Design and Performance Characteristics of the Viking Lander Inertial Reference Unit

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This paper gives a detailed insight into the peculiar problems that the designer of a planetary lander inertial reference unit (IRU) requiring heat sterlization will confront. Solutions for such unanticipated deficiencies as gyro flexlead soldering processes, endstone design, and preconditioning processes, as developed for the Viking (Mars) Lander IRU, are presented. The Viking Lander IRU redundancy implementation is discussed with emphasis placed on the advantages and disadvantages of the scheme used and a description of the electronics mechanization. The Viking Lander IRU realized performance for both Viking Landers is discussed with emphasis given to measurable coefficient stabilities from IRU acceptance through Mars landing.

I. Introduction

THE Viking Lander IRU is the first guidance package containing inertial sensors to have been successfully designed and built to meet the heat sterilization compatibility requirements imposed on a planetary landing mission. Preliminary reliability studies resulted in the selection of ball-bearing gyro candidates over gas-bearing gyros because of the mission configuration. The gas-bearing gyro is well suited to continuous operation but is less reliable for shutdown and startup type applications. The Viking mission required that the IRU be in a nonoperating condition during the 10-month launch and cruise phase because of electrical power contraints, requiring startup after injection into Mars orbit.

The simple construction hinged pendulous type accelerometer was selected over the various other types available because of its high tolerance to extreme dynamic environments (pyro shock, etc.), relative low cost, and good accuracy potential. It was concluded that the task required to harden the various types of accelerometers to the heat sterilization temperatures was equal.

The severity of the heat sterilization process, in addition to the extreme environments predicted for the IRU during interplanetary cruise, Mars orbit, and landing, presented several unique problems in the design of the IRU and, more specifically, to the gyros and accelerometers contained therein.

In presenting the design problems and features of the IRU, the requirements and predicted environments for the package will be described, followed by a description of the final configuration and functions of the IRU in the Viking Lander. In the IRU design approach, emphasis will be placed on the design problems associated with the heat sterilization compatibility requirement, the extreme operating and nonoperating temperature ranges, and high input rate transient due to parachute deployment. The redundancy mechanization to achieve a "no single failure" criteria will be discussed in light of severe limitations in IRU weight, size, and power allocations.

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The intent of this paper is to provide an insight into the pitfalls associated with the design of planetary lander systems requiring special processing (heat sterilization), in order that the knowledgeable designer will avoid the many pitfalls described herein for follow-on similar mission requirements.

II. Predicted Environments

The mounting location of the Viking Lander IRU external to the Lander body dictated the severe environments imposed on the IRU. Mounting of the IRU inside the Lander body where the environments were more benign was not possible because of the many components which were required to operate after landing. The Viking Lander IRU operation was complete 5 min after touchdown.

The predicted environments for the Viking Lander IRU are listed in Table 1.

III. Final Configuration

The Viking Lander IRU is a redundant inertial reference unit used to provide Viking Lander attitude and velocity information in all three axes from separation through landing. After landing, the IRU data are acquired for 5 min to provide the Lander computer with the necessary information to compute the Lander latitude, azimuth, and tilt, in order to

Table 1 IRU qualification environments

Environment	Units	Operating	Nonoperating
Vibration			
Random	GRMS	8.5	8.5
Shock			
Pyro	*g* peak	6000 @ 4000 Hz	1300 @ 3200 Hz
Landing	*g* peak Half sign	30 22 ms	N/A
Deceleration			
Axial	*g*	17	N/A
Lateral	*g*	0.25	N/A
Pressure			
Minimum	Torr	1×10^{-14}	1×10^{-14}
Temperature			
Sterilization	°F	N/A	254 ± 3 for 362 h
Cruise			
Radiation	°F	-15 to +180	-15 to +80
Conduction	°F	+3 to +80	+3 to +80
Launch	°F	N/A	+35 to +125
Landing	°F	-115 to +97	N/A

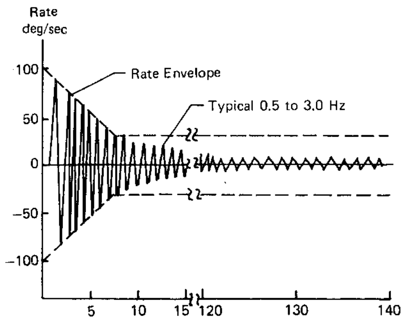


Fig. 1 Parachute opening transient.

