Linking Advanced Distributed Simulations with Flight Testing

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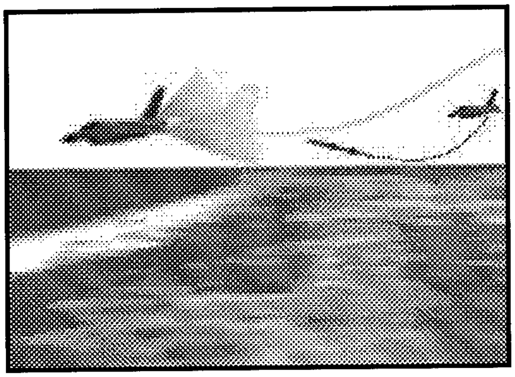

In support of a Joint Advanced Distributed Simulation(JADS), Systems Integration Test(SIT), Live Fly Phase(LFP), a tightly integrated link consisting of GWEF- CCF- PRIMES (Guided Weapons Evaluation Facility -Central Control Facility-Preflight Integration of Munitions and Electronics Systems) was developed. The system objective is to support real-time, open loop integration of live entities into a Hardware-In-The-Loop (HIL) environment. This paper includes discussion of the architecture and process required to achieve a real-time link between GWEF, CCF, and PRIMES. Also, information is presented on test results from actual flight tests, which describe the preliminary results of the GWEF-CCF-PRIMES Link infrastructure

Project Background

The test and evaluation community is relatively new to Advanced Distributed Simulation Technology (ADS). Each facility participating in the JADS program has independently developed a method for testing specific aspects of various weapons systems. The MISILAB, which organizationally is part of the GWEF, but is located in a separate facility, has supported AMRAAM simulations and characterizations over the past decade. The CCF has supported real-time mission control, and monitoring functions providing pre and post-flight analysis in the DOD community for the past 40 years. The PRIMES Test Facility has been involved in the ground testing of munitions systems, Electronic Warfare (EW), and Electromagnetic Interference (EMI)/Electromagnetic Compatibility Testing (EMC) for the past 17 years. The challenge was to develop a network architecture which would interface to the legacy systems in each test facility in a real-time distributed environment.

The main objective of the JADS LFP program was to evaluate the utility of using Advanced Distributed Simulation (ADS) to support cost effective testing on an integrated missile weapon/launch aircraft (A/C) system in an operationally realistic scenario. The incorporation of actual aircraft radar data into the AMRAAM HIL simulation in real time enhances the fidelity of the simulation and provides additional insight regarding the performance of the total weapon system in an operational environment.

The initial planning for the program began in October 1994, and development work continued until May 1997. Flight testing and analysis is ongoing until November 1997. The final report for the Eglin phase of the program will be completed March 1998. The JADS analysis team at Kirtland AFB is currently reviewing the data from four risk reduction flight tests (March 21, June 5, June 24, and July 11, 1997).

The test required a real-time, tightly integrated, open loop coupling of a shooter A/C, target A/C, and instrumented captive carry missile with a Government Supplied Hardware (GSH), AIM-120, test station operating in a HIL simulated environment. The 'missile' used in the GWEF-CCF-PRIMES link is an Advanced Medium Range Air to Air Missile (AMRAAM) with the seeker attached to a 3-axis flight motion simulator in the Missile Simulation Laboratory (MISILAB). The test required the exact presentation of the A/C to missile interface and sensor detected environment by the AMRAAM test station as it occurred in the open air environment. A concept drawing for the overall program is shown in figure 1.

JADS System Integration Test
Live Fly Phase Scenario

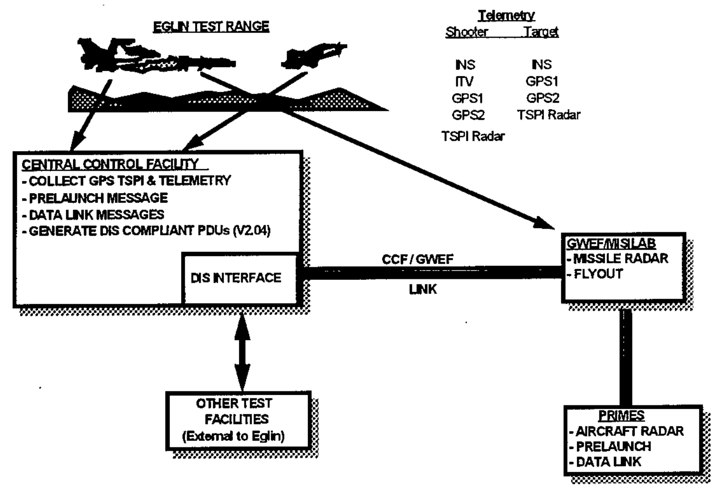

Figure 1 JADS SIT LFP Configuration

Technical Challenge

A number of technical risks are associated with using range sensor instrumentation to monitor open air test items and accurately communicating the information to recreate the environment in a HIL facility. The challenge is to time coherently coordinate: the launch event sequence and targeting communication between the shooter A/C and the missile test station, RF scene, and 3 axis flight table. The Time-Space-Position Information (TSPI) from the shooter and target A/C are used to create the duplicate geometries in the MISILAB. The flight table serves the purpose of positioning the AMRAAM RF seeker with respect to the HIL RF scene to mimic the true aspect between the missile and the target A/C as it occurs in the open air environment.

