 1.72842717E 12
9.00000000E 06 6.60095762E 05 1.86158608E 04	8.44000000E-03 2.37544925E-05 6.69014220E 11	9.14000000E 01 3.07000000E 01 6.9669J1196 05	3.40960630E-11 3.55301213E 02 2.90575840E 02 8.92226V81E 12

Table II (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.40000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 8.00000000E 03
TEMPERATURE= 2.10000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIN.)
1.00000000E 07	1.91000000E-03	8.50000000E 01	7.56731968E-12
6.73069667E 05	5.40853918E-06	2.80000000E 01	3.53145265E 02
1.87979141E 04	1.62799677E 11	7.14723233E 05	2.99343308E 02
			3.95573758E 13
1.10000000E 07	5.06000000E-04	8.50000000E 01	1.78995127E-12
7.53838027E 05	1.44161238E-06	2.50000000E 01	3.50995877E 02
1.98938424E 04	4.31291291E 10	8.05391969E 05	2.99343308E 02
			1.67235451E 14
1.20000000E 07	1.57000000E-04	8.50000000E 01	4.88734521E-13
8.56634121E 05	4.50046231E-07	2.20000000E 01	3.48853050E 02
2.12069072E 04	1.33819630E 10	9.20839866E 05	2.99343308E 02
			6.12486525E 14
1.30000000E 07	5.44000000E-05	8.50000000E 01	1.53949959E-13
9.42297533E 05	1.56900394E-07	2.00000000E 01	3.46716784E 02
2.22419919E 04	4.63680756E 09	1.01916490E 06	2.99343308E 02
			1.94441954E 15
1.40000000E 07	2.04000000E-05	8.50000000E 01	5.34013920E-14
1.01870004E 06	5.92012912E-08	1.85000000E 01	3.44587079E 02
2.31261220E 04	1.73880283E 09	1.10860951E 06	2.99343308E 02
			5.60553381E 15
1.50000000E 07	8.27000000E-06	8.50000000E 01	1.98932213E-14
1.10858533E 06	2.41485282E-08	1.70000000E 01	3.42463935E 02
2.41248275E 04	7.04897031E 08	1.21390739E 06	2.99343308E 02
			1.50475031E 16
1.60000000E 07	3.54000000E-06	8.50000000E 01	8.01445375E-15
1.17787192E 06	1.04011387E-08	1.60000000E 01	3.40347352E 02
2.48673030E 04	3.01733433E 08	1.29779758E 06	2.99343308E 02
			3.73504318E 16
1.70000000E 07	1.74000000E-06	8.50000000E 01	3.69310104E-15
1.25639671E 06	5.14431686E-09	1.50000000E 01	3.38237330E 02
2.56828401E 04	1.48309654E 08	1.39295319E 06	2.99343308E 02
			8.10547302E 16
1.80000000E 07	9.66000000E-07	1.18800000E 02	1.36917301E-15
1.88142768E 06	2.87385500E-09	1.40000000E 01	3.36133869E 02
3.14284828E 04	5.89114597E 07	2.09897141E 06	2.61432768E 02
			1.90942099E 17
1.90000000E 07	5.90000000E-07	1.31200000E 02	7.03122729E-16
2.23763686E 06	1.76627156E-09	1.30000000E 01	3.34036969E 02
3.42747626E 04	3.25804647E 07	2.51203878E 06	2.51357319E 02
			3.57487120E 17

Table II (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.40000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 8.00000000E 03
TEMPERATURE= 2.10000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIN.)
2.00000000E 07	3.90000000E-07	1.44200000E 02	3.90346420E-16
2.66430008E 06	1.17488766E-09	1.20000000E 01	3.31946630E 02
3.73999672E 04	1.95946921E 07	3.00985894E 06	2.42222770E 02
			6.20532834E 17
2.50000000E 07	9.58000000E-08	2.17200000E 02	5.03963289E-17
5.06915230E 06	2.97891731E-10	9.50000000E 00	3.21593351E 02
5.15878373E 04	3.19554388E 06	5.91098077E 06	2.07250803E 02
			4.11241865E 18
3.00000000E 07	4.42000000E-08	3.03500000E 02	1.36624248E-17
8.62706791E 06	1.41937760E-10	7.80000000E 00	3.11404098E 02
6.72994105E 04	1.05512198E 06	1.03889143E 07	1.83549688E 02
			1.34346349E 19
3.50000000E 07	2.74000000E-08	4.02900000E 02	5.56201065E-18
1.31367362E 07	9.09154649E-11	6.80000000E 00	3.01378869E 02
8.30468934E 04	4.92711153E 05	1.63457912E 07	1.66357933E 02
			2.99096754E 19
4.00000000E 07	2.01000000E-08	5.14000000E 02	2.68088017E-18
1.99934337E 07	6.89495092E-11	5.70000000E 00	2.91517666E 02
1.02452685E 05	2.83316610E 05	2.57189821E 07	1.53406181E 02
			5.72223192E 19
4.50000000E 07	1.62000000E-08	6.39000000E 02	1.58557616E-18
2.72456165E 07	5.74834005E-11	5.20000000E 00	2.81820488E 02
1.19599116E 05	1.83676356E 05	3.62539510E 07	1.43091437E 02
			9.02457039E 19
5.00000000E 07	1.38000000E-08	7.76000000E 02	1.00527488E-18
3.66069029E 07	5.06817548E-11	4.70000000E 00	2.72287336E 02
1.38631252E 05	1.28841705E 05	5.04158174E 07	1.34788611E 02
			1.34001348E 20
6.00000000E 07	1.10000000E-08	1.08000000E 03	5.14502901E-19
5.70129600E 07	4.33560573E-11	4.20000000E 00	2.53713187E 02
1.73008104E 05	7.37917869E 04	8.42678577E 07	1.22387387E 02
			2.37874883E 20
7.00000000E 07	9.58000000E-09	1.44000000E 03	2.88054886E-19
8.88868267E 07	4.06285156E-11	3.60000000E 00	2.39794988F 02
2.15779017E 05	4.81994936E 04	1.41044394E 08	1.15142685E 02
			3.92782492E 20

