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Atmospheric Entry into Jupiter's Atmosphere in View of Recent Flyby Results

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Nomenclature

A	= frontal cross sectional area of probe
C_D	= drag coefficient
g	= gravitational constant
m	= probe mass
q	= heating rate
R	= universal gas constant
R_N	= nose radius
t	= time
T	= temperature
V	= probe velocity
y	= distance above reference altitude
ρ	= gas density

Subscripts

conv	= convective
E	= entry condition
0	= pertains to a reference altitude
rad	= radiative
∞	= ambient flight condition

Received July 21, 1975; revision received October 14, 1975.

Index categories: Entry Vehicles; Radiation and Radiative Heat Transfer.

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Introduction

TEMPERATURE profiles of Jupiter's atmosphere, based on the data of the Pioneer 10 occultation experiment,[1,2] indicate that the atmosphere is much warmer than was previously thought. These results by Kliore et al., are not in agreement with Earth-based observations of the Jovian atmopshere,[3-5] nor with the results of the Pioneer 10 infrared experiment of Munich.[6] Nonetheless, the implications of Kliore's preliminary results are of interest because of the generally held belief that entry into a warmer atmosphere would produce less aerodynamic heating of an entry probe. And any lessening of the extreme heat levels that a Jupiter probe is expected to encounter could permit a significant reduction in heat shield weight and a corresponding increase in science payload.

This paper examines the heating levels experienced by a probe entering the "Kliore" model atmosphere and compares the results with those of the Jupiter model atmospheres given in Ref. 7, with the heating levels of Tauber[8] and Tauber and Wakefield.[9] The computations made in this paper employ a point-mass atmopsheric entry trajectory program, that is, the Allen-Eggers analysis[10] and simple correlations of heating. First the atmospheres are identified and then the atmospheric entry analysis is given along with the heating correlations. The result of the heating calculations are compared and discussed.

Atmospheric Heating and Entry into Model Atmospheres of Jupiter

The Kliore model atmosphere is compared with the model atmospheres of Jupiter obtained from Ref. 7 in Fig. 1. Results inferred from the other Pioneer 10 experiments and Earth-based observations are also shown. It is seen that the Kliore atmosphere is distinguished by a temperature bulge at about 200 K.

A simplified entry analysis with constant probe mass probably would not significantly change the relative relations among the heating values for the various model atmospheres. The factors that influence the heating of the probe during deceleration are the atmospheric composition and scale height. The Kliore measurements give no direct measure of the composition. He assumed a composition of 85% hydrogen and 15% helium by number, and found the atmospheric model was insensitive to the assumed composition. At any given altitude the scale height is determined by the temperature at that altitude, and the density variation is given by

$$\rho_\infty = \rho_0 \exp\left[-\frac{Mg}{RT}y\right] \tag{1}$$

The probe deceleration can be described by the expression

$$\mathrm{d}V_\infty/\mathrm{d}t = -\frac{C_D A}{m}\,\tfrac{1}{2}\rho_\infty V_\infty^{\,2} \tag{2}$$

Apart from the ballistic coefficient, m/C_DA, it is seen that the deceleration is influenced mainly by the time variation of the density ρ_∞ as the probe decelerates in the atmosphere. The convective and radiative heating rates at the stagnation point are given by correlations of some numerical solutions of the fully coupled shock-layer equations obtained by Wilson[11] for an atmosphere that is 85% hydrogen and 15% helium. Without the effects of mass addition, these are

$$q_{\text{conv}} = 0.21 \times 10^{-14} R_N{}^{1/2} \rho_\infty{}^{1/2} V_\infty^3 \qquad (3)$$

$$q_{\text{rad}} = 0.74 \times 10^{-17} R_N \rho_\infty^{0.7} V_\infty^{3.28} \qquad (4)$$

where cgs units are employed and the heating is given in kw/cm^2.

For the Kliore atmosphere extrapolated to higher altitudes[12] and for the three published model atmospheres (warm, nominal, and cold), entry trajectory calculations were performed and heating estimates were obtained for a typical probe entering Jupiter's atmosphere at a shallow angle. The approximate characteristics of the probe are: a ballistic coefficient of 23 gm/cm^2 and a nose radius of 30 cm. The entry angle is 9° and the entry velocity 48 km/sec.

The velocity history vs altitude (where the zero altitude point corresponds to 1 atm pressure[7]) is shown in Fig. 2. The short vertical lines that cross the velocity history curves mark the occurrence of the maximum heating and deceleration values. For each velocity history curve, peak heating occurs before peak deceleration. The horizontal lines in Fig. 2 at 85% and 61% of the entry velocity mark the approximate location of peak heating and deceleration as derived in Ref. 10 (a more general derivation is given by Ref. 13). Also shown on this figure are the range of Kliore's measurements, and the altitude at which the temperature bulge occurs. For entry into the Kliore model atmosphere it can be seen that maximum heating occurs well before the bulge is encountered and that maximum deceleration occurs near the bulge.

