An Overview of the Joint Advanced Missile Instrumentation (JAMI) Program
An OSD Central Test and Evaluation Investment Program (CTEIP) Initiative

Don Scofield
JAMI Program Manager
Department of the Navy
NAWC-WD, Code: 54A000D
China Lake, CA 93555

Dave Powell
NAWC-WD, Code 543B00E
Point Mugu, CA 93042

Thomas J. Macdonald
TASC
Reading, MA 01867-3297

ABSTRACT

JAMI, a 1997 new-start multi-year CTEIP program, will develop an integrated instrumentation package for tri-service small missile test and training applications. JAMI will provide telemetry, time-space-position information(TSPI), flight termination and end-game vector scoring in a low-cost, modular package that will allow world-wide test and training -- eliminating, in most cases, the need for range-specific (or multi-system) facilities. JAMI will incorporate GPS-based technology as the TSPI and vector scoring engine, state-of-the art telemetry, and an off-the-shelf UHF Flight Termination Receiver (FTR), and address the feasibility of a solid state programmable Safe-and-Arm. The effort will include a Test Technology Development and Demonstration (TTD&D) risk reduction effort which will: validate tri-service requirements, provide a technology demonstration, assess the applicability of advanced antenna technology, and determine the achievable performance and complexity of alternative kinematic GPS vector scoring techniques. To effect the vector scoring function, a cooperative arrangement with the target will address the mechanization of the target portion of the scoring function.

INTRODUCTION

For test and training applications, small missiles -- such as the AMRAAM, RAM, Standard Missile, and the Evolved Sea Sparrow Missile (ESSM) -- must be instrumented to provide four range functions: telemetry, time-space position information (TSPI), destruct, and end-game scoring. There is a need for the development of Joint Advanced Missile Instrumentation (JAMI) because:

- There is no *single* instrumentation package that supports all four functions
- The instrumentation that does exist is range specific
- JAMI would provide a cost-effective solution to end-game scoring, thus eliminating the need for vector scoring systems such as NAVS (which in fact has been recently canceled)
- Existing state-of-the-art instrumentation package such as the AMRAAM Warhead Replacement Tactical Telemetry Module (WRTTM) supports missile destruct, missile tracking, and telemetry, however, it
  - does not support end-game scoring,
  - is Gulf Range Drone Control Upgrade System (GRDCUS)-based, which limits test and training to the Gulf Range.
  - does not contain a dual redundant FTS, and
  - is expensive

Advancements in GPS technology, e.g., kinematic processing and small digital translators, can overcome these two deficiencies, i.e., no single instrumentation package and test & training limited to specific ranges.

JAMI will have applicability to tri-service small missile programs, e.g., JAMI has support from the HARM, Standard Missile and ESSM program offices, as well as the Next Generation Target Control System (NGTCS) and RAJPO programs. For these reasons, OSD chose to initiate in FY 97 a CTEIP program. As part of this effort, OSD is also providing ‘Test Technology Development and Demonstration (TTD&D)’ funding that is earmarked to mitigate the risks associated with JAMI development.

BACKGROUND

There are a host of participant types in a typical test or training scenario, though many scenarios involve a shooter aircraft, a missile and a target drone. OSD-sponsored programs are providing GPS-based TSPI for each of these platforms.

The GPS Range Applications Joint Program Office (RAJPO) at Eglin Air Force Base began the development of GPS equipments for range applications in 1983. RAJPO was chartered to develop a family of GPS equipments to track test range airborne and ground-based platforms. During the last ten years, GPS receivers have been shown to provide high accuracy (2-4 ft RMS) real-time TSPI for tracking a wide range of user platforms, including high-dynamic shooter aircraft.

In addition, GPS translators have been shown to support very high dynamic platforms (>60 Gs) and for certain applications can provide sub-foot non real-time TSPI. In January 1996, RAJPO released an RFP for the next generation digital translator development, referred to as Translated GPS Range System (TGRS). TGRS will be a candidate GPS engine for tracking missiles.

In the summer of 1995, the Next Generation Target Control System (NGTCS) awarded a contract to develop a tri-service interoperable target control system. NGTCS will make GPS the standard for target-based TSPI.

