INTEGRATED TESTING AND TRAINING INSTRUMENTATION, A REALITY

AUTHORS:

Lt. Col. Tom Whittemore, Director, Range
Applications Joint Program Office (RAJPO)
and Nat Raimondo (TASC)

INTRODUCTION

Historically, requirements for instrumentation that supports testing and training have diverged, for a variety of reasons. In general, testing evaluates how well the system or product meets stated operational or contractual requirements, while training evaluates how well the user operates the system in the battlefield environment. Developmental testing evaluates specific system performance characteristics, both to ensure that requirements are met and to establish limits of the capability under development. For these applications, a high degree of instrumentation accuracy is usually required.

In operational testing the system is operated as it is intended to be used in the battlefield, so instrumentation requirements are generally similar to those imposed by training activities. Compromises in testing and training instrumentation frequently occur, due to constraints imposed by budgets, technology, and available resources.

Today's environment is causing the Department of Defense (DoD) to reconsider and redefine how we perform testing and training, to be more thorough in our testing and more realistic in our training. Opposing these demands are budget pressures to reduce the cost of both testing and training. As we try to define a new paradigm for testing and training, we ask the questions that have always faced the testers and trainers:

- Why are different instrumentation assets needed for developmental and operational testing?

- Why are different accuracies required? Why can't these activities be merged?

- Why can’t common instrumentation and facilities be used in testing and training exercises?

- Why can’t we create more realistic testing and training battlefield environments?

- Why can’t the Services cooperate more fully in joint testing and training, since we fight together? How can we involve our allies in effective mutual testing and training?

- Why do recent procurements by our allies reflect the desire not to purchase our systems?

- How can we convince our allies that it is cost effective to use the same instrumentation we use?

- If we cannot standardize and control the cost of our testing and training instrumentation, how can we expect our allies to follow our lead?

- Why do we lack the funds to test our products sufficiently before they enter the inventory, yet come up with enough to fix them after they are deployed?

Fortunately, several new technologies are providing cost–effective answers to all of these concerns. The Global Positioning System (GPS), modern data link networking and control techniques, internetting, and modern simulation technology are all finding applications in testing and training. These technologies are forcing a major cultural change within the DoD that will revolutionize how we conduct future testing and training. This paper focuses on how the use of GPS and modern data links will enable far greater integration of test and training activities.

GPS FOR RANGE INSTRUMENTATION

The DoD conducted a study in the early 1980s that concluded that GPS was the appropriate positioning and timing instrumentation source for future test and training applications. The tri–service GPS Range Applications Joint Program Office (RAJPO) was formed to develop such instrumentation for use on all military test ranges. This instrumentation now provides accurate Time–Space Position Information (TSPI) without interfering with or increasing the cost of the system under test.

It was a goal of the RAJPO to develop a GPS–based TSPI system that did not interfere with the established range operating procedures and analysis techniques. It was decided by the RAJPO and the range interface control working groups that the RAJPO TSPI outputs will meet range approved interface specifications. Future modifications to the system will not alter the approved interface formats. In summary, the RAJPO system does not include any sophisticated display capability, since that activity is the responsibility of the range receiving the system.

The assets developed by the RAJPO have been, or are in the process of being, installed at all DoD Test and Evaluation (T&E) sites. The Air Force Operational Test and Evaluation Center (AFOTEC) is responsible for all Operational T&E (OT&E). Many of the OT&E support activities use training–like scenarios and systems to accomplish their missions. AFOTEC is using RAJPO assets and integrating them with existing training assets to employ a capability that uses the best of each of these systems. It is a logical next step to review their experiences and plans of AFOTEC as we consider an integrated testing and training capability.

Test Range System Overview

Figure 1 depicts a typical GPS receiver-based RAJPO system. The platform instrumentation is installed in a five–inch (Sidewinder) missile pod, and interfaces with suitably–equipped high–performance aircraft. The pod includes a multi–channel GPS P(Y)–code receiver, a strapdown inertial reference unit, a data link transceiver, solid state memory, GPS and data link antennas, and associated power supplies. When necessary, an encryption device can be added to encode the transmitted TSPI data. If the platform can accommodate it, the instrumentation can be installed internally, on plates. The GPS receiver, inertial sensor and supporting hardware are installed on one plate, and the data link electronics are installed on another. Each measures approximately 18″ x 24″ x 10″. Antennas are semi–permanently installed on the platform.