Table 11 (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.40000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 8.00000000E 03
TEMPERATURE= 2.10000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIN.)
8.00000000E 07 1.19988060E 08 2.50985520E 05	8.69000000E-09 3.97651698E-11 3.42169308E 04	1.84000000E 03 3.40000000E 00 2.05898111E 08	1.93130328E-19 2.18532953E 02 1.06250032E 02 5.50146799E 20
9.00000000E 07 1.57973410E 08 2.87986181E 05	8.07000000E-09 3.99649321E-11 2.56435286E 04	2.28000000E 03 3.20000000E 00 2.93373449E 08	1.36225457E-19 2.01927029E 02 1.00875956E 02 7.40507388E 20
1.00000000E 08 2.04718758E 08 3.27837381E 05	7.63000000E-09 4.10265336E-11 1.99564766E 04	2.77000000E 03 3.00000000E 00 4.12790020E 08	9.93883845E-20 1.85977205E 02 9.64713187E 01 9.70649832E 20
2.00000000E 08 7.83136353E 08 6.41207132E 05	5.73000000E-09 9.15854194E-11 4.19756498E 03	9.89000000E 03 2.80000000E 00 4.69397064E 09	1.95112894E-20 6.25645440E 01 7.61879006E 01 3.90481117E 21
3.00000000E 08 1.70804259E 09 9.46954254E 05	5.22000000E-09 1.09617432E-09 1.81821931E 03	2.08000000E 04 2.70000000E 00 1.34505203E 11	8.14967970E-21 4.76201630E 00 6.91090765E 01 8.47997456E 21
4.00000000E 08 3.13064498E 09 1.28202520E 06	4.99000000E-09 3.96988861E-10 1.02415323E 03	3.53000000E 04 2.50000000E 00 9.33991372E 10	4.25045534E-21 1.25696222E 01 6.54552933E 01 1.53995956E 22
5.00000000E 08 5.12841215E 09 1.64085843E 06	4.86000000E-09 5.65199339E-11 6.61856342E 02	5.32000000E 04 2.30000000E 00 2.23655491E 10	2.52709798E-21 8.59873617E 01 6.32173558E 01 2.50157918E 22
6.00000000E 08 7.49806807E 09 1.98405790E 06	8.78000000E-09 3.90195802E-11 8.54989297E 02	7.44000000E 04 2.20000000E 00 1.24959340E 10	3.12258212E-21 2.25015235E 02 6.16994775E 01 1.97591208E 22
7.00000000E 08 1.09417372E 10 2.39675031E 06	4.73000000E-09 1.10088777E-11 3.47202694E 02	9.87000000E 04 2.00000000E 00 9.54991391E 09	1.15277246E-21 4.29653241E 02 6.06838968E 01 5.25722969E 22
8.00000000E 08 1.55201947E 10 2.85448008E 06	4.69000000E-09 6.78094405E-12 2.69675440E 02	1.26000000E 05 1.80000000E 00 8.31556153E 09	8.05831817E-22 6.99981381E 02 5.97742797E 01 7.41771154E 22

Table II (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.40000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 8.00000000E 03
TEMPERATURE= 2.10000000E 02

HEIGHT	PRESSURE	TEMPERATURE	DENSITY
PRESSURE SCALE HEIGHT	COLUMNAR MASS	MOLECULAR MASS	GRAVITY
SPEED OF SOUND	NUMBER DENSITY	DENSITY SCALE HEIGHT	VISCOSITY(MIX.)
			VISCOSITY(KIN.)
9.00000000E 08	4.67000000E-09	1.57000000E 05	6.08185074E-22
2.04762232E 10	4.50876801E-12	1.70000000E 00	1.03575966E 03
3.27872188E 06	2.15504491E 02	7.41348021E 09	5.91089423E 01
			9.71890709E 22
1.00000000E 09	4.65000000E-09	1.90000000E 05	4.41530002E-22
2.80841618E 10	3.23539466E-12	1.50000000E 00	1.43722806E 03
3.83981574E 06	1.77312131E 02	7.32768928E 09	5.85882641E 01
			1.32693733E 23