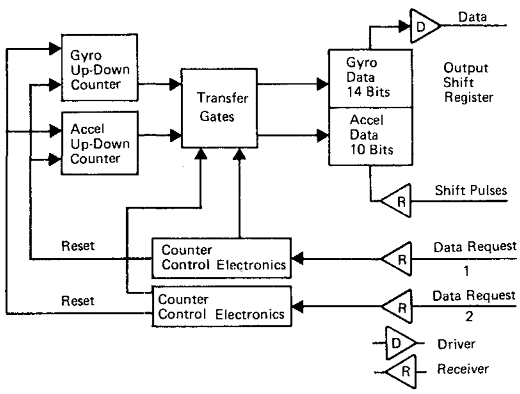


Fig. 2 IRU output mechanization.

position the high gain antenna toward Earth so that data can be downlinked directly to the Earth from the Lander.

The Viking Lander IRU provides continuous attitude information for rate inputs of up to ±12.5 deg/s about all axes. The IRU also can provide attitude information for a period of not more than 192 s continuously at rate inputs in excess of ±12.5 deg/s up to ±100 deg/s about all axes. The worst-case maximum rates occur at parachute opening and are not expected to exceed 97 deg/s. The expected parachute transient is shown in Fig. 1.

The IRU also provides continuous velocity information along the flight path (X axis) for acceleration inputs up to $\pm 20g$ (644 ft/s^2) and along the lateral axes (Y and Z axes) up to $\pm 5g$ (161 ft/s^2).

The IRU provides digital two's complement output attitude and velocity information asynchronously to the guidance and control sequencing computer (GCSC) upon command. Each axis of attitude and velocity data is transferred as a packed 24 bit word to the GCSC – 14 bits of attitude data and 10 bits of velocity data. One channel of the output circuit mechanization is shown in Fig. 2.

The gyro and accelerometer servo electronics utilize a pulse width modulated digital torquing scheme. This scheme was selected because of its constant power input to the torquer, thereby eliminating a source of scale factor error associated with temperature variations in the torquer. The IRU was mechanized so that switching between rate modes is automatically performed within the IRU. In order to prevent switching back and forth between operating modes under high rate oscillatory conditions, such as the parachute transient of Figure 1, a 3.45 s time delay is provided to insure that the rate input is not oscillating at greater than 12.5 deg/s.

The continuous high rate mode time duration limit of 192 s was required in order to prevent thermal damage to the gyro torquer. Automatic removal of the high mode torque current is provided by internal timing circuitry within the IRU. Since the parachute phase of the mission begins approximately 165-180 s prior to landing, a gyro failing to recover from high mode operation would still provide attitude information through landing.