Ground installations include a data link network controller and processor, a differential GPS receiver and processor, and one or more data link transceivers and antennas, either collocated with these components or connected to them through range communications resources. This equipment can be fixed or mounted in a trailer. Use of multiple remote transceivers assures the desired levels of coverage and link reliability for any mission scenario. Associated system software analyzes topography and mission profiles to determine optimal locations for remote transceiver stations.

A less expensive C/A–code GPS receiver that can operate with this range system is available for use on low–dynamic platforms such as tracked and wheeled vehicles, ships and some rotary–winged aircraft. Thus, a full set of system components are available that accommodates all types of participants.

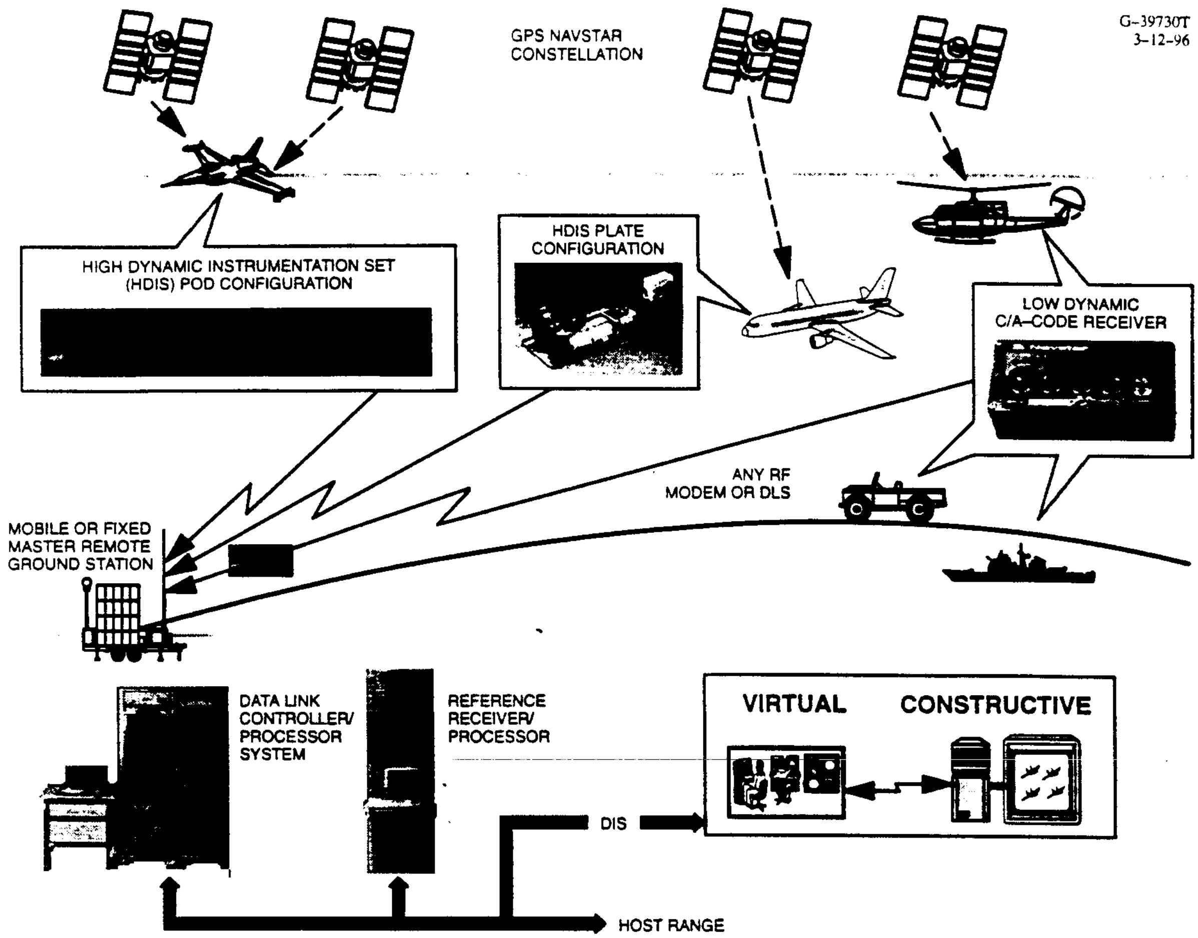


Figure 1 RAJPO GPS Receiver-based Assets

The system can operate in either real–time or passive modes. The real–time mode uses data link communications to acquire the TSPI and associated mission data as it is generated. In the passive mode, all data is recorded in the platform memory system, for later analysis. The present configuration permits recording of up to six hours of mission data. As the density of commercially–available PCMCIA solid–state memory modules increases, the amount of data recorded and the length of the mission can also increase. Recording can also take place while operating in the real–time mode, as backup in case of loss of data link connectivity.

