Engineering Notes

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Space Shuttle as a Dynamic Test Tool for Missile Guidance Systems

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Overview

EVALUATION of missile guidance system accuracy since Minuteman I has traditionally been based on a combination of observed total miss (the score) and detailed information in boost from precision range instrumentation systems. The scoring data served as an overall check on total guidance and control error, and the detailed evaluation of the boost phase range instrumentation data yielded information on guidance error model structure and anomaly identification. At the end of a lengthy test program (e.g., about 100 Minuteman III R&D test launches plus an equivalent number of operational testing flights), a relatively accurate assessment of total system error can be made by examining the scoring patterns and statistics.

However, missile development since the early 1960s has worked against both the statistical and detailed assessment approaches to G&C system accuracy assessment. First, G&C accuracy has improved significantly. Second, high missile costs, for both acquisition and test, militate against very large test programs in which accuracy can be assessed via brute force statistics applied to shot patterns. Finally, developments in range instrumentation have not, in general, kept pace with the improvements in guidance technology. In fact, with the decommissioning of the MISTRAM X-band interferometer at the Eastern Test Range in 1971, the flight-test community has not had a conventional ground-based range-instrumentation system better than, or comparable to, the inertial guidance systems whose performance was being assessed (a deliberate distinction: the space-based GPS system offers considerable opportunities). Therefore, testing of the Minuteman II and Minuteman III missile has, for 10 yr, relied primarily on scoring data to evaluate accuracy. Such testing, while unable to identify specific error sources or confirm guidance anomaly hypotheses, benefited from the large number of tests made and from the generally well-behaved performance of the G&C systems.

The major deficiencies of current test programs for high-accuracy missile guidance systems are: 1) very limited number of tests for statistical assessment; 2) exposure of a limited number of G&C systems to a flight test environment; and 3) poor range instrumentation for anomaly detection and resolution.

Dynamic Test Concepts

Dynamic test concepts considered, and in some cases tried, included: van/truck or aircraft, rocket sled, centrifuge, and special-purpose missile. The first three have the great advantage of being nondestructive; the guidance system is not destroyed as it would be an actual missile test. But the replication of an actual missile environment is poor; even the rocket sled is limited to a fraction of the total ΔV generated in the actual missile flight. Although the acceleration level on the sled is near that of a flight, it is at that level only momentarily and the errors generated (the IMU errors are functions of the thrust accelerations) integrate to a very low level relative to their values on an actual flight. In addition, the sled track measurement of velocity is insufficient to resolve the small IMU errors generated on a sled test; sled test instrumentation would have to be much better than flight test instrumentation to discern the equivalent error. Van and centrifuge tests are even less representative of missile flight trajectories and are also handicapped by instrumentation problems.

An alternative test concept is to actually fly the IMU (or more than one) on a separate booster, preferably a "free" or low-cost surplus system (.e.g., Minuteman I). Flight environment replication is good. Range instrumentation problems still exist and (particularly if multiple IMUs are used to get good measurement data) this approach destroys the test assets and is very costly.

The ideal dynamic test concept would have the following properties: large total velocity (approximating or exceeding the actual missile's); high acceleration approximating the missile's level; existing payload support interfaces; significant number of flights; existing metric data acquisition capability; nondestructive test design; carry multiple IMUs; not be dedicated to single-purpose G&C testing (to reduce costs); and permit flexible test schedules.

This list of desired properties is met in most, although not all, particulars by the Space Shuttle. The potential suitability of the Shuttle as a tool to address guidance testing issues led to a study of the feasibility and payoffs of this concept.

Shuttle Testing of AIRS

In the mid-1980s, the Shuttle schedules present an opportunity to significantly increase the flight time for currently in-development IMUs in a reasonably representative flight environment, while simultaneously obtaining accurate instrumentation data for performance evaluation. Key issues are: 1) test accuracy payoff and 2) integration of the IMU package into the Shuttle.

Basically, the AIRS shuttle test concept is:

1) Package the IMU with an associated computer plus data collection unit in a rapidly installable/removable module for Shuttle (a suitcase concept).

2) As space permits, fly one or more units on Shuttle flights, with installation on a noninterference basis at con-

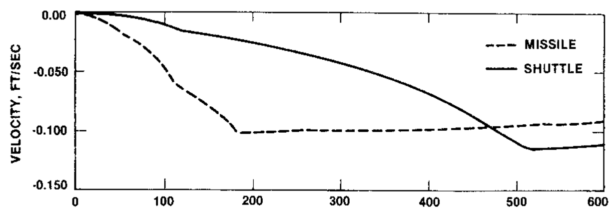

Fig. 1 Shuttle vs missile velocity error profiles for azimuth alignment (1 s).

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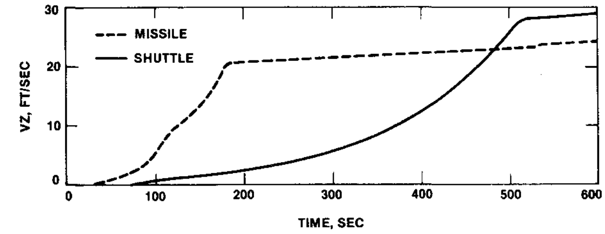

Fig. 2 Shuttle vs missile velocity error profiles for gyro mass unbalance drift (1 deg/h/g).