JAMI, the natural extension of the TGRS development, will provide a small missile the same testing flexibility as GPS affords the target and shooter, i.e., the capability to be tested anywhere in the world. As a case in point, the Swedish Government has been looking to the US to provide GPS-based instrumentation for shooters, missiles, and targets that would be flown on their Arctic range. This range is shared by many foreign countries. RAJPO/NGTCS equipment is being considered for the shooter and target instrumentation; JAMI will fulfill the missile instrumentation requirement.

RISK REDUCTION AREAS

The TTD&D (i.e., risk reduction) portion of the program has two goals:

- Assess the end-game scoring performance, and implementation issues of alternative GPS-based processing algorithms (with particular attention paid to the impact on NGTCS and RAJPO instrumentation) to ascertain the feasibility of using GPS for end-game scoring
- Assess the performance of alternative multi-band conformal antenna design approaches to derive a JAMI baseline.

End-game Scoring Accuracy - Translators have been shown to provide the required accuracy to support missile *tracking* through the use of differential processing. Accuracies on the order of 2-4 feet are achievable for P-code translators. In end-game scoring, the real concern is *relative* accuracy between the target and the missile. In this case, the target is equipped with a P-code receiver (NGTCS) and the missile is equipped with a translator (TGRS), probably a ‘reduced bandwidth’ P-code design. The relative accuracy in a postmission mode should also be 2-4 feet. However for end-game scoring, better than 1 foot accuracy may be required.

To achieve <1 foot accuracy requires kinematic processing, a technique that determines position based on contiguous Doppler measurements of the GPS carrier. Kinematic GPS has been successfully used in low-to-moderate dynamic applications, but its application to the end-game scoring scenario is inherently risky for the following reasons:

- End-game scenarios involve high dynamic maneuvers which can cause the GPS receiver to ‘cycle slip’. If undetected, this will have a deleterious effect on accuracy
- Antenna motion on high dynamic platforms can introduce phase variations that need to be taken into account
- Long observation times (to resolve ranging ambiguities) could affect the time during which kinematic accuracy is available
- The GPS measurements are from two fundamentally different processors. The ideal situation for achieving maximum accuracy is GPS measurement from identical equipments, i.e., two receivers or two translators, processing the same GPS signals using the same computational techniques. In this case, we have a translator and a receiver. The receiver provides, at best, integrated Doppler measurement samples to the ground, while the translator provides the entire GPS spectrum for ground-based processing.

Antenna Design - The second major area of concern is the development of an antenna system to support the instrumentation. The proposed system requires the development of a three band antenna, i.e., receive-only UHF, receive-only L-band, transmit only S-band. In addition, the antenna must be of a conformal design mounted over a limited area of the missile surface and be able to support the link budgets of the various rf systems (UHF destruct , L-band GPS satellite reception, S-band telemetry and GPS translator signal downlink). Although this is a difficult design problem, it can be solved with modern conformal antenna technology. The design issue is the development of a *cost-effective* solution that can be easily adapted to different missile sizes.

JAMI APPROACH - TTD&D effort

A two-phased TTD&D approach has been proposed**:**

- Phase 1 will focus on validating the end-game scoring accuracy requirement and evaluating existing GPS low cost hardware to determine the accuracy and dynamic robustness of existing receivers.

- Phase 2 will investigate the applicability of advanced conformal antenna technology to provide a high performance multi-band antenna subsystem, and the achievable performance and complexity of alternative kinematic processing techniques.

Phase 1 - An assessment will be made of the achievable accuracy of existing GPS technology without resorting to kinematic techniques. Two tests were conducted using comercail off-the-shelf receivers on a supersonic track vehicle. In the first test, a power supply failure limited the solution to the first three seconds of flight. The maximum acceleration was greater than 20 g. The results of the first test is shown in figure 1 and indicates that the GPS receiver was able to track through the high jerk of ignition and maintain track through the first three seconds when power was lost. The offset of the GPS solution has been traced to the g sensitivity of the crystal clock.