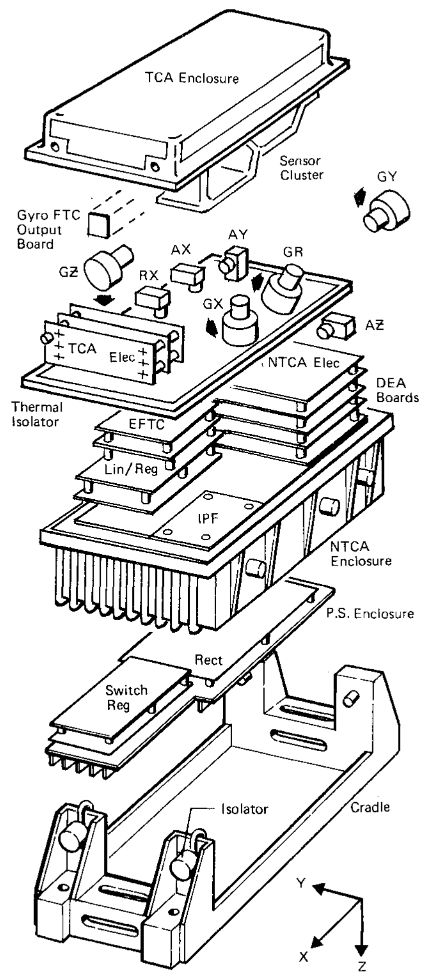


Fig. 3 IRU exploded view.

In order to minimize flight computer software and prevent the need for scale factor switching within the computer, the change in IRU scale factor when changing operating modes was implemented within the IRU digital electronics.

An exploded view of the Viking Lander IRU is shown in Fig. 3. All components that require thermal control, such as the gyro's accelerometers and rebalance electronics, are mounted in the temperature control assembly (TCA), which is thermally isolated from the non-temperature control assembly (NTCA) in order to minimize control heater power during operation and reduce heat loss during system warmup.

A TCA cover heater was also incorporated to maintain the ambient gyro temperature at approximately +15°F during the nonoperating interplanetary cruise phase of the mission.

The Viking IRU weight, power, and size are listed in Table 2.

IV. Redundancy Implementation

The "no single point failure shall cause loss of the mission" criteria was compromised for the IRU because of limited flight computer memory storage capacity. Instead of mechanizing for in-flight fault detection, fault isolation, and switching, it was decided to incorporate sufficient redundancy into the IRU so that any single failure within the IRU could be detected and worked around before the critical Mars entry and landing phase. This approach was justified on the basis that the entry/landing phase was a short 6 hours as compared with the 10-month launch/cruise phase. A simplified block diagram representing the final configuration is shown in Fig 4.

Table 2 IRU size, weight, and power

Weight	32 lb
Size including isolators and cradle	
Length	16.0 in.
Width	10.4 in.
Height	9.13 in.
Power electronics	
Normal mode	42 W
High mode (all gyros)	138 W
Power heater	
Warmup	128.5 W
Cover	12.5 W
0°F operating	33.5 W
80°F operating	10 W

Redundancy is incorporated to avoid loss of either 3-axis attitude information or crucial flight path (X-axis) velocity information. Since there was no real-time sense and switch capability implemented, selection of the sensors and electronics to be used during descent and landing was based on data gathered during preseparation checkout. Selection is implemented by a software data base uplink before separation.

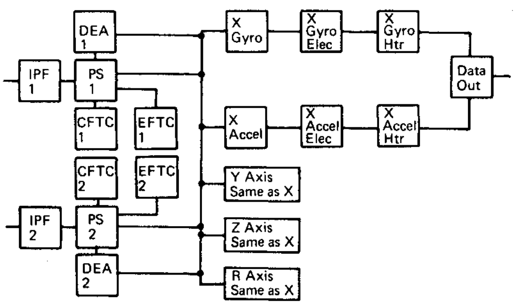
Sensor Redundancy Implementation

Sensor redundancy was implemented using four gyros and four accelerometers. Attitude redundancy was implemented by skewing the input axis of the fourth gyro at equal angles (54.735 deg) to the input axes of the primary triad gyros. Velocity redundancy was only implemented along the vehicle flight path axis (X axis), as a landing could be achieved without the lateral velocity information. The skewed gyro redundancy approach has the advantage of providing total attitude information with any one of the primary gyros failed with the minimum increase in weight and power. It also provides the capability of ground checkout failure detection without knowledge of vehicle orientation, as the acceleration along each axis can be determined from the velocity output data. In-orbit failures can be detected in the same manner. This approach, however, has the disadvantage of having some reduction in accuracy due to misalignment of the skewed gyro and computational errors in computing the attitude data for the failed gyro axis. Loss of the lateral velocity data can also cause reduction in accuracy because there is no method of correcting for cross axis errors due to winds encountered during entry.