Table III

Minimum Density Model

INPUT CONSTANTS

PLANET RADIUS= 3.381000000E 08 SURFACE GRAVITY= 3.750000000E 02
MOLECULAR MASS= 4.320000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 4.000000000E 03
TEMPERATURE= 1.500000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIN.)
0	4.000000000E 03	1.500000000E 02	1.385549638-05
7.698589268 05	1.066666678 01	4.320000000E 01	3.750000000E 02
2.018402298 04	1.932003158 17	7.698589268 05	5.749631208 02
			4.149711478 07
5.000000000E 05	1.960000000E 03	1.240000000E 02	8.812733708-06
6.364108998 05	5.242159968 00	4.320000000E 01	3.738916818 02
1.887008118 04	1.145179298 17	6.382969968 05	6.323751218 02
			7.699934968 07
1.000000000E 06	8.150000000E 02	9.850000000E 01	4.299872148-06
5.099354418 05	2.186246798 00	4.320000000E 01	3.727850028 02
1.629128938 04	5.994603688 16	5.089398108 05	7.095246738 02
			1.650413918 08
1.500000000E 06	3.020000006 02	9.700000000E 01	1.604432478-06
5.019428048 05	8.129269898-01	4.320000000E 01	3.716799638 02
1.623329828 04	2.237212248 16	5.064264158 05	7.120593498 02
			4.438076138 08
2.000000000E 06	1.110000000E 02	9.700000000E 01	9.945722888-07
4.978369328 05	2.995332428-01	4.320000000E 01	3.709765698 02
1.616676818 04	8.290683628 15	5.037794278 05	7.149896438 02
			1.282927878 09
2.500000000E 06	4.050000000E 01	9.630000000E 01	2.185154218-07
4.942442948 05	1.096150928-01	4.320000000E 01	3.694748078 02
1.610832878 04	3.046967508 15	5.016393138 05	7.179835508 02
			3.283903478 09

Parameter Units

Height	centimeters	Temperature	degrees Kelvin
Pressure scale height . .	centimeters	Molecular mass . . .	dimensionless
Speed of sound	centimeters/sec	Density scale height	centimeters
Pressure	dynes/cm^2	Density	grams/cm^3
Columnar mass	particles/cm^2	Gravity	cm/sec^2
Number density	particles/cm^3	Viscosity (mix) . . .	poise
		Viscosity (kinematic)	cm^2/sec

Table III (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.381000000E 08 SURFACE GRAVITY= 3.750000000E 02
MOLECULAR MASS= 4.320000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 4.000000000E 03
TEMPERATURE= 1.900000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIN.)
3.000000000E 06 4.901384236E 05 1.604128026E 04	1.470000000E 01 3.990502186E-02 1.115200776E 19	9.550000000E 01 4.320000000E 01 4.989936856E 05	7.997740676E-08 3.683746896E 02 7.205828676E 02 9.009830366E 04
3.500000000E 06 4.869457856E 05 1.598238216E 04	5.270000000E 00 1.434887386E-02 4.027554036E 14	9.480000000E 01 4.320000000E 01 4.967778046E 05	2.886388676E-08 3.672762116E 02 7.232383946E 02 2.503950956E 10
4.000000000E 06 4.824399146E 05 1.591480306E 04	1.880000000E 00 5.134095846E-03 1.449002366E 14	9.400000000E 01 4.320000000E 01 4.940610556E 05	1.039162226E-08 3.661793746E 02 7.263094446E 02 6.989374976E 10
4.500000000E 06 4.788472766E 05 1.586594356E 04	6.620000000E-01 1.813286456E-03 5.140619316E 13	9.330000000E 01 4.320000000E 01 4.918529486E 05	3.686631296E-09 3.650841766E 02 7.290289866E 02 1.977493646E 11
5.000000000E 06 4.747414046E 05 1.578731256E 04	2.320000000E-01 6.373790636E-04 1.817127296E 13	9.250000000E 01 4.320000000E 01 4.894100596E 05	1.303169606E-09 3.639906206E 02 7.321747566E 02 5.618432206E 11
6.000000000E 06 4.670428956E 05 1.565878416E 04	2.780000000E-02 7.683624256E-05 2.213311306E 12	9.100000000E 01 4.320000000E 01 4.844713286E 05	1.987291756E-10 3.618084276E 02 7.381843006E 02 4.690591176E 12
7.000000000E 06 5.222020396E 05 1.655768906E 04	3.690000000E-03 1.024046586E-05 2.987049566E 11	8.950000000E 01 3.800000000E 01 5.445158716E 05	1.884328196E-11 3.596327956E 02 7.443447006E 02 3.990186176E 13
8.000000000E 06 5.738599376E 05 1.739772566E 04	5.980000000E-04 1.672897036E-06 4.923314846E 10	8.800000000E 01 3.400000000E 01 6.020078756E 05	2.778862366E-12 3.574637246E 02 7.506617416E 02 2.701327536E 14
9.000000000E 06 6.186621386E 05 1.802214206E 04	1.140000000E-04 3.208549196E-07 9.548339266E 09	8.650000000E 01 3.100000000E 01 6.529862116E 05	4.913824086E-13 3.553012136E 02 7.571423946E 02 1.940839916E 15