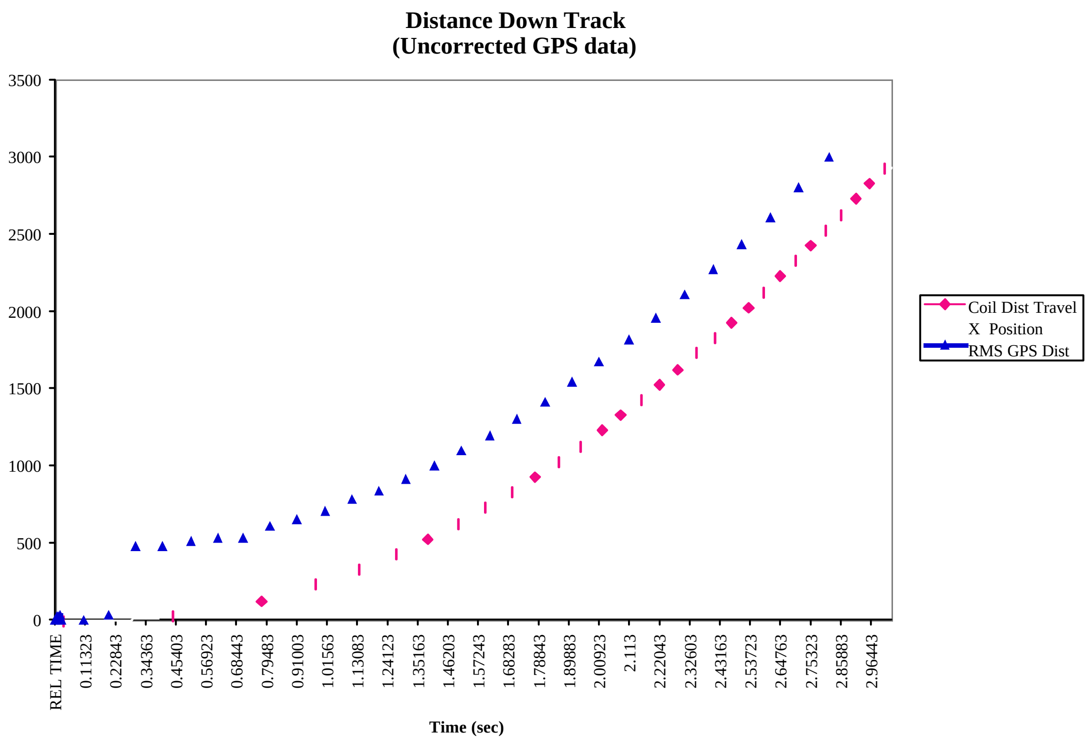

Figure 1. Test #1 position verses time

Figure 2 shows the results of the second test. In this test Ashtech, Inc. G12 and GG24 receivers were used and compared to ground truth. The position solutions were better than the first test but complete data analysis has not been completed.