Electronics Redundancy Implementation

Electronics redundancy was implemented by providing two totally separate strings of input electronics. Each input string consisted of an input filter, a power supply capable of supplying the total system power, a digital electronics assembly capable of supplying all digital interfaces within the system, and a temperature controller for the gyro and accelerometer temperature/controlled electronics.

The electronics for each gyro and accelerometer is totally independent and, therefore, not redundant. Redundancy of the power supplies was protected from short circuits by fusing the power supply inputs to each gyro and accelerometer channel to prevent hard shorts in a single channel causing loss of the entire IRU.



DEA – Digital Electronics Assembly
PS – Power Supply
CFTC – Cover Fine Temperature Control
EFTC – Electronics Fine Temperature Control
IPF – Input Power Filter

Fig. 4 Redundancy block diagram (simplified).

V. Sensor Design and Process Changes

The extreme nonoperating temperature range (-25 to 254°F) required that basic design and process changes be made to the sensors used in the Viking Lander IRU. The gyro high rate capability of 100 deg/s also dictated gyro design changes. It was also found during the predevelopment phase that gyro and acclerometer parameters showed a high sensitivity to the extreme temperatures and required preconditioning. Figure 5 shows the gyro scale factor sensitivity to heat sterilization time as an example of parameter sensitivity.

Gyro Design Changes

1) The damping fluid was changed to polychlorotrifluorethylene (PCTF) in place of polybromatrifluorethylene (PBTF) to avoid fluid corrosive action with the beryllium case and the silver flexlead materials. Also, the PCTF was significantly less susceptible to molecular breakdown at the high-temperature exposures associated with heat sterilization.

2) Conventional fluid-filled gyros are designed to accomodate fluid volumetric changes associated with a temperature range of $\approx 250°F$. The Viking gyro required an additional convolution to the compensatory bellows to accomodate a temperature range of $\approx 300°F$.

3) The gyro wheel was altered in size and shape to effect a change in angular momentum as dictated by the torquing capability requirements of the Viking IRU.

Gyro Preconditioning

The purpose of subjecting the gyro subassemblies and final assembly to sterilization preconditioning is to establish the mechanical integrity of the assemblies, insure that all outgassing of epoxy resins has occurred before final assembly, and to mechanically stabilize the major subassemblies over the maximum temperature range.

The preconditioning is performed on all subassemblies in progression through final gyro assembly. The completed gyro is put through three complete sterilization exposures, alternating with performance testing to establish the completed instruments performance characteristics across the sterilization cycle.

1) All assemblies containing epoxy resins were subjected to the maximum sterilization temperature of 254°F at an ambient pressure of 50μ Hg for a period of 48 h.

2) All subassemblies were temperature cycled from -65 to 300°F at a rate of 12 deg/min with a 2 h dwell at -65°F and 300°F for three- to five cycles.

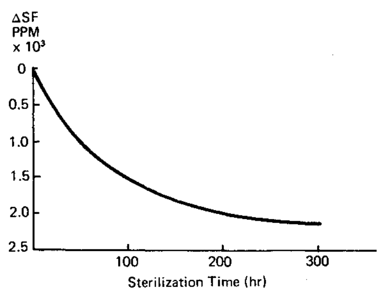


Fig. 5 Gyro scale factor sensitivity to heat sterilization time.

3) All assemblies were exposed to dry heat at 254°F for 60 h to insure mechanical stability after assembly.

4) The entire gyro assembly was preconditioned by exposure to three dry heat cycles at 254°F for 60 h with performance testing before and after each cycle.

Accelerometer Design Changes

1) The accelerometer was fluid filled with silicon damping oil in order that the accelerometer would not be damaged when subjected to nonoperating shock and vibration.

2) The bellows assembly was redesigned to compensate for the damping fluid volumetric changes over the wide temperature range required by the Viking Lander IRU.