Table III (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.32000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 4.00000000E 03
TEMPERATURE= 1.50000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIM.)
1.00000000E 07 6.73069667E 05 1.87979141E 04	2.48000000E-05 7.02260585E-08 2.11383874E 09	8.50000000E 01 2.80000000E 01 7.14723233E 05	9.82562974E-14 3.53145265E 02 7.63793846E 02 7.77348492E 15
1.10000000E 07 7.53638027E 05 1.98938424E 04	6.59000000E-06 1.87751493E-08 5.61701504E 08	8.50000000E 01 2.50000000E 01 8.05391969E 05	2.33118159E-14 3.50995877E 02 7.63793846E 02 3.27642363E 16
1.20000000E 07 8.56634121E 05 2.12069072E 04	2.06000000E-06 5.90506519E-09 1.75584992E 08	8.50000000E 01 2.20000000E 01 9.20839866E 05	6.41269499E-15 3.48853050E 02 7.63793846E 02 1.19106530E 17
1.30000000E 07 9.42297533E 05 2.22419919E 04	7.13000000E-06 2.05643347E-08 6.07286386E 08	8.50000000E 01 2.00000000E 01 1.01916490E 06	2.01776325E-14 3.46716784E 02 7.63793846E 02 3.78534918E 16
1.40000000E 07 9.91892140E 05 2.28198022E 04	2.68000000E-07 7.77742453E-10 2.28430961E 07	8.50000000E 01 1.90000000E 01 1.07943558E 06	7.20508448E-16 3.44587079E 02 7.63793846E 02 1.06007618E 18
1.50000000E 07 1.10858533E 06 2.41248275E 04	1.09000000E-07 3.18281690E-10 9.29066220E 06	8.50000000E 01 1.70000000E 01 1.21390739E 06	2.62196024E-16 3.42463935E 02 7.63793846E 02 2.91306418E 18
1.60000000E 07 1.32614520E 06 2.63860992E 04	4.68000000E-08 1.37506579E-10 3.54301518E 06	9.57000000E 01 1.60000000E 01 1.46116739E 06	9.41073417E-17 3.40347352E 02 7.19829513E 02 7.64902618E 18
1.70000000E 07 1.58158174E 06 2.88154944E 04	2.31000000E-08 6.82952411E-11 1.96411003E 06	1.07000000E 02 1.50000000E 01 1.75348225E 06	3.89483505E-17 3.38237330E 02 6.80759529E 02 1.74785202E 19
1.80000000E 07 1.88142768E 06 3.14284828E 04	1.28000000E-08 3.80800662E-11 7.80607333E 05	1.18000000E 02 1.40000000E 01 2.09897141E 06	1.61422511E-17 3.36133869E 02 6.40066760E 02 3.56111685E 19

Table III (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.32000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 4.00000000E 03
TEMPERATURE= 1.50000000E 02

HEIGHT	PRESSURE	TEMPERATURE	DENSITY
PRESSURE SCALE HEIGHT	COLUMNAR MASS	MOLECULAR MASS	GRAVITY
SPEED OF SOUND	NUMBER DENSITY	DENSITY SCALE HEIGHT	VISCOSITY(MIX.)
			VISCOSITY(KIM.)
1.90000000E 07	7.85000000E-09	1.31200000E 02	9.35510749E-18
2.23763686E 06	2.35003928E-11	1.30000000E 01	3.34036969E 02
3.42747626E 04	4.33485844E 05	2.51203878E 06	6.14778541E 02
			6.57158180E 19
2.00000000E 07	5.20000000E-09	1.44200000E 02	5.20461893E-18
2.66430008E 06	1.56651688E-11	1.20000000E 01	3.31946630E 02
3.73999672E 04	2.61262562E 05	3.00985894E 06	5.86412187E 02
			1.12671493E 20
2.50000000E 07	1.29000000E-09	2.17200000E 02	6.78614450E-19
5.06915230E 06	4.01127696E-12	9.50000000E 00	3.21593351E 02
5.15878373E 04	4.30297663E 04	5.91098077E 06	4.77810520E 02
			7.04097179E 20
3.00000000E 07	5.96000000E-10	3.03500000E 02	1.84226362E-19
8.62706791E 06	1.91391187E-12	7.80000000E 00	3.11404098E 02
6.72994105E 04	1.42274367E 04	1.03889143E 07	4.04209271E 02
			2.19409029E 21
3.50000000E 07	3.71000000E-10	4.02900000E 02	7.42029298E-20
1.33328069E 07	1.23100867E-12	6.70000000E 00	3.01378869E 02
8.36643509E 04	6.67138094E 03	1.65897583E 07	3.50822132E 02
			4.72787440E 21
4.00000000E 07	2.72000000E-10	5.14800000E 02	3.62222004E-20
2.00245519E 07	9.33048085E-13	5.70000000E 00	2.91517666E 02
1.02532384E 05	3.82797827E 03	2.57590117E 07	3.10360433E 02
			8.56823795E 21
4.50000000E 07	2.20000000E-10	6.39100000E 02	2.15291466E-20
2.72498802E 07	7.80638772E-13	5.20000000E 00	2.81820488E 02
1.19608474E 05	2.49397997E 03	3.62596245E 07	2.78548747E 02
			1.29382159E 22
5.00000000E 07	1.87000000E-10	7.75500000E 02	1.36309860E-20
3.65833160E 07	6.86774504E-13	4.70000000E 00	2.72287336E 02
1.38586583E 05	1.74702412E 03	5.03833329E 07	2.52868491E 02
			1.85510052E 22
6.00000000E 07	1.51000000E-10	1.08390000E 03	6.86975416E-21
5.86144216E 07	5.95160422E-13	4.10000000E 00	2.53713107E 02
1.75421126E 05	1.00931523E 03	8.66348938E 07	2.13890261E 02
			3.11350677E 22