The values for the maximum deceleration, the heating, and the factors influencing the heating are summarized in Table 1. Table 1 and Fig. 2 show that insofar as the heating history is concerned, the Kliore model atmosphere is like the nominal atmosphere but raised about 100km in altitude. The bar chart in Fig. 3 was constructed from Table 1, and shows that the levels of heating and deceleration associated with entering the Kliore model atmopshere are bracketed by the warm and nominal model atmospheres. The value of the deceleration for the Kliore model is closer to the deceleration value for the warm model atmosphere and the value for the heating is closer to that for the nominal atmosphere. Another way of comparing the heating results is to examine the altitude at which maximum heating occurs. It can be seen from Fig. 4 that maximum heating occurs for the Kliore model atmosphere well above the temperature bulge that occurs at 200

Table 1 Maximum deceleration and conditions at maximum heating to Jupiter entry; $V_E = 48.6$km/sec; $RN = 30.48$cm; $m/C_D A = 23.53$ gm/cm^2; entry angle = 9.42°

	Atmosphere			
	Kliore	Warm	Nominal	Cold
Deceleration, Earth G's	254	210	337	532
V_∞ cm/sec	4.16×10^6	3.99×10^6	4.70×10^6	4.06×10^6
ρ_∞ gm/cm^3	5.02×10^{-7}	4.48×10^{-7}	4.48×10^{-7}	1.03×10^{-6}
Q CONV, kw/cm^2	19.34	16.11	20.02	25.87
q RAD kw/cm^2	44.96	36.18	48.14	69.00
Total, kw/cm^2	64.30	52.29	68.16	94.87
Altitude, km	222.60	147.40	110.50	72.90
Scale height, km	20.20	29	21	12.30

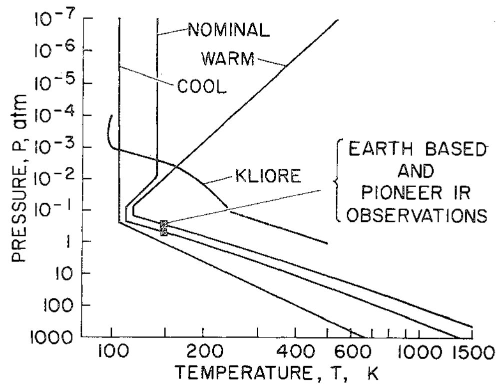

Fig. 1 Pressure vs temperature for Jupiter model atmospheres.

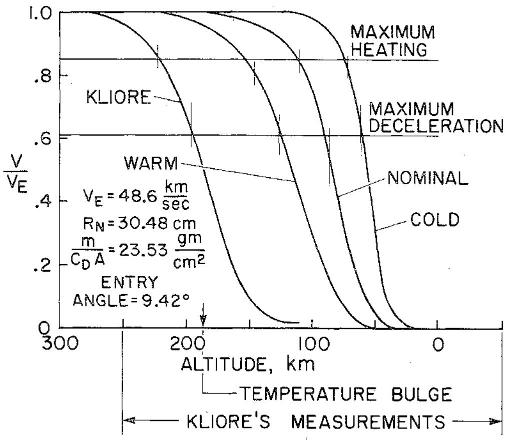

Fig. 2 Entry into model atmospheres of Jupiter.

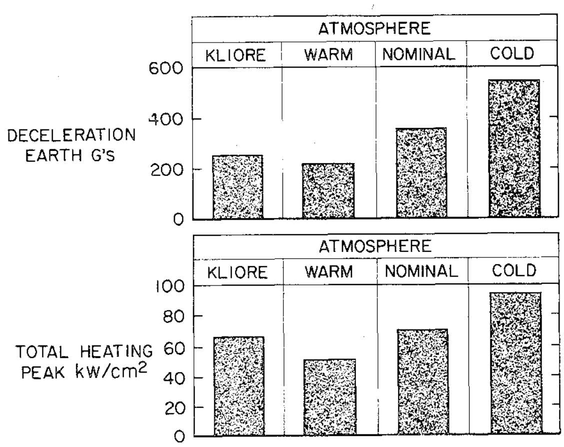

Fig. 3 Comparison of deceleration heating for entry into Jupiter model atmospheres.