3) During predevelopment testing, the accelerometer showed excessive bias shifts across heat sterilization. It was found that the pendulum hinge spring material was experiencing excessive relaxation (creep) during the nonoperating/1-*g*/heat sterilization process. The beryllium copper hinge spring material was changed to Elgiloy‡ which exhibited improved relaxation (creep) characteristics resulting in only minor bias shifts across heat sterilization.

Accelerometer Preconditioning

The preconditioning for the accelerometer subassemblies and final assembly were the same as that described for the gyro.

VI. Problems Encountered during Development

In the IRU development phase, several gyro design problems were uncovered during thermal vacuum testing that were subsequently concluded to be directly related to the heat sterilization, low temperature soaks, or prolonged vacuum exposure. The successful solution to these problems required extensive research, testing, and experimentation. It is felt that knowledge of these problems and solutions will greatly assist IRU designers for future planetary landers.

IRU heat sterilization requirements were derived from the requirement to subject the encapsulated Lander to 233°F for a period of 40 h with allowance for up to three recycles. The IRU qualification requirement was 254°F for 362 h and the flight component acceptance requirement was 233°F for 54 h.

Thermal Vacuum Testing (TV)

The predicted IRU temperature environment for the 11-month quiescent Earth to Mars cruise and Mars orbit (Lander nonoperating) was 0 to +75°F which constituted the IRU acceptance levels for TV test. The derived qualification levels (based on prediction uncertainties) was -25 to +80°F.

The test transition rates were based also on predicted transitions for the IRU interface during the cruise and Mars orbit phases. Neither the nonoperating nor the operating transition conditions were found to be a limiting factor for the Viking application (as opposed to IRU power warmup and power shutdown during low temperature soak).

Gyro Flexlead Problem

The first problem encountered during TV testing was gyro flexlead breakage. The flexleads (see Fig. 6) provide the flexible current paths from gyro case to float assembly for torquer, pickoff, and spin motor. It was found (with the aid of a plexiglass gyro) that during low temperature cooldown below 0°F the flotation fluid pressure in the flexlead cavity was reduced to the point that voids began to form. This produced localized pressure differentials that produced forces on the flexleads sufficient to cause kinks. Repeated testing resulted in kinked flexleads but no breakage. It was subsequently discovered that the ingredient necessary to result in fracture was pre-exposure to the heat sterilization process.

‡A cobalt/chromium/nickle alloy produced by Elgin Watch Company.

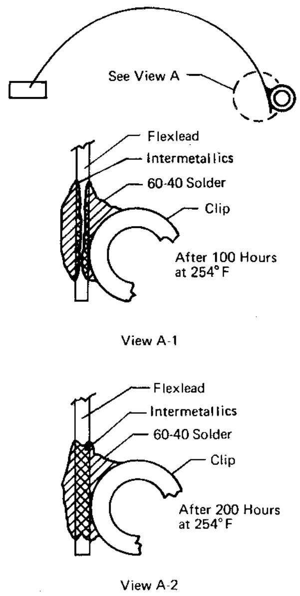


Fig. 6 Flexlead assembly.

The sterilization process caused a significant strength reduction of the flexlead at its soldered terminations.

The flexlead assembly consisted of a 0.223 in. radius coin silver (85% Ag, 15% Cu) ribbon, 0.00025 in. thick by 0.007 in. wide, soldered at both ends with 60-40 solder to fine silver (90% Ag, 10% Cu) clips. Microphotographs of cross-sectioned solder joints revealed that progressive intermetallics were formed in the flexlead material with increased exposure of the flexlead assembly to the sterilization temperature. After 200 h of sterilization exposure, the intermetallics formation was found completed with none of the flexlead alloy material present within the solder joint in its original structure. An illustration of this progession is shown in Fig. 6. Tensile tests of the unsterilized and sterilized assemblies confirmed a significant difference in load capability (112 and 76 K psi, respectively). Experimentation showed that low tin solders produced less intermetallics. Ag 1.5 solder (0.75 to 1.25% Sn, 1.3 to 1.7% Ag, remainder Pb) was found to produce essentially no intermetallics and was selected to replace the 60-40 solder.

