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Engineering Notes

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Spin Rate of Galileo Probe During Descent into the Atmosphere of Jupiter

L. J. Lanzerotti*
Bell Laboratories, Lucent Technologies, Murray Hill, New Jersey 07974
K. Rinnert†
Max-Planck-Institut für Aeronomie, D-37191 Katlenburg–Lindau, Germany
D. Carlock‡
Hughes Space and Communications Company, El Segundo, California 90009
C. K. Sobeck§
NASA Ames Research Center, Moffett Field, California 94035
and
G. Dehmel¶
Universität Braunschweig, D-38106 Brunswick, Germany

Introduction

AMONG the instruments that were carried on the Galileo atmospheric probe, the lightning and radio emissions detector (LRD) was designed to measure radio frequency signals in the inner magnetosphere and in the atmosphere of Jupiter. The instrument, consisting of a ferrite core radio frequency antenna followed by analog and digital processing electronics, was also configured to measure the magnitude of the local magnetic field in the spin plane of the probe along the probe trajectory. In the process of determining this field, the spin rate of the probe (but not the spin handedness during initial descent) was also determined.[1] Thus, a most important engineering parameter associated with the descent of an entry probe into an atmosphere of a giant planet could be determined and then compared with design-phase expectations. The measurements of the spin of the probe in the atmosphere, as well as comparisons with the preflight expectations, are important for future entry probe missions that may be planned for the outer planets.

The probe was intentionally designed to maintain a spin about its vertical axis throughout descent after parachute deployment. Before entry, at about one Jovian radius above the planet, the LRD measured the probe spin rate to be 10.4 rpm, consistent with the spin-up of the Galileo Orbiter before probe release in July 1995. During atmospheric entry, uneven ablation may have created grooves in the heat shield of the deceleration module. The resultant asymmetric aerodynamic forces could impart a rapid spin[2] on the decelerating probe, whose direction of rotation cannot be determined a priori. After parachute deployment, and aeroshell separation, the probe's descent module (DSM) rapidly passes through a transient spin rate response, which settles to a spin rate proportional to the descent velocity. The shape of the transient response depends on the initial spin, atmospheric conditions, swivel bearing friction, and damping performance. Figure 1 shows a general view of the Galileo probe and the forward and aft aeroshell shields.

Design Requirement

The original requirement explicitly levied on the probe's spin (ω_p) performance was that after parachute deployment, the spin should be

$$\tfrac{1}{4}\,\text{rpm} < \omega_p < 40\,\text{rpm}$$

with any initial transients ($\omega_p > 40$ rpm) that might occur after deployment being acceptable.[3] The actual design of the probe, however, was simply intended to ensure that 60 s after parachute deployment

$$\omega_p < 50\,\text{rpm}$$

to ensure that any frequency variation in the probe–Orbiter communication link that might be caused by the spinning did not exceed the acquisition limit of the Orbiter-mounted relay radio receivers.[4] This new requirement was the result of preflight communications link analyses.

Appreciable spin decay does not begin either at pilot chute deployment or upon main chute deployment. Rather, the spin rate significantly abates after aeroshell jettison, when the spin vanes mounted on the DSM first become aerodynamically effective upon exposure to the freestream velocity, and the rotational moment of inertia has been favorably decreased by a factor of almost 6. Consequently, the correct interpretation of specification and analytical data requires that spin decay time commence with aeroshell jettison.