GPS Operation

The multi–channel P(Y)–code GPS receiver is tightly coupled to a strapdown inertial reference unit. This tight coupling and a “smart” dual GPS antenna system assure that precise TSPI data will be generated through all aircraft maneuvers, even if GPS signal tracking is momentarily lost.

To obtain the level of TSPI accuracy necessary for many test applications, differential GPS correction techniques are used. Corrections to each of the GPS position estimates are derived by the GPS reference receiver located at the base station. The corrections are transmitted to system participants. Alternatively, uncorrected participant data can be transmitted to the base station, where the corrections are applied. Which of these correction techniques is used depends on a variety of operational issues. Testing on a DoD calibrated range (figure 2) has demonstrated that both techniques produced essentially the same high level of accuracy.

Both techniques make the differential corrections in what is referred to as the "measurement domain." That is, separate differential corrections are calculated for all individual satellite–to–platform pseudo–range measurements. Users of differential GPS data have learned that differential correction of the final GPS–derived position vector can produce significant errors. Table 1 demonstrates the accuracy of the system in a variety of operating modes, as determined on a DoD calibrated range. These data were taken under various high stress maneuvers, including Figure Eights, Cuban Eights, Climb and Dive, Oval Tracks and High–G Loops. All maneuvers were accomplished in both clockwise and counterclockwise directions to evaluate the impact of pod location. Pods were mounted on various wing stations to evaluate the impact of aircraft shading.

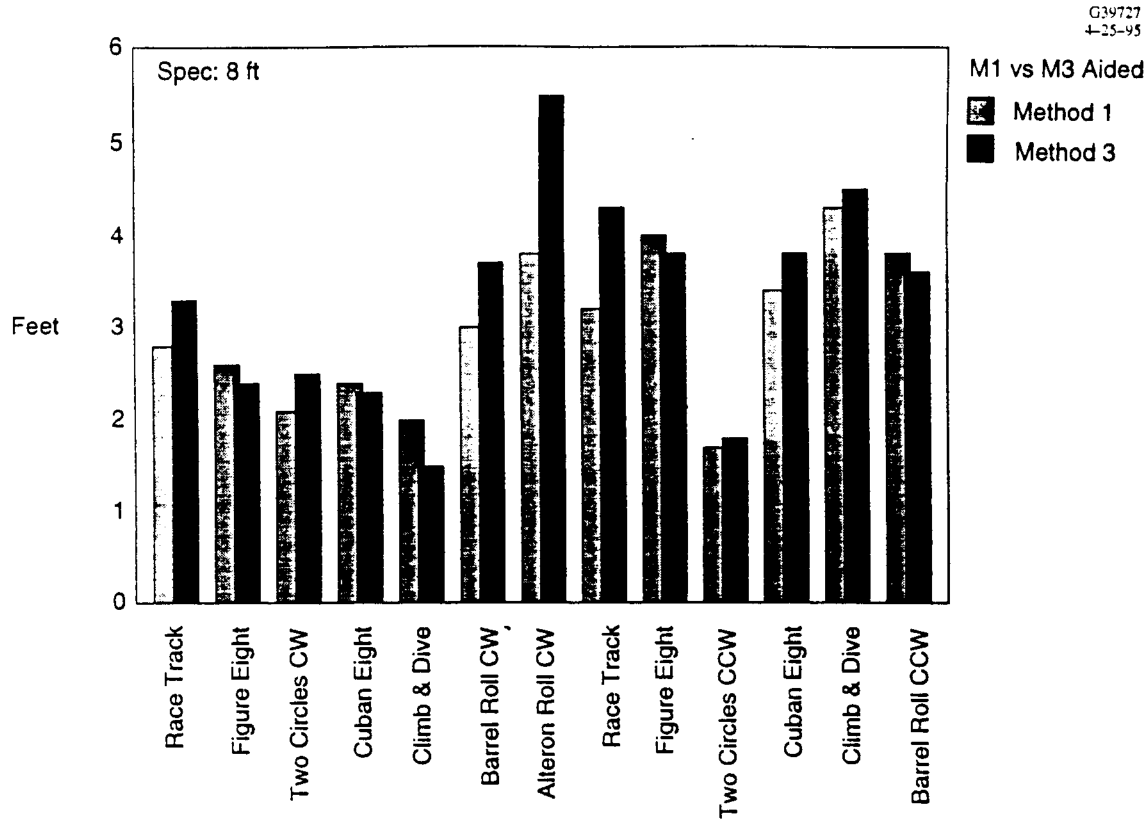
In summary, the accuracy of the RAJPO assets was validated in highly–stressed operating conditions, to assure the end user that the instrumentation will perform satisfactorily in the most severe operating conditions.