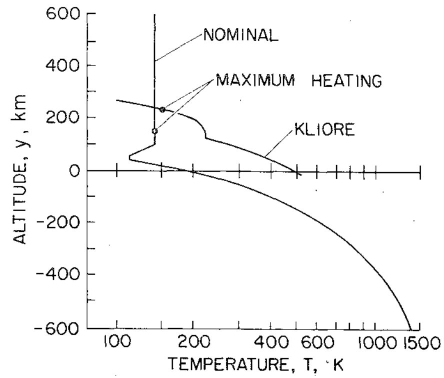

Fig. 4 Altitude for maximum heating for Jupiter model atmospheres.

K. Thus, the high heating part of the entry is over before the expanded scale height associated witi the thermal bulge can alleviate entry heating.

Conclusions

Although Kliore's occultation measurements of Jupiter's atmosphere disagree with Earth-based observations and with another Pioneer 10 experiment, the impact on entry heating of Kliore's model of Jupiter's atmosphere was examined. It was found that the warm temperature bulge exists at a level too low in the atmosphere to affect entry heating and that the nominal atmosphere fits Kliore's model atmosphere best insofar as heating is concerned. Therefore, previous estimates of the heating levels to be expected for a probe entering Jupiter's atmosphere are not affected by Kliore's postulated atmospheres.

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Stability Conditions for Spin-Stabilized Rockets

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Introduction

THE Hurwitz problem on the location of zeros of polynomials in the complex plane finds practical application in analyzing questions of stability.[1] The purpose of the present study is to make use of the same criterion to derive the stability conditions of Davis et al.[2] for spin-stabilized rockets in the presence of all aerodynamic forces and moments afresh. In the earlier method considerable manipulation is required to arrive at the main condition utilizing the square root of a complex number. Such a criterion is found to present difficulty in obtaining useful analytic results for upper and lower bounds on stability.[3] Also, it is not possible to deduce the third condition, Eq. (19) of Ref. 2 as prescribed when d (as defined in Ref. 2) becomes zero, a situation which may arise in practice since the aerodynamic lift has the opposite effect to that of the Magnus moment. The two effects tend to approach each other and will become coincident at a certain stage of the motion leaving the Magnus force and the overturning moment to influence the projectile, which has been observed to be stable if spun fast enough.

The condition of Eq. (19) of Davis et al. has also been derived from the condition of Eq. (17) in a novel way, thus proving their contention (cf. p. 377, Ref. 2) that the latter condition is a consequence of the former.

Mathematical Preliminaries

Definition: Hurwitz polynomial–A polynominal

$$P(Z)=Z^n+(p_1+iq_1)Z^{n-1}+\ldots+(p_n+iq_n) \tag{1}$$

is called a Hurwitz polynomial if all its zeros lie in the left half plane $Re(Z)<0$.

Theorem.[4] The polynomial $P(Z)$ has all its zeros in the left half plane $Re(Z)<0$ if and only if the determinants

$$\Delta_1=p_1 \tag{2}$$

and

$$\Delta_k=\begin{vmatrix} p_1 & p_3 & p_5 & \cdots & p_{2k-1} & -q_2 & -q_4 & \cdots & -q_{2k-2} \\ 1 & p_2 & p_4 & \cdots & p_{2k-2} & -q_1 & -q_3 & \cdots & -q_{2k-3} \\ & & & \cdots & & & & \cdots & \\ 0 & & & \cdots & p_k & 0 & & \cdots & -q_{k-1} \\ 0 & q_2 & q_4 & \cdots & p_{2k-2} & p_1 & p_3 & \cdots & p_{2k-3} \\ 0 & q_2 & q_3 & \cdots & q_{2k-3} & 1 & p_2 & \cdots & p_{2k-4} \\ & & & \cdots & & & & \cdots & \\ 0 & & & \cdots & q_k & 0 & & \cdots & p_{k-1} \end{vmatrix} \tag{3}$$

for $k=2, 3, \ldots, n$ $(p_2=q_r=0$ for $r>n)$ are all positive.

Derivation of the Stability Conditions

Utilizing the notations and assumptions of Davis et al., the characteristics equation of the spin stabilized rocket in the presence of all transverse aerodynamic forces and moments is governed by

$$Q(\lambda)=\lambda^2+(b-ia)\lambda-(c+id) \tag{4}$$

where a, b, c, d are all constants.

We shall now find conditions that are necessary and sufficient for $Q(\lambda)$ to have both the roots in the left half plane. It may then be concluded that under those conditions $Q(\lambda)$ is a Hurwitz polynomial and stability of motion prevails.

A straightforward application of the preceding theorem to Eq. (4) yields

$$b>0 \tag{5}$$

and

$$abd-b^2c-d^2>0 \tag{6}$$

Received August 26, 1975; revision received November 25, 1975.

Index category: LV/M Dynamics and Control.

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