Gyro Endstone Problem

The second problem encountered during TV testing was breakage of the sapphire endstones (see Fig. 7) resulting in gyro performance degradation. The condition was pronounced at the bellows end of the gyro where there is no case backing to support the endstone and was evidenced as "punch through" by the float pivot (see Fig. 8a). As with the flexleads, the damage was found to occur at low temperatures. The gyro design and thermal interface was such that during IRU cooldown, heat leaves the gyro primarily through the torquer end. During cooldown, the pressure at the bellows end less the pressure drop across the float caused by the flow of fluid around the float is a function of fluid flow rate, which is a function of the contraction rate of the fluid at the torquer end and of viscosity, and hence is a function of cooldown rate and temperature. The pressure differential across the float moves the float in the direction of the torquer end until the float pivot bottoms on the torquer endstone. Force is exerted on the endstone until pressure equalization is realized with thermal stabilization. For IRU warmup, the opposite is true with float pivot force exerted on the bellows endstone. Emphasis was placed on the bellows endstone as the "punch-through" fracture incurred during the higher temperature change rate associated with fast warmup was the cause of gyro performance degradation. Test results showed the bellows endstone would fracture at $\approx$20 lb force, whereas forces exerted during warmup from -25°F resulted in forces of

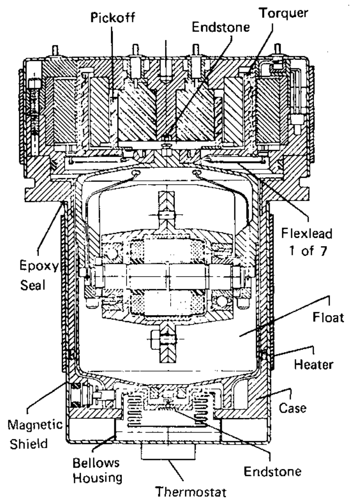


Fig. 7 Gyro cutaway.

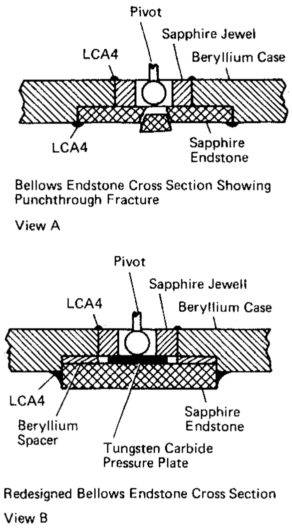


Fig. 8 Bellows endstone.

≈35 lb. Various solutions were considered, including altering the gyro thermal design, using thicker sapphire endstones, and incorporating high load-bearing pressure pads. The use of a thicker endstone and incorporating a high load-bearing pressure pad was selected as it involved the minimum change to the gyro design offering the better chance of not adversely altering the inherent performance characteristics of the gyro. Several metallic pressure pad materials were tested and discarded due to excessive brinnelling from the pivot contact. The selected design (see Fig. 8b) incorporated a tungsten carbide pressure pad bonded to a double thickness sapphire endstone. This combination resulted in a 40 lb pivot bearing capacity.

As a safety factor of ≈2 was concluded necessary for both the flexlead and endstone load capacities, continuous trickle heaters were added to the IRU to assure the gyro nonoperating temperatures would never be below +10°F during any phase of the mission. Test results showed that warmups from +10°F would result in endstone loads of ≈20 lb.