Table III (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.32000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 4.00000000E 03
TEMPERATURE= 1.50000000E 02

HEIGHT PRESSURE SCALE HEIGHT SPEED OF SOUND	PRESSURE COLUMNAR MASS NUMBER DENSITY	TEMPERATURE MOLECULAR MASS DENSITY SCALE HEIGHT	DENSITY GRAVITY VISCOSITY(MIX.) VISCOSITY(KIM.)
7.00000000E 07	1.31000000E-10	1.43860000E 03	3.94278730E-21
8.86006034E 07	5.55567384E-13	3.60000000E 00	2.35794980E 02
2.15674099E 05	6.59736235E 02	1.40907267E 08	1.49658822E 02
			4.70882165E 22
8.00000000E 07	1.19000000E-10	1.83840000E 03	2.64700935E-21
1.19883722E 08	5.44540300E-13	3.40000000E 00	2.18532953E 02
2.50876372E 05	4.68971065E 02	2.05719069E 08	1.64234961E 02
			6.20454783E 22
9.00000000E 07	1.11000000E-10	2.28230000E 03	1.87184479E-21
1.58132769E 08	5.49703528E-13	3.20000000E 00	2.01927029E 02
2.88131400E 05	3.52362227E 02	2.93669395E 08	1.47400600E 02
			7.87461659E 22
1.00000000E 08	1.05000000E-10	2.76950000E 03	1.36797699E-21
2.04681805E 08	5.64585320E-13	3.00000000E 00	1.85977205E 02
3.27807791E 05	2.74679993E 02	4.12715510E 08	1.33808679E 02
			9.78151535E 22
2.00000000E 08	7.90000000E-10	9.89010000E 03	2.69001095E-21
7.83144272E 08	1.26269601E-11	2.80000000E 00	6.25645440E 01
6.41210373E 05	5.78716022E 02	4.69401810E 09	7.08084807E 01
			2.63227481E 22
3.00000000E 08	7.21000000E-11	2.08240000E 04	1.06271478E-22
1.77578315E 09	1.51406454E-11	2.60000000E 00	4.76201630E 00
9.65549665E 05	2.50847748E 01	1.39839648E 11	4.87981705E 01
			4.50701989E 23
4.00000000E 08	6.90000000E-11	3.53180000E 04	5.87438769E-23
3.13224134E 09	5.48942513E-12	2.50000000E 00	1.25696222E 01
1.28235202E 06	1.41544203E 01	9.34467628E 10	3.74703342E 01
			6.37859402E 23
5.00000000E 08	6.72000000E-11	5.32060000E 04	3.49386489E-23
5.12899054E 09	7.81510198E-13	2.30000000E 00	8.59873617E 01
1.64095095E 06	9.15056185E 00	2.23680715E 10	3.05284892E 01
			8.73774177E 23
6.00000000E 08	6.62000000E-11	7.43640000E 04	2.24845474E-23
7.85131807E 09	2.94202302E-13	2.10000000E 00	2.25015235E 02
2.03025063E 06	6.44962323E 00	1.30846442E 10	2.98228544E 01
			1.14847117E 24

Table III (continued)

INPUT CONSTANTS

PLANET RADIUS= 3.38100000E 08 SURFACE GRAVITY= 3.75000000E 02
MOLECULAR MASS= 4.32000000E 01

INITIAL CONDITIONS

HEIGHT= 0 PRESSURE= 4.00000000E 03
TEMPERATURE= 1.50000000E 02

HEIGHT	PRESSURE	TEMPERATURE	DENSITY
PRESSURE SCALE HEIGHT	COLUMNAR MASS	MOLECULAR MASS	GRAVITY
SPEED OF SOUND	NUMBER DENSITY	DENSITY SCALE HEIGHT	VISCOSITY(MIX.)
			VISCOSITY(KIN.)
7.00000000E 08	6.54000000E-11	9.86960000E 04	1.59396140E-23
1.09412938E 10	1.52215772E-13	2.00000000E 00	4.29693241E 02
2.39670174E 06	4.80084069E 00	9.54952688E 09	2.24148203E 01
			1.40623545E 24
8.00000000E 08	6.49000000E-11	1.26123000E 05	1.11401879E-23
1.55353453E 10	9.27273495E-14	1.80000000E 00	6.99901381E 02
2.85588100E 06	3.72811673E 00	8.32367910E 09	1.98284365E 01
			1.77990144E 24
9.00000000E 08	6.46000000E-11	1.56577000E 05	7.93951806E-24
2.18973707E 10	6.23696817E-14	1.60000000E 00	1.03575966E 03
3.37507328E 06	2.98912205E 00	7.85560045E 09	1.77959687E 01
			2.24144194E 24
1.00000000E 09	6.43000000E-11	1.90000000E 05	6.10545787E-24
2.80841618E 10	4.47388982E-14	1.50000000E 00	1.43722806E 03
3.83981574E 06	2.45186452E 00	7.32768928E 09	1.61550690E 01
			2.64600450E 24