The real-time open air environment is considered a "dirty" environment due to low signal to noise margins, doppler, and multipath effects for RF downlink communication of data. Couple those effects with burst errors (signal dropouts) due to host vehicle dynamics causing masking of RF signals, and the end result is what is considered typical telemetry data. The bit error rates of hard-wire communications paths available in a conventional self contained HIL are orders of magnitude less than a typical telemetry downlink. The first challenge is to utilize the data that has been corrupted by the environment and minimize the effects in the HIL simulation. The second challenge is to maintain the temporal relationship of events in the HIL facility. Millisecond time errors equate to inertial alignment errors of the HIL missile which equate to target positioning errors. The GSH missile is very sensitive to timing errors in the communication between the A/C and missile for targeting information.

Another technical challenge is to synchronize the progression of time in the HIL facility with the progression of time of day in the open air test environment. The following paragraphs discuss specific facilities, techniques and development processes required to make the JADS link a reality.

Development Challenge

Due to the technical risk associated with this effort, a unique development process was established. A series of risk reduction efforts were utilized involving the PRIMES facility to simulate a full complement of open air test data. The simulation included GPS, radar, INS, RF scene, and AMRAAM Instrumented Test Vehicle (ITV) raw data sources. Rational behind the risk reduction effort were:

- Cost associated with open air testing (flying two F-16 A/C vs ISTF testing)
- Frequency at which data was required for unit testing and debugging purposes
- Repeatability and controlled nature of the test
- The availability and accuracy of truth data.

The risk reduction efforts were designed for the PRIMES facility to incrementally emulate each data source, enabling detailed testing of specific hardware systems and software processes. The risk reduction effort progressed from an all software generation of the raw data sources to an F-16 A/C with the ITV and Range Acquisition Joint Program Office (RAJPO) GPS pods being integrated into the test. These data sources included the airborne target and ECM Generator System (TEGS), which provided the F-16 APG-68 target simulation, an X-Y positioner, which provided target motion, and a six degree of freedom (DOF) flight simulation program, representing the engagment profile. Simulated radar TSPI sources were integrated with the 6 DOF flight simulation. The INS telemetry stream of the virtual target was also simulated and provided to the CCF as a data source. Four GPS RAJPO instrumented pods were used as TSPI sources for the target and shooter aircraft, and the encrypted ITV telemetry data was also used a data source. A diagram depicting this effort is shown in figure 2.

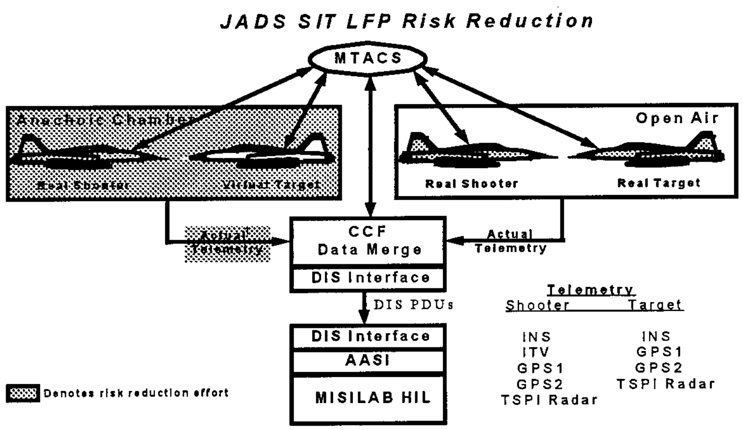

Figure 2 JADS Risk Reduction Configuration

The PRIMES objective was to present the data to the CCF exactly representing the native data received during a real-time mission. This effort allowed the CCF and GWEF to test each function as a unit and as an integrated system. Even though there were some unique situations which arose when merging the simulated environment with real-time systems, this effort allowed the CCF and GWEF to test each function as a unit and as an integrated system.

Open Air Test Items and Range Sensors

Two instrumented F16 test vehicles serve as the shooter and target A/C. In the JADS configuration, the shooter and target aircraft fly an engagement profile. When the shooter aircraft issues a simulated AMRAAM launch command, umbilical and radar data link (RDL) messages are captured and telemetered to CCF. RDL messages provides post-launch targeting position updates to the missile. CCF collects range sensor data to generate TSPI data for both the target and shooter A/C and pre-processes the ITV telemetry data containing specific missile-A/C communications for the MISILAB. The MISILAB uses the data to conduct the real-time HIL simulation of the missile launch and flyout. The shooter aircraft is equipped with an AMRAAM Integration Test Vehicle (ITV), which*looks* like a real AMRAAM. When the pilot 'fires' the missile, the ITV performs the required aircraft-missile communications and telemeters targeting messages (aircraft provided messages to the missile with pre-launch and mid-course target location information).