Design Implementation

The final design used three fixed-spin vanes. Different deflection angles are used to compensate for asymmetric roll forces wrought

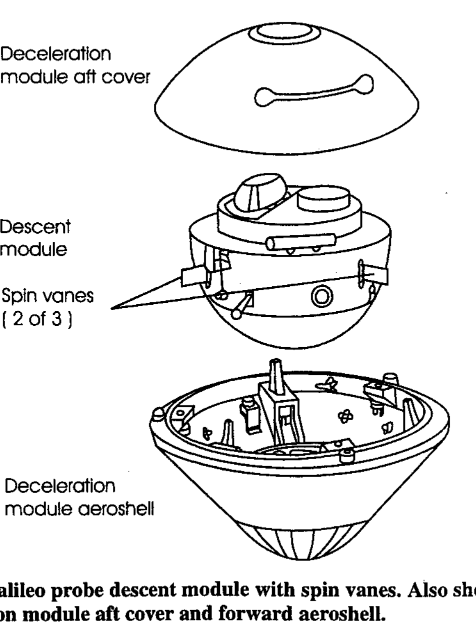

Fig. 1 Galileo probe descent module with spin vanes. Also shown are deceleration module aft cover and forward aeroshell.

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*Distinguished Member, Technical Staff. Fellow AIAA.

†Dr. Dipl. Physiker.

‡Senior Project Engineer, Spacecraft Engineering Operations. Senior Member AIAA.

§Galileo Probe Systems Engineering Manager, Space Projects Division.

¶Dr. Dipl. Ingineer, Institut für Nachrichtentechnik.

by the presence of external protuberances, most notably the axicon arm of the nephelometer instrument, the in-flight disconnect brackets with wiring harness, and the electrostatic discharge shield of the temperature sensor of the atmospheric structure instrument.[4] The spin vanes were set at the angles indicated in Table 1 and were verified by measurements with a theodolite and mirror before shipment for launch.[2,5,6] A close-up of the number 1 spin vane (orientation of 263 deg) is shown in Fig. 2.

Analytical Assessment of Performance

The spin rate of the descent module on the parachute was computed by using a six-degree-of-freedom computer program developed for the Pioneer Venus program, which had several probe entries into that planet's atmosphere. This analysis program included the product of inertia terms; however, because no pitch or yaw disturbances are introduced, there is no dynamic coupling of these terms into the spin. For the first several hundred seconds of descent, it is assumed that the parachute is not rolling and that the lower portion of the swivel, the bridle, and the descent module rotate as a rigid body. After the initial transient dies out and the system reaches its equilibrium velocity (weight equal to drag), the deceleration module's rolling moment created by the spin vanes eventually becomes less than the opposing rolling moment attributable to swivel friction. For the remainder of the descent, the descent module's spin rate locks on to the spin rate of the parachute. The maximum probe spin rate occurs just before parachute mortar firing, and it decays exponentially after aeroshell jettison to a near-asymptotic value in lock with the parachute spin rate. The final prelaunch computed transient spin performance[7] is graphically illustrated in Fig. 3.

The calculations show that if the initial spin handedness (looking down onto the descent module) is positive (9.9 rad/s or 95 rpm), the spin rate will decay to about 1.4 rad/s (13 rpm) about 400 s after aeroshell jettison. If the initial spin handedness is negative (−7.9 rad/s or −75 rpm), the rate will decay to about −1.2 rad/s (−11 rpm) about 400 s after aeroshell jettison. However, in this case, the spin rate has to cross zero and become right handed because of the orientation of the spin vanes. No evidence was found in the LRD data for a zero crossing.

Table 1 Spin vane angles

Vane	Orientation, deg	Deflection angle (±0.3), deg
1	263	13
2	143	13.5
3	23	2.9

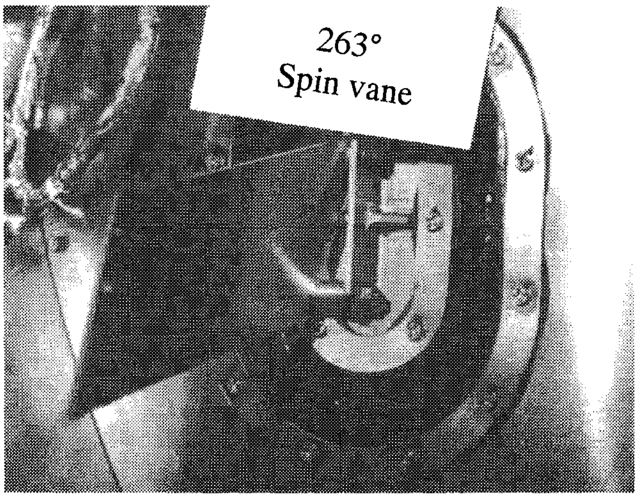

Fig. 2 Close-up view of probe descent module 1 spin vane (orientation of 263 deg).