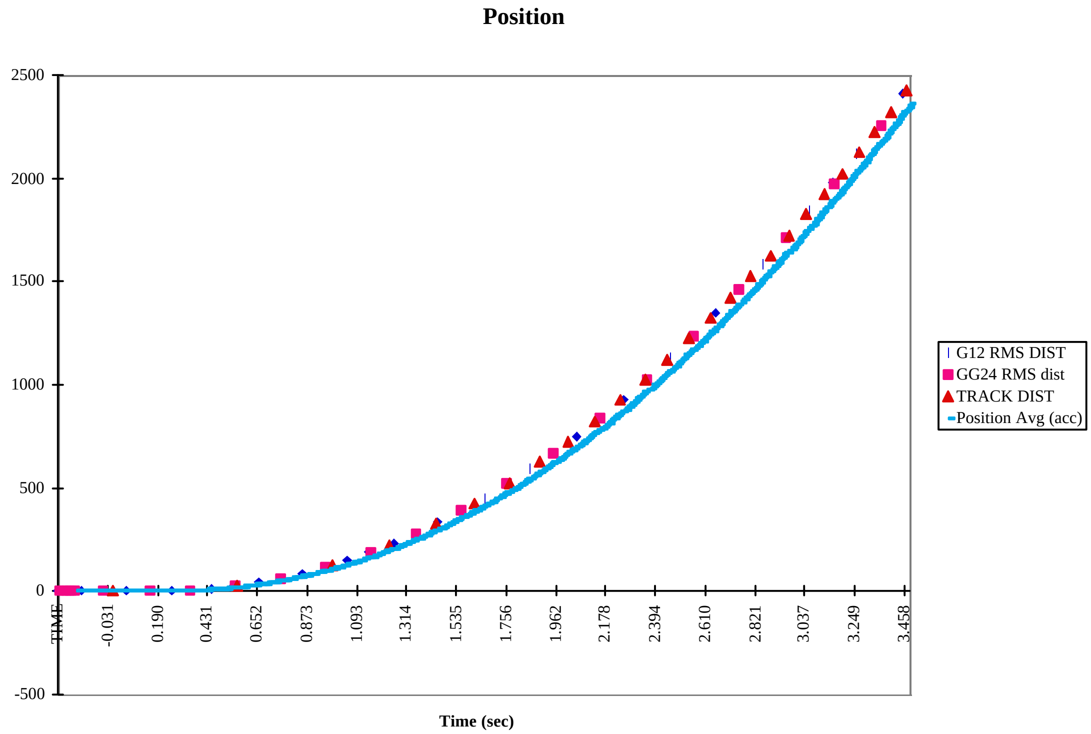

Figure 2. Test #2 position verses time.

Phase 2 - The following will be explored:

- Performance of alternative multi-band antenna designs. This is envisioned to be a paper/simulation analysis, supplemented with available empirical data
- The performance, complexity of alternative kinematic algorithms
- The benefit of using a translator in the target (vs. a receiver)
- Ambiguity resolution as a function of number of receiver tracking channels and satellites in view
- Performance vs. dynamics
- Performance vs. translator implementation (L1 or L1/L2, C/A or P-code, full or reduced bandwidth P-code)
- Optimal ways to exploit IMU data for use in the kinematic solution
- Solution settling time vs. dynamics and kinematic algorithm.

The results of this effort will provide a baseline for initiating the main line CTEIP program aimed at developing a cost-effective missile instrumentation package.

JAMI APPROACH - Main Line CTEIP Program

The JAMI CTEIP effort will consist of several component development initiatives and one or more missile integration demonstrations. Based on the results of the TTD&D effort, development specification will be prepared and contractors selected for primary system components such as the programmable SAF, the TSPI GPS tracking receiver and the end game scoring engine. The CTEIP portion of the JAMI program is scheduled to last for four years with funding beginning in 1999.

The JAMI CTEIP program will concentrate on the development of prequalified instrumentation, TSPI tracking, scoring and flight termination system (FTS) components and will demonstrate several of these components in an integrated package. A goal for the FTS part of the effort is the development of miniature, dual redundant hardware that can be prequalified to levels which envelope existing missile environmental levels.

Another product to be delivered is a design toolbox. This toolbox will be an electronic database which includes a information on JAMI qualified hardware, qualification test reports, telemetry system design tools such as range TM link calculations, and programmable component programming interfaces.

In addition, JAMI may also consider:

- Technology insertion options such as advanced receiver/inertial technology that could eventually replace the translator, i.e., today's receiver technology can not track in high dynamics and, today, an inertial can not be used to aid the receiver because of size constraints. However, a receiver/inertial solution would significantly reduce the downlink bandwidth requirements from MHz to kHz.

- Techniques to eliminate the UHF antenna by finding alternative means of implementing missile destruct using L-band, i.e., reworking range safety for a different system can be very costly. However, eliminating UHF would help mitigate the antenna design/cost problem.

SUMMARY

GPS technology offers the means to develop instrumentation for small missile test and training applications. Joint Advanced Missile Instrumentation (JAMI), building on prior GPS development efforts, will provide an integrated low-cost package that will support small missile testing anywhere in the world. As such, JAMI will complement the NGTCS instrumentation development for targets.

Because of the risk associated with the antenna design and the kinematic processing for end-game scoring, TTD&D risk reduction funding is included in the JAMI funding profile. Integration of JAMI developed components into candidate missile platforms will begin around the year 2000.