END OF PROBLEM

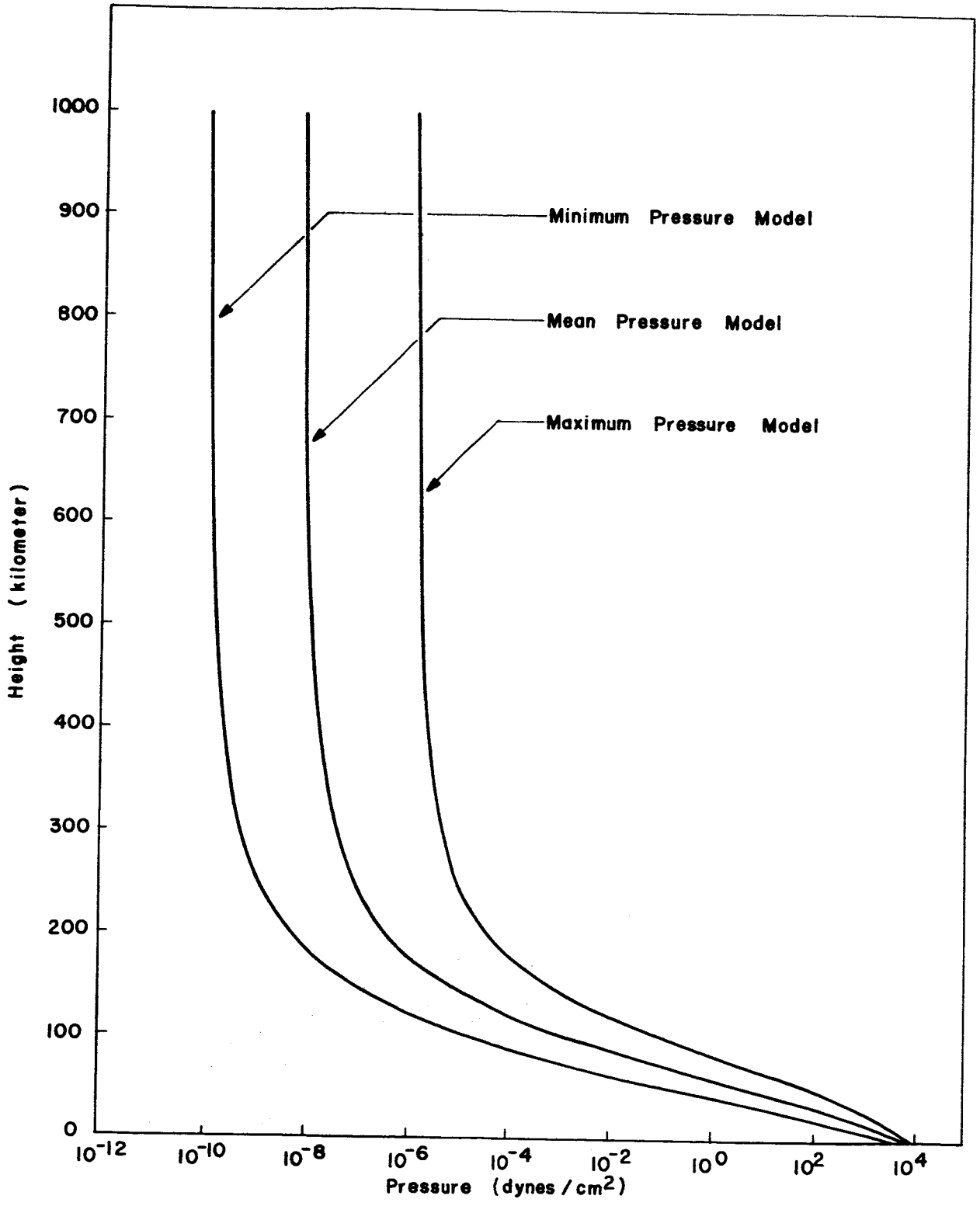

Figure 1: Variation of Pressure with Altitude for Three Atmospheric Models

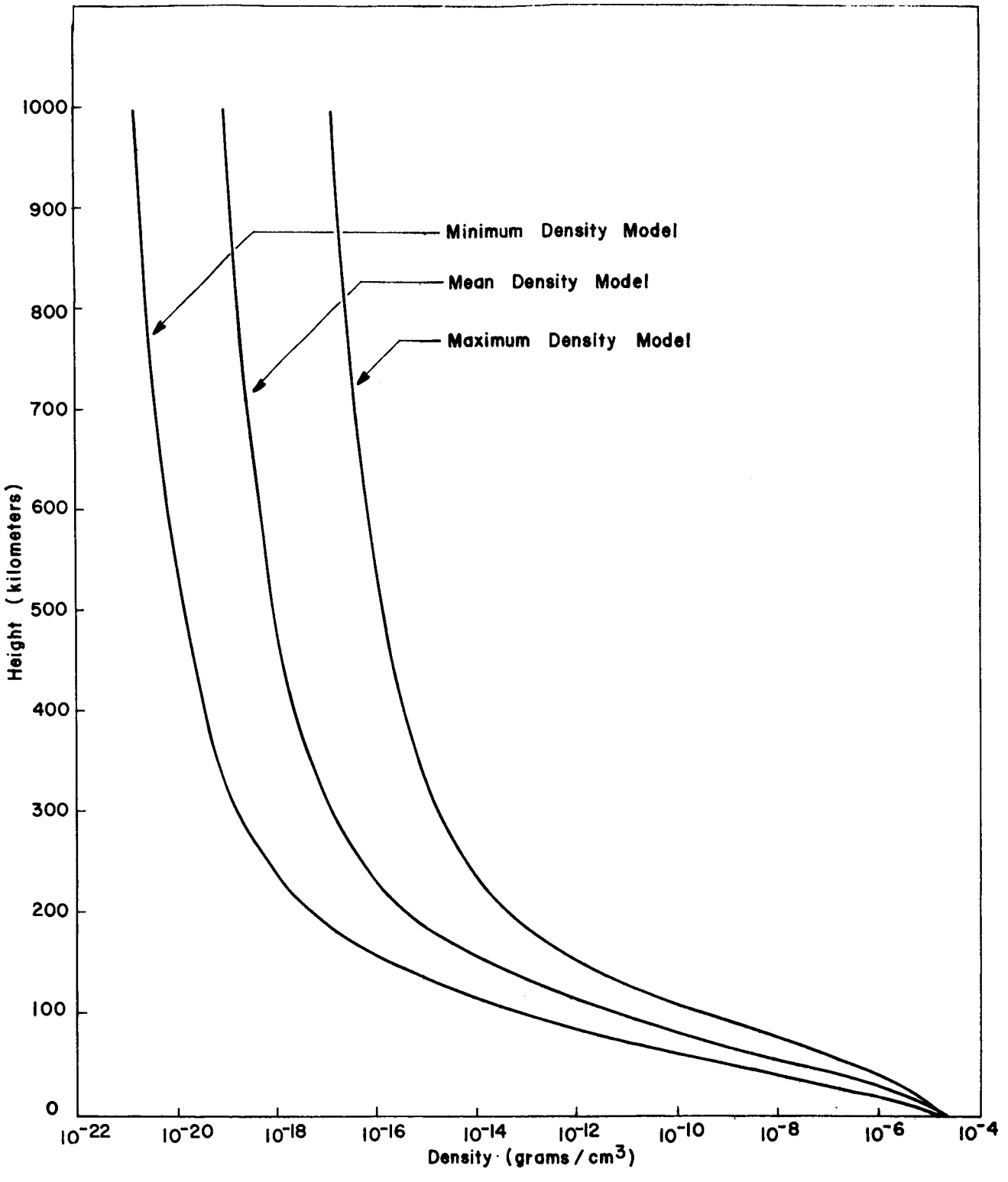

Figure 2: Variation of Density with Altitude for Three Atmospheric Models

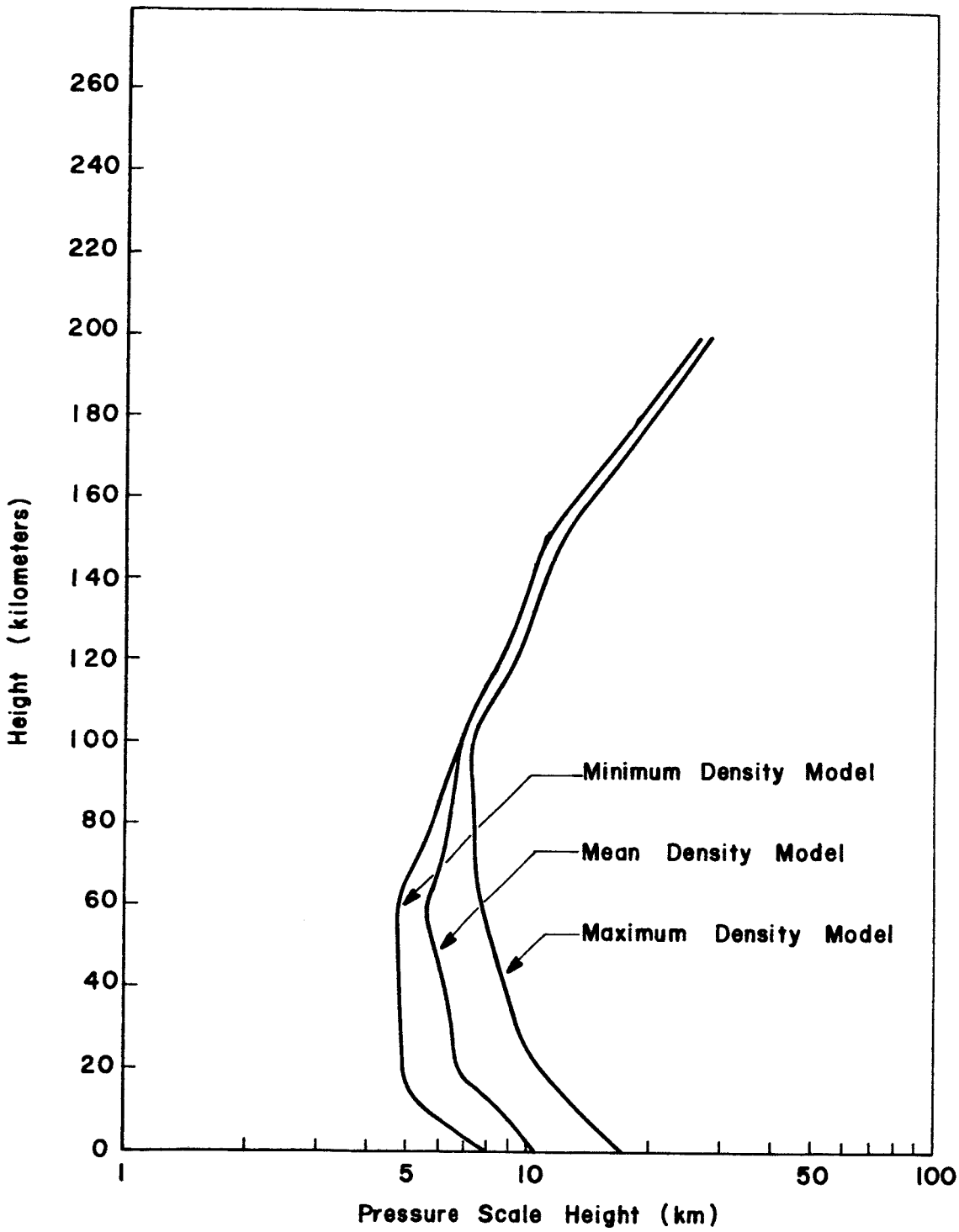