Performance Assessment Test

During the second wind-tunnel test at NASA Ames Research Center facilities, the rolling moment effectiveness of the spin vanes vs the deflection angle was determined as the roll angle and the angle of attack were varied parametrically. The total rolling moment on the model was then determined as a function of the total spin vane deflection (of all three vanes). The deflection angles ultimately chosen resulted in maximum driving torques (±3 standard deviations), which were less than the minimum swivel torque. As noted earlier, this allowed the descent module to lock up on the parachute after the initial transient had decayed.[4] During system drop test 1 (July 1982), the terminal spin rate was measured to be 14.7 rpm (Ref. 8).

Mission Assessment: LRD Data

The LRD made one measurement of the descent module spin rate over 1.5 spin periods at the end of each of its 256-s data acquisition intervals after the instrument calibration sequence that occurred immediately after experiment turn on. Twelve data intervals were accumulated and transmitted before instrument failure because of the high temperature of the Jovian atmosphere. The spin rate determinations are plotted in Fig. 4. Calculations of the possible effects on the spin rate measurements of probe swinging as well as determinations of the Jovian magnetic field led to the conclusion that any swing of the order of 1 Hz would have an inclination of ≲25 deg. Also shown in Fig. 4 is an a posteriori assessment of the nontransient

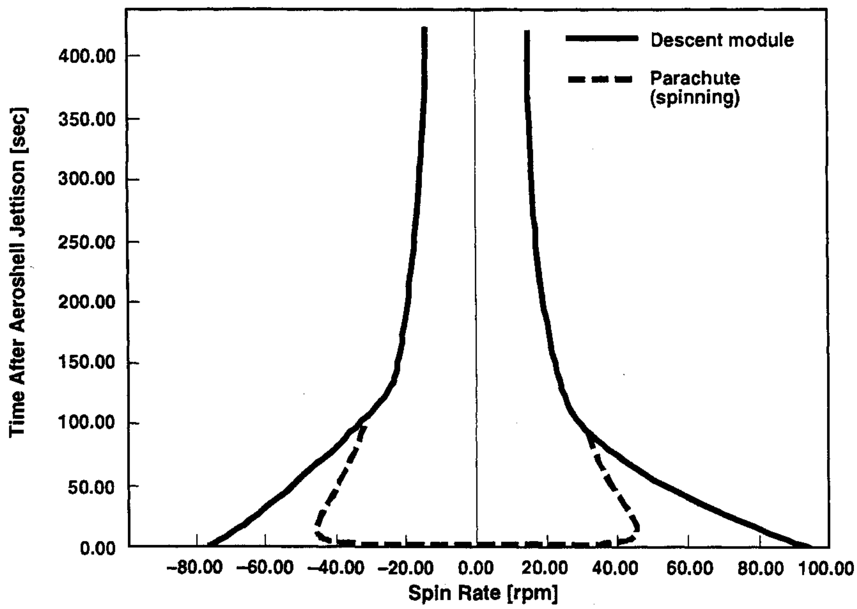

Fig. 3 Calculated prelaunch spin assessment of probe descent module.