Table 1 1994 Flight Mission Error Statistics (F–15 and F–16 Aircraft, Various High G Maneuvers)

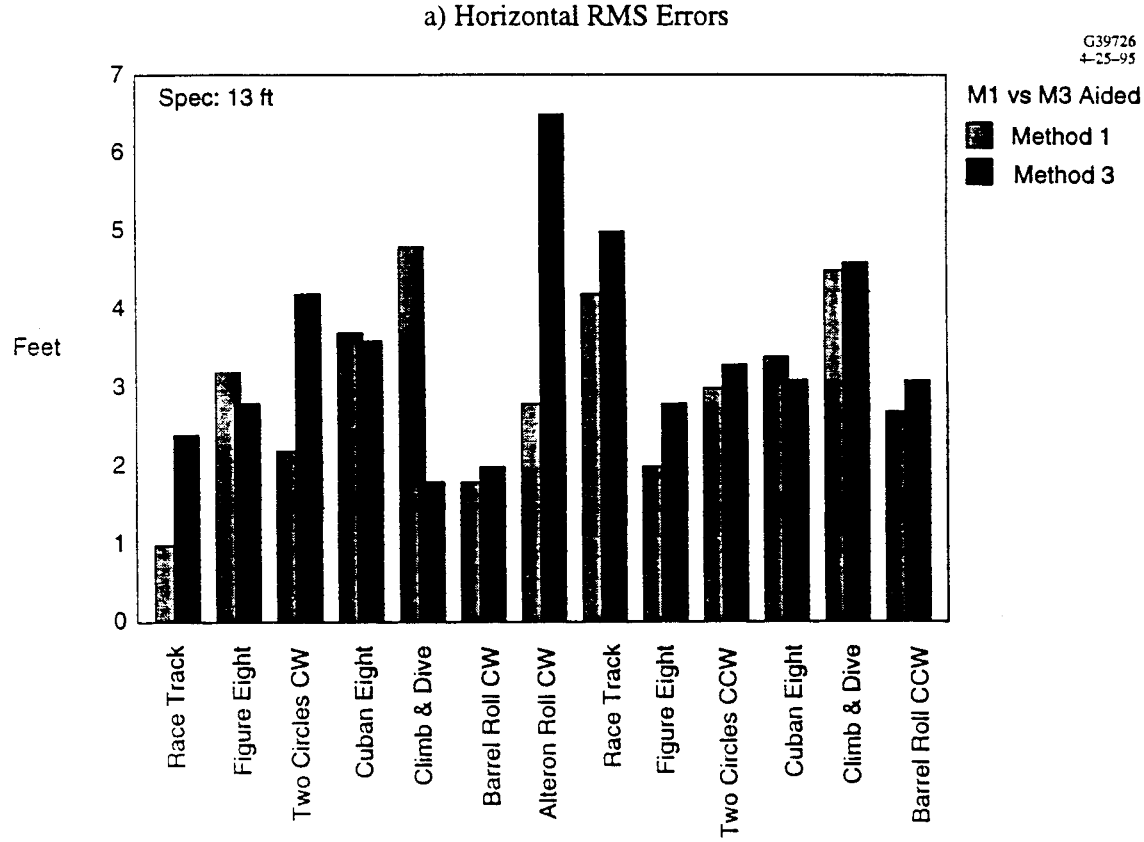
ITEM	ABSOLUTE UNAIDED		ABSOLUTE AIDED		DIFFERENTIAL UNAIDED		DIFFERENTIAL AIDED	
	Spec	Average	Spec	Average	Spec	Average	Spec	Average
Horizontal Position (ft)	26	20.2	23	8.9	14	8.2	8	2.3
Vertical Position (ft)	43	31.3	38	15.6	23	10.3	13	3.7
Horizontal Velocity (ft/sec)	20	7.9	1.7	0.7	20	5.6	1.7	0.41
Vertical Velocity (ft/sec)	34	4.8	2.7	0.7	34	4.5	2.7	0.4