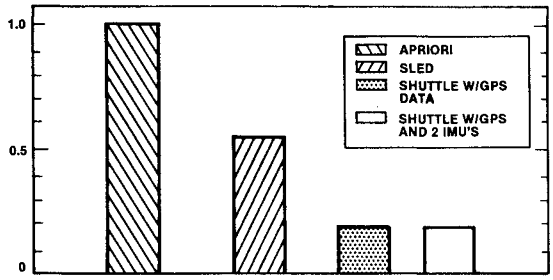

Fig. 3 Normalized composite IMU miss estimates.

venient times during Shuttle prelaunch preparation (NASA refers to this as "ship and shoot").

3) Use Shuttle power (and cooling if available).

4) Use the substantial Shuttle metric data available including Shuttle (multiple) IMU, GPS (Shuttle is configured for GPS receivers), and the test article multiple IMU data for boost IMU analysis.

5) Obtain zero-*g* data to evaluate biases and low-*g* performance.

6) Collect data during re-entry to obtain additional test results.

7) Remove modules after landing for post-test assessment.

This approach can make effective use of last-minute Shuttle space available on a cost-effective and noninterference basis with primary Shuttle payloads. Because it is the boost and reentry ΔV magnitudes that are important in generating the test data, the test concept is generally independent of the Shuttle mission profile and the test packages can fly on any Shuttle mission. These factors indicate that the AIRS test module will be a desirable Shuttle payload, filling small gaps in the full Shuttle payload capability left by large primary payloads.

The most notable advantage of the Shuttle relative to the rocket sled test is the total ΔV imparted. Because the Shuttle orbits, the total ΔV is about 15% greater than the ΔV on a ballistic missile trajectory; however, the acceleration level is less. Where a missile generates 7 to 8 (peak) *g*s, the Shuttle gives about 3.3 *g*s but for a much longer time. The consequences are that higher-order terms (e.g., g^2 and higher order) in the IMU model will not be as strongly propagated as velocity errors, but low-order terms in the IMU error model (biases and linear *g*-dependent terms) propagate to an equal or greater level on the Shuttle relative to a missile flight, as the longer time duration of the acceleration dominates. Figures 1 and 2 show velocity error propagation of typical IMU error terms.

Error analysis computations were based on the assumption of GPS data of the quality observed on two actual missile tests in 1980.[1] Figure 3 illustrates the relative level of post-test evaluation of total IMU error (for an additional, high-accuracy IMU) as a function of the instrumentation used (GPS or dual guidance data). These results show that with GPS data (of quality already demonstrated on missile flights), very effective observation of some major IMU errors can be achieved. Total error is evaluated to a level very close to the system's projected long-term capability. Thus, not only can certain systematic errors be identified, but anomalies or mismodeling in excess of the IMU error budget can be identified. The nondestructive nature of the test permits repeated testing in a variety of orientations so that candidate error sources can be extracted through optimal orientation selection.

Carrying multiple systems enhances test accuracy and increases test time on the IMU at low cost. The results are greatly superior to rocket sled testing. The test articles are recoverable after exposure to environments no more severe than those of the missile flight, which will lessen probability of environmentally induced failures. Opportunities to Shuttle-test IMUs before they actually fly on R&D test missiles are a method of further enhancing the role of the R&D tests.

The suitcase concept aims at modularity and minimum interference with Shuttle schedules , mission planning, and prime payloads. However, the package must meet Shuttle payload requirements and interface with Shuttle power and data sources.

A complete package would contain the IMU, computer, data-recording unit, and power-cooling and data-interface units. The IMU calibration can be performed as much as several days prior to launch or as close as several hours before launch.

Conclusion

Testing high-precision IMUs on the Shuttle offers a test capability not duplicated on any other dynamic test. The Shuttle can substantially increase the test time where the "real" flight tests are limited in number, can fly multiple units on a noninterference basis with the Shuttle's primary missions, and can provide high-quality metric test data for performance assessment in an environment remarkably similar (in the sense of total ΔV delivered) to that of the missile. As a nonprimary payload, the incremental cost to the Shuttle program should be low, and the concept will adapt well to relatively short-notice changes in Shuttle payload availability.

Specific interface and packaging issues remain to be assessed. However, the IMU support requirements, weight/volume constraints, and timelines are not at variance with known Shuttle requirements, and use of an existing design payload support module will simplify this problem.

Reference

[1] Barkley, R. L. and Hietzke, W., "GPS Instrumentation Performance as an ICBM Guidance Systems Evaluator," *AIAA Guidance and Control Conference Proceedings,* Aug. 1982, p. 28.

Some Effects of High-Rate Springs in Elevator Control Systems

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Introduction

A CONVENIENT, simple, and inexpensive means of increasing the controls-free longitudinal static stability of an aircraft with manual flying controls is to install a nose-

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