Gyro Shield Leak Problem

As discussed earlier, because of electrical power limitations, only the sensors and critical electronics were heated and temperature controlled. This required thermally isolating the sensors from IRU mounting structure and heating them directly. Two wraparound heater blankets were used on each gyro, as shown in Fig. 7. The heater blanket on the smaller diameter is bonded to the magnetic shield and is dependent on helium backfill (between shield and case) to transfer heat into the gyro. The second function of the helium is to pressurize the bellows. On the bellows end of the gyro an over-temperature-control thermostat is affixed and is in series with the two heater blankets. After prolonged TV testing (due to flexlead and endstone problems), the gyro thermostats were found opening and controlling gyro temperature. Gyro heater control set point was +160°F and the thermostat open point was +167°F resulting in coarse and unacceptable temperature control. It was found that the integrity of the epoxy seal (between magnetic shield and case) degraded with time and environments, allowing the helium to leak out during TV testing. This degradation was attributed to the flexibility of the shield and the large seal diameter. With the helium gone, the shield was isolated and went above set-point temperature as the control thermistor was imbedded within the gyro. This caused the thermostat to open even though gyro temperature was well below set point. The solution was to cap and backfill with helium the bellows housing internal of the shield and to fill the gap between shield and case with thermal grease.

The nature of the problems experienced with the gyro and the manner in which they were uncovered back up the conclusion that extensive thermal vacuum testing can be invaluable to realization of a successful mission.

Accelerometer Bias Temperature Hysteresis Problem

During the design development testing of the accelerometer, a bias temperature hysteresis condition was found. This condition manifested itself as racheting of the bias parameter with the bias magnitude measurement being dependent on the past nonoperating soak temperature. The typical bias delta observed when exposing the accelerometer to the Viking temperature extremes was 1000 μg, which was unacceptable instability. (Note that this condition, although unacceptable, was far superior to the pre-Viking accelerometer design when subjected to the Viking temperature extremes.) It was found that the stress relief of the pendulum frame and hinge springs was incomplete. Acceptable stress relief processes were developed through experimentation, which ultimately resulted in the highly stable bias parameter required for the Viking mission.

Table 3 Gyro bias stability

VLC-1	Baseline FAT, deg/h 4/14/75	Cruise check-out, deg/h 11/10/75	Preseparation checkout, deg/h 7/19/76
X gyro	6.504	6.488	6.452
Y gyro	5.688	5.786	5.763
Z gyro	0.688	0.694	0.655
R gyro	2.600	2.733	2.710
VLC-2	3/19/75	11/19/75	9/2/76
X gyro	1.869	1.954	1.929
Y gyro	3.760	4.081	4.070
Z gyro	5.335	5.261	5.232
R gyro	1.282	1.328	1.331

Table 4 Accelerometer bias stability

VLC-1	Baseline FAT, μg 4/14/75	Cruise checkout, μg 11/10/75	Preseparation checkout, μg 7/19/76
X accel	1280	1149	1111
Y accel	-893	-1042	-1129
Z accel	-582	-724	-763
R accel	1045	913	921
VLC-2	3/19/75	11/19/75	9/2/76
X accel	2048	2095	2049
Y accel	627	709	699
Z accel	-912	-1023	-1035
R accel	813	727	724

Table 5 Deorbit execution error contribution

Assumed value (3σ)	Error (3σ) pointing, deg	Error (3σ) magnitude, %
Accel bias, σg		
$X=50$	...	0.467
$Y=50$	0.274	...
$Z=75$	0.403	...
Gyro bias, deg/h		
$X=0.3$	...	...
$Y=0.3$	0.074	...
$Z=0.3$	0.062	...

Table 6 Estimated deorbit errors

Pointing, deg	Magnitude, %	Touchdown error
VLC-1 0.24 (0.84σ)	0.20 (1.27σ)	-24 km (1.06σ)
VLC-2 0.29 (1.01σ)	0.055 (0.35σ)	+9 km (0.4σ)

Table 7 Maximum attitude rates at parachute opening

	VLC-1, deg/s	VLC-2, deg/s
Roll	1.40	1.19
Pitch	60.13	48.52
Yaw	6.59	-16.17

Table 8 IRU maximum high mode operation

	VLC-1, s	VLC-2, s
Roll	7.70	10.90
Pitch	20.95	20.94
Yaw	11.70	16.12
Redundant	23.00	18.00