Data Link Network Techniques

Members of the test range community aided the RAJPO in the procurement of a new communications subsystem, referred to as the RAJPO Data Link System (DLS), for communicating platform–derived TSPI data to ground recording facilities. This data link is optimized for the transmission of GPS and platform data, but it is widely recognized to be well–suited to a variety of additional range–related applications. A single DLS network employs Time Division Multiple–Access (TDMA) techniques, and can accommodate up to



a) Horizontal RMS Errors



b) Vertical RMS Errors

Figure 2 FF-15 Flight Test, Method 1 vs. Method 3 Differential Results

2000 participants. As many as 250 timeslots are available to participants each second; thus, up to 25 participants can report their position at a ten message–per–second rate. Alternatively, 2000 participants can report their position once every eight seconds.

If additional capacity is required, up to three separate DLS "nets" can be accommodated within the operating frequency range (1350-1390 and 1429-1435 MHZ) to support 75 aircraft. Each net employs two frequency channels for diversity, each with 1.6 MHZ bandwidth. A future upgrade will enable the operation of these multiple nets to be synchronized more effectively, to minimize interference between the nets.

L–Band operation with current power output and antenna characteristics ensures high–reliability communications with maneuvering aircraft at ranges up to approximately 80 miles. During typical operations with high–altitude aircraft in more conventional attitudes, we regularly observe reliable message reception at ranges beyond 150 miles.

Normally, the base station assigns each participant the appropriate set of timeslots for reporting. When a message is missed, the base station can be programmed to automatically request its retransmission. Alternatively, polling can be employed, in which each participant responds whenever it receives a request message from the command center.

During the mission, each data link transceiver (DLT) continually monitors its ability to communicate with the base station, either directly or by relay through another airborne or ground–remote transceiver. Whenever it must report, the participant DLT automatically selects the most efficient routing of its message to the base station, without operator intervention. This capability greatly extends the range of the system, while assuring high message reliability. Duplicate correctly–received messages are suppressed, and if multiple versions of a message all contain errors, they are combined and the error–correction process is repeated on the composite message.

Operations involving multiple ranges can be readily accommodated, since each range is assigned unique frequency channels and timeslots. A participant leaving one range and entering another is automatically assigned a new frequency and timeslot sequence. If a participant DLT does not properly transfer to the new frequency, it automatically tunes to a default frequency. From this default frequency, the DLT can be automatically commanded to the proper frequency and timeslot to assure operation in the new range.

DLS Performance

Acceptance testing verified high message integrity and reliability between aircraft at relative velocities up to Mach 2.5, over a wide range of altitudes and relay configurations, and over water (where multipath propagation could potentially affect data link performance).

Much of the GPS performance validation process reported in Figure 2 also confirmed the ability of the DLS to perform properly throughout the test period.

A Demonstration of the RAJPO TSPI Operating in the Training Environment

The RAJPO recently evaluated the capability of the GPS/inertial suite in the TACTS/ACMI[1] training environment. Due to budget limitations, the test was accomplished by installing a RAJPO pod and a standard P–4 training pod on the same aircraft. GPS/inertial TSPI data from the RAJPO pod was passed to the training pod through an umbilical cable assembly, and incorporated into the ACMI pod multilateration transmission for relay to ACMI ground equipment. On the ground, the GPS/inertial solution was extracted from the multilateration signal, and used to drive the ACMI displays.