Figure 3: Variation in the Pressure Scale Height for Three Atmospheric Models

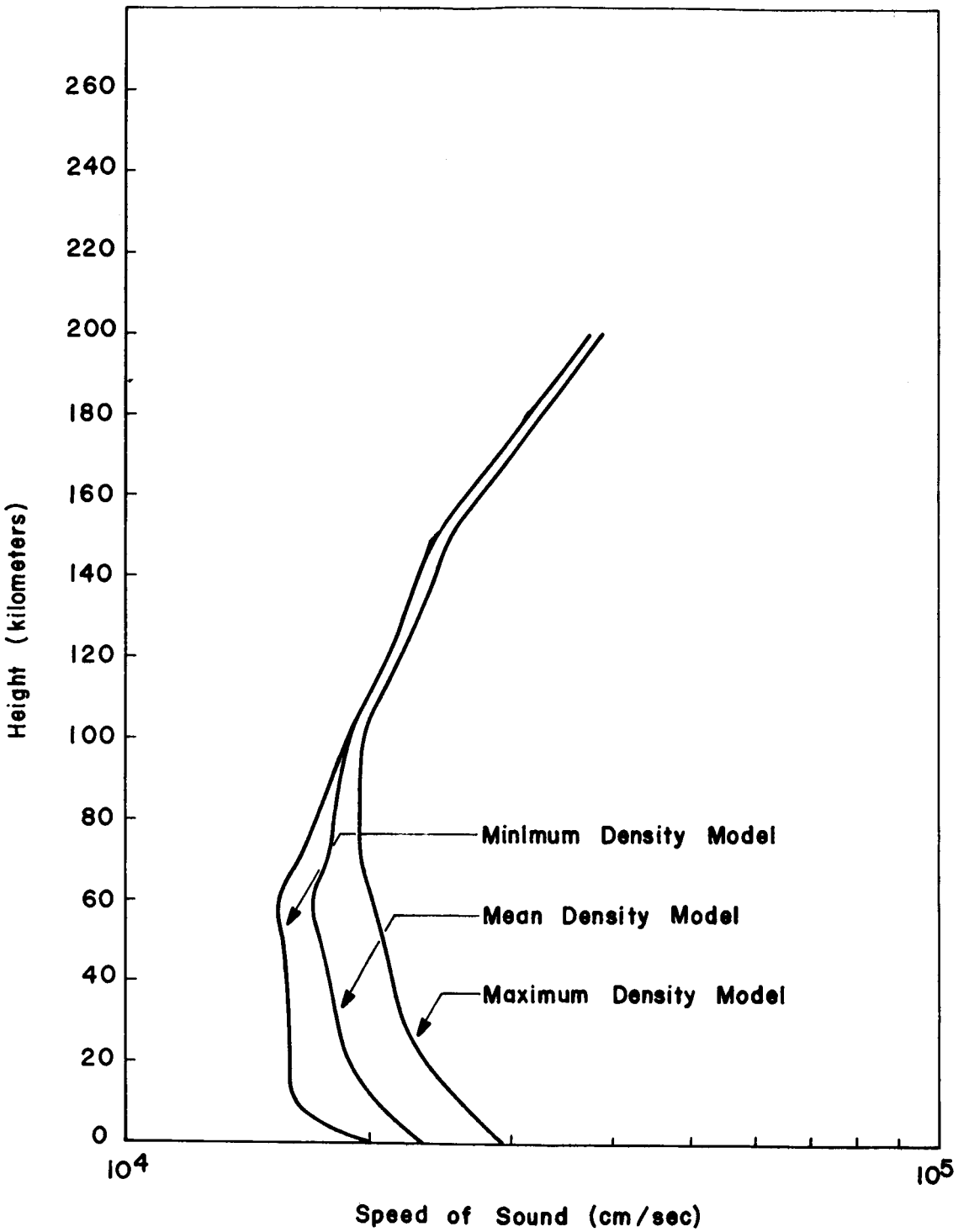

Figure 4: Variation in the Speed of Sound for Three Atmospheric Models

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THE ATMOSPHERE OF MARS: A DERIVATION OF ENGINEERING AND DESIGN PARAMETERS

By W. T. Roberts and George S. West

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This document has also been reviewed and approved for technical accuracy.

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