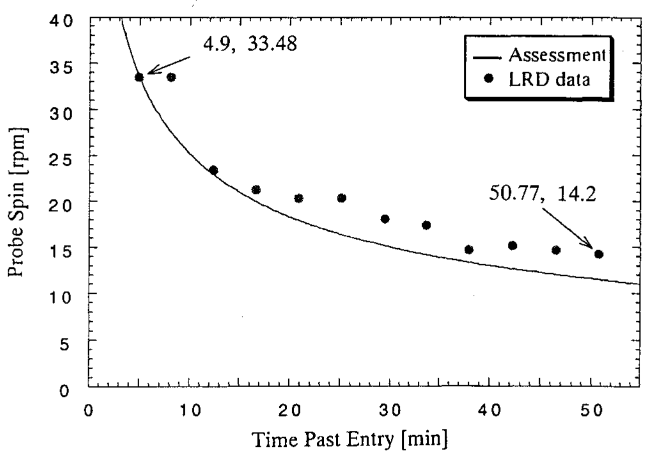

Fig. 4 Measured probe descent module spin performance compared with a posteriori spin assessment. Two sets of numbers correspond to descent time and spin rate in the first and last data acquisition intervals.

spin response. This assessment was derived from further model calculations based on drop and wind-tunnel tests.

Five minutes past entry, the spin rate was measured as ±33 rpm (33.48 rpm at 4.9 min). A cursory comparison with Fig. 3 suggests that the spin direction at aeroshell jettison was positive, i.e., not reversed by ablative grooving, although insufficient data during this initial descent period exist to conclude this with certainty. Ancillary data, however, confirm that the intent of the transient spin requirement was adequately met. Because the Orbiter-mounted relay radio receivers managed to lock onto the probe's modulated signal much sooner than expected (~35 s instead of the specified 1-min maximum), it is clear that any high-rate probe spin that might have been induced by entry forces was quickly damped. If this were not the case, the phase error of the received signal—predominantly due to spinning effects during initial signal acquisition—would have been too high to permit rapid signal acquisition.[9]

For the remainder of the descent mission, the spin assessment appears to provide a more conservative, lower-bound spin estimate, matching the flight data to within about 5 rpm. However, the assessment itself is based on an equation of motion, which assumed that the parachute was nonspinning and, hence, would not be expected to accurately replicate the actual flight condition of a spinning parachute/spinning DSM whose composite rolling moment and roll damping coefficients were never measured or analyzed. Furthermore, the assessment ignored the possibility of dynamic coupling of pitch and yaw disturbances into the probe spin. Again, this was because aerodynamic test and design efforts were focused toward meeting the transient spin requirement. For the balance of the descent mission (beyond 5 min past entry), it was always deemed sufficient that the probe simply have a nonzero spin. (It is interesting to note that the terminal spin rate measured during the aforementioned test in Earth's atmosphere was within 4% of the final Jovian spin measurement.) The last point recorded, at 50.77 min after entry, corresponded to a spin of 14.2 rpm.

Conclusions

The comparison of the measured probe descent spin with the calculated spin assessment, as well as the excellent acquisition of the communications link to the Orbiter, show that the aerodynamic spin design of the probe was entirely adequate. The spin was slow enough to provide favorable conditions for timely establishment of a communications link with the overflying Orbiter and fast enough to provide the science payload sensors a continuous 360-deg survey of the local horizon throughout the Jovian descent mission.

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J. D. Gamble
Associate Editor

Flowfield over Bulbous Heat Shield in Transonic and Low Supersonic Speeds

R. C. Mehta*
Vikram Sarabhai Space Center, Trivandrum 695022, India

Nomenclature

C_p = pressure coefficient
D = maximum payload shroud diameter, m
d = booster diameter, m
e = specific energy, J/kg
F = vector of x-directed fluxes
G = vector of r-directed fluxes
H = source vector
M = Mach number
p = static pressure, N/m^2
q = heat flux, W/m^2
Re = Reynolds number
t = time, s
U = conservative variables in vector form
u, v = velocity components, m/s
x, r = coordinate directions, m
ρ = density, kg/m^3
σ = stress vector, N/m^2

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*Engineer, Aerodynamics Division. Senior Member AIAA.