The experiment was an unqualified success. When the aircraft left Eglin Air Force Base en route to the Gulfport National Guard ACMI installation, GPS/inertial data provided position information to ACMI displays whenever any multilateration signal path from the aircraft was available. Whenever enough paths were available to allow successful multilateration position determination, the multilateration–derived position was superimposed on the display with the GPS–derived position. There was no perceived difference in the presentation quality of the two positioning techniques. The experiment was repeated successfully at the Nellis Air Force Base ACMI range. This experiment demonstrated that a GPS/inertial package added to a TACTS/ACMI pod can eliminate many of the shortcomings of a multilateration positioning system:

- The area of coverage is extended to all points where one or more Tracking Instrumentation Subsystem (TIS) tower(s) can receive a signal from a participant
- Position, velocity and time are available at any altitude, down to ground level without the use of a pod radar altimeter
- Positioning “holes” are minimal, if not eliminated altogether
- The passive nature of the GPS/inertial solution reduces the restriction in the number of participants on the range.

[1] Tactical Air Crew Combat Training System/Air Combat Maneuvering Instrumentation System

Users of the Navy Range, Responder, Reporting System (R3) have purchased RAJPO pods that were modified to use the VHF R3 transponder in place of the DLT. This configuration uses the R3 as a communication link only, thus eliminating the shortcomings associated with R3 multilateration (as discussed above), while allowing retention of the R3 system ground infrastructure.

GPS Accuracy on Training Ranges

Training ranges require the accuracy provided by the RAJPO system to support activities such as low level flying, no–release bomb drop scoring, precise missile flyout simulations, damage assessment profiling, and real–time computerized steering of Electronic Warfare threat emitters. Analysis may show that for many such scenarios, GPS differential correction may not be required, thus simplifying the positioning process. The accuracy available with the RAJPO TSPI package and the versatility of the DLS make it possible and practical to consider the same instrumentation for developmental and operational testing, as well as training. The use of differential corrections for test applications where high accuracy is required, and non–differential techniques for training (where high accuracy may not be required) is an example of this versatility.

The Synergy between the RAJPO and TACTS/ACMI Systems

As stated previously, AFOTEC is investigating various techniques to maximize the use of the RAJPO system in their existing OT&E environment. Since the OT&E environment attempts to replicate the fighting environment, the OT&E environment is often a TACTS/ACMI system. Figure 3 clearly indicates the synergistic results when the two systems are combined.

RAJPO Systems	TACTS/ACMI Systems
• Strengths > TSPI > Data Link > Flexibility	• Strengths > User Interface > Displays > Aircraft Interfaces
• Weaknesses > User Interface > Display > Knowledge of Aircraft Interfaces	• Weaknesses > TSPI > Data Link > Flexibility

Figure 3 RAJPO and TACTS/ACMI Comparisons

The important characteristics of the RAJPO system that supports testing and training missions are as follows:

- A tested and validated GPS/inertial suite

- A tested and validated data link optimized for use with GPS as the positioning and timing source

- A data link with excellent coverage and adaptability for operation with high and low dynamic platforms

- An Advanced Digital Interface Unit (ADIU) that will be installed in a pod and operate as an "instrumentation personal computer in the sky." The ADIU will provide a modern P–4B interface capability to the 1553 Buss of the aircraft.

- An Intelligent Flash Solid State Recorder (IFSSR) using commercial off the shelf (COTS) hardware that will record data limited only by the availability of industrial quality PCMCIA memory modules/cards.

- An Encryption module that will permit over–the–air keying. This will permit uplink and downlink of encrypted data, up to the Top Secret level.

The important characteristics of the TACTS/ACMI systems that support testing and training missions are as follows:

- An Advanced Display Debriefing System (ADDS) far advanced than current systems used on test ranges. The system is an excellent tool for real–time and post flight system analysis

- The Computational Control System (CCS) has the computing capability for hosting pairing algorithms and flyout simulations, as well as supporting damage assessment, no bomb drop scoring and steering of computer controlled threat simulators

- Years of experience in understanding the various aircraft interfaces.

A Candidate Approach

When a common system is used for testing and training, one can consider integrating these activities, to produce a clearer assessment of the performance of the system and the operators. This should lead to more precise determination of both the equipment's utility and the performance of the operators, enhancing our ability to improve both equipment and operators.

Equipment miniaturization makes it possible to build a common test and training pod. Adding GPS/inertial positioning capabilities to training pods will allow training ranges to obtain major increases in coverage and capacity, at minimal costs. Existing ranges need not wait for systems presently under development to become available to gain the advantages of GPS use. We have demonstrated that it is a relatively minor change to modify the ACMI CCS/DDS[2] to use GPS data for positioning and the TACTS/ACMI multilateration system as a data link.