Table 9 IRU computed landing site parameters

		VLC-1	VLC-2
Mars gravity	ft/s^2	12.20099	12.24428
Vehicle tilt			
Yaw		1°47′10″	-7°37′22″
Pitch		-2°23′50″	-3°01′00″
Total		2°59′25″	8°12′16″
Mars rate	deg/h	14.63282	14.58283
Latitude	North	22°40′53.5″	47°42′24.3″
Azimuth	Leg 1 CW from North	321°37′38″	209°04′38″
Target azimuth	Leg 1 CW from North	320°00′00″	210°00′00″

VII. Viking Lander IRU Performance

Both Viking Lander IRU's performed without flaw from final acceptance testing through landed operations. Both IRU's provided the necessary information to the guidance and control sequencing computer so that the Lander high gain antenna was correctly positioned and direct downlink communications was established immediately after landing. The IRU performance data given herein are taken from the Viking Lander Descent Analysis Report.[1]

Bias Stability

Both Viking missions were flown using the primary triad of sensors in the IRU. The gyro and accelerometer biases determined during the preseparation checkout repeated the values determined during cruise checkout (8 months prior for Lander I and 9½ months prior for Lander II) so closely that no computer data base revision was required prior to separation. The gyro and accelerometer bias stability is shown in Tables 3 and 4 from acceptance test through preseparation checkout for both Viking Lander IRU's. The *Y* axis gyro bias shift noted on the the Viking Lander II IRU occurred during Lander level heat sterilization at the Cape prior to launch and was well within the specification requirements.

Deorbit and Entry Performance

One of the most crucial phases of the Viking missions was the deorbit burn. The gyro and accelerometer bias errors during deorbit burn contribute to the pointing and magnitude error during deorbit execution, as shown in Table 5.

Based on the Lander trajectory reconstruction, the deorbit execution errors were estimated to be as given in Table 6 for both Landers.

The fact that the deorbit burn was nominal and quite accurate suggests that some IRU and/or initial orbiter alignment accuracy numbers may have been too conservative.

The IRU sensed maximum input rate at parachute opening, as given in Table 7 for each Lander, was based on 0.1-s sample time.

During this time, the IRU operated in high mode. The total time of high-mode operation for each Lander is given in Table 8. The maximum time of high-mode operation for any gyro is well below the design limit of 192 s.

IRU Landed Performance

In order to point the high gain antenna toward the Earth after landing, IRU data were accumulated for 300 s on the Mars surface to determine the vehicle tilt, latitude, and azimuth. This information is then used by the computer in order to point the high gain antenna toward Earth for direct communications with the Lander.

Direct Earth-Lander communications were accomplished on both Landers using the data supplied by the Lander IRU's. The Mars landing site location, Lander tilt, azimuth, and Mars gravity and rate as computed using the IRU data are listed in Table 9.

VIII. Conclusion

The Viking Lander IRU performed without flaw the mission for which it was designed. The performance of both Viking IRU's exceeded the design limits specified for the Viking mission.

The most severe problems encountered were those associated with arriving at the final gyro and accelerometer designs. The gyro flexlead and endstone solutions were arrived at only after extensive trial-and-error experimentation. The accelerometer hinge spring material selection was more straightforward in retrospect, but still difficult because of the miniature dimensions (hinge size) and low stress levels involved. The gyro and accelerometer preconditioning processes were established after several costly iterative attempts. These problems can now be anticipated and approached in a more scientific manner for follow-on missions.

Acknowledgment

The Viking Lander IRU was designed and manufactured by Hamilton Standard, a division of United Technologies Corporation, to Martin Marietta specifications. The accelerometer used in the Viking Lander IRU was designed and manufactured by Bell Aerospace, a division of Textron Incorporated.

References

[1] Final Report, "Entry Data Analysis for Viking Landers 1 and 2," Martin Marietta Corp., Denver, Colo., NASA, Nov. 1976.