There is a major infrastructure that supports existing TACTS/ACMI systems. More than 1,000 pods are used on these ranges. It is naive to recommend a plan that will obsolete these systems overnight. To start the evolutionary conversion of training systems to a GPS positioning scheme, an upgrade kit could add the GPS/inertial capability to all training pods that pass through a depot center for repair, or overhaul. New pods would have GPS/inertial capability installed. These pods would use the GPS/inertial suite for positioning, and the multilateration system for communications. Conventional TACTS/ACMI pods would operate on the range using the multilateration system in the normal manner for positioning and communications. This process will permit both conventional TACTS/ACMI pods and GPS–capable TACTS/ACMI pods to operate on the same range. Aircraft with GPS TACTS/ACMI pods will have much more capability, but the transition process is simplified by the ability to commingle pods.

As training ranges are funded for upgrading, the RAJPO DLS ground electronics can be added to the Command Center. This will allow use of the same data link (the RAJPO DLS) for training that is currently used for testing. Platform position information received by the DLS system can be passed to the CCS/DDS, in a manner completely transparent to the user. These ranges are now capable of supporting RAJPO pods, GPS–equipped TACTS/ACMI training pods, and standard TACTS/ACMI training pods. We could start now to use the same environment for testing and training.

---

[2] Command Control Subsystem/Data Display Subsystem

As present TACTS/ACMI pods become obsolete, or if range maintenance costs of the TIS and CCS environments become prohibitive, ranges could terminate the multilateration function. This would eliminate a major range operational and maintenance expense.

Summary

The RAJPO GPS/inertial suite and the DLS were developed in response to range–generated requirements. To date, they are the only systems of their kind that have been validated on a DoD calibrated test range. On test ranges, the capabilities of these systems are gaining in maturity. A Next Generation Target Control System (NGTCS) will use GPS and DLS variants for the control of full and sub–scale drones.

The DLS system was developed for use on test ranges. The DLS is optimized for the collection of GPS and platform data from high, medium and low dynamic platforms. It is presently in use, or being installed, at all DoD test ranges. Adding the maturing DLS to the TACTS/ACMI environment can be accomplished in an evolutionary manner. This is a major step in fulfilling the requirement to achieve integrated testing and training facilities.

In order to support future OT&E missions, AFOTEC is moving forward with the integration of RAJPO and ACMI assets. AFOTEC has the responsibility to support future operational test activities for programs such as the F–22, B1–B, B–2, CV–22, AIM–9X, JSF, JASSM, and SAP's. Class 2 modifications are in process for platforms to accept RAJPO pods and plates.

We have described an approach that will allow addition of GPS positioning into the TACTS/ACMI environment without obsoleting the existing training infrastructure. It has been demonstrated that a GPS/inertial suite can be added to a TACTS/ACMI pod, and the CCS/DDS can be easily modified to accept this data. When the range operates in this mode, the TACTS/ACMI multilateration positioning system is used as a data link. Operation in this mode mitigates range coverage, and link capacity limitations imposed by a multilateration positioning system.

The approach proposed here, or some modification thereof, is necessary to permit testing and training activities to be combined at existing training range facilities. An analysis of functions supported by a test range may indicate that it is desirable to expand the capabilities of that range to support training functions. Nothing included here precludes this action.

Reductions in overall operating costs will result by integrating testing and training activities. The manner in which testing and training will be performed will be considered in an entirely different manner.

Internationally, test ranges in Germany and the United Kingdom are already committed to use variants of the RAJPO system. Other test ranges are contemplating this approach. Many foreign governments are seriously considering new training ranges that will use GPS as the positioning and timing source. However, some countries have elected to purchase training systems independent of the DoD. Influencing the selection of DoD–developed systems requires:

- A commitment by the DoD to an integrated testing and training approach
- A DoD policy integrating GPS–based testing and training ranges.

The ability of our allies to use the same systems that we use for testing will permit us to better evaluate their system development and implementation techniques, as well as to support concurrent development efforts.

Our allies' ability to use the same systems that we use for training will enable us to perform coordinated multinational training in either real, synthetic or combined environments. The experiences in the Persian Gulf demonstrated that future encounters with aggressor forces will likely involve multi–national allied forces. The ability to test and train those forces in the real or a synthetic environment will better prepare ourselves, and our allies, for these encounters.