Time-Space-Position-Information (TSPI)

In order to provide a high fidelity scene that is a representation of the real open air environment, multi-sensors and extensive pre-processing is required. A coherent, non-interrupted TSPI scene generation for each participant dictates the requirement for the multi instruments/sensors best estimate of trajectory (BET). TSPI for each A/C is generated using the precision inertial sensor assembly, which is standard in an operational F-16 A/C. Two RAJPO GPS pods with datalink, and a ground based FPS-16 or Stand Alone Star Calibration Data System Radar (SASCADS) are also used as TSPI sources.

TSPI is incorporated into an optimal estimate using a TSPI Data Processor (TDP) Kalman filter process. Pre-processing of the inertial navigation system data (INS) is required to remove time stamping inaccuracies (sampling jitter), thus lowering INS noise(error) before it is used by the Kalman filter. The Kalman filter reduces sensor noise and provides the multi-instrument solution, which totally eliminated incoherent artifacts due to single instrument perturbations or datalink dropouts. A smoother algorithm is applied to the TSPI solution before the data is incorporated into 2.04 DIS compliant PDU's. The TDP's filter output rate varies between ten to thirty outputs a second. An Entity State PDU is developed with each TDP output cycle. PDU's are converted from the geocentric WGS-84 format to a topocentric rectilinear coordinate system (local tangent plane). TSPI is interpolated to a 600 HZ update before it is provided to the MISILAB. The TSPI information, which is constantly updated, is used to drive the target and shooter positions in the HIL. The data is free of incoherent effects that could cause the 3-axis table from accepting motion requests which would cause the table dynamics to be exceeded.

Telemetry Data

Three serial Pulse Coded Modulation (PCM) telemetry data streams are RF downlinked to the CCF. The shooter and target A/C PCM streams contain the A/C inertial data. The AMRAAM ITV TM stream contains the umbilical (launch) and targeting information. The AMRAAM ITV data is preprocessed and packed into a DIS 2.04 compliant PDU. One variation employed in packing the major frame PCM data into the PDU is the data-tag relationship is not maintained.

A decision was made early in the development process that AMRAAM telemetry data would not be fabricated in the event a dropout occurred. The only technique employed to minimize the effects of data transmission errors is filtering. The primary technique for filtering spurious data samples is monitoring time stamps on data samples to determine if the time is progressing. Monitoring of condition codes and an internal asynchrounous counter/timers provides a reliable indication that valid data was received.

Initial flight test data indicated that masking of telemetry signals can have catastrophic effects on the ability to provide the GSH missile test station with data that will not hinder proper operation. In order to minimize the masking effects, the use of wing station fuel tanks and centerline fuel tanks were eliminated, requiring both aircraft to refuel during flight testing. Test results indicate telemetry dropouts can result from the profile selected and vehicle dynamics. The antenna configurations for the aircraft and the AMRAAM missile also play impact determining where dropouts occur.

MISILAB Integration

The GWEF/MISILAB required extensive modifications in order to meet the requirements of the JADS program. A real-time interface was required to communicate to the Shared Common RAM Network (SCRAMNET) in the MISILAB. The Advanced Aircraft Simulation Interface (AASI) was developed to meet this requirement.

The AASI connects to the Engagement Display System (EDS) in the MISILAB through a SCRAMNET Interface, and replaces the umbilical and RDL simulator panels within the GSH missile, resulting in the emulation of the shooter aircraft. In the autonomous mode of operation, the EDS calculated the umbilical and RDL data based on the scenario. Now when the launch cycle is initiated, the umbilical and RDL data is passed over SCRAMNET to the AASI in real-time. In a real-time engagement simulation, the missile seeker receives an umbilical message (target location, range, velocity, uncertainties, etc). The requirement is that both the ITV and the GSH missile must be initialized with the same targeting information. However, the launch cycles of both the ITV and the GSH are non-deterministic. The solution is to send recursive launch messages from the ITV to the GSH missile. This ensures the GSH missile will be initialized with the identical targeting message as the ITV. Upon launch, the seeker commands, which are intended for the missile's actuators, are sent to the analog computers, which compute/predict missile response to these commands. Responses are then sent to the Gould SEL 32/9780, which is the central control system of the simulation. Target information is updated, and the new actuator commands are issued until the process is completed. The ITV data is updated on a secondary ScramNet ring by a DEC Alpha 600 as new or updated data is available. The Missile TSPI is read from the ScramNet ring, converted to PDUs (coordinate conversion required), and is broadcast back to CCF. A diagram of the MISILAB configuration is shown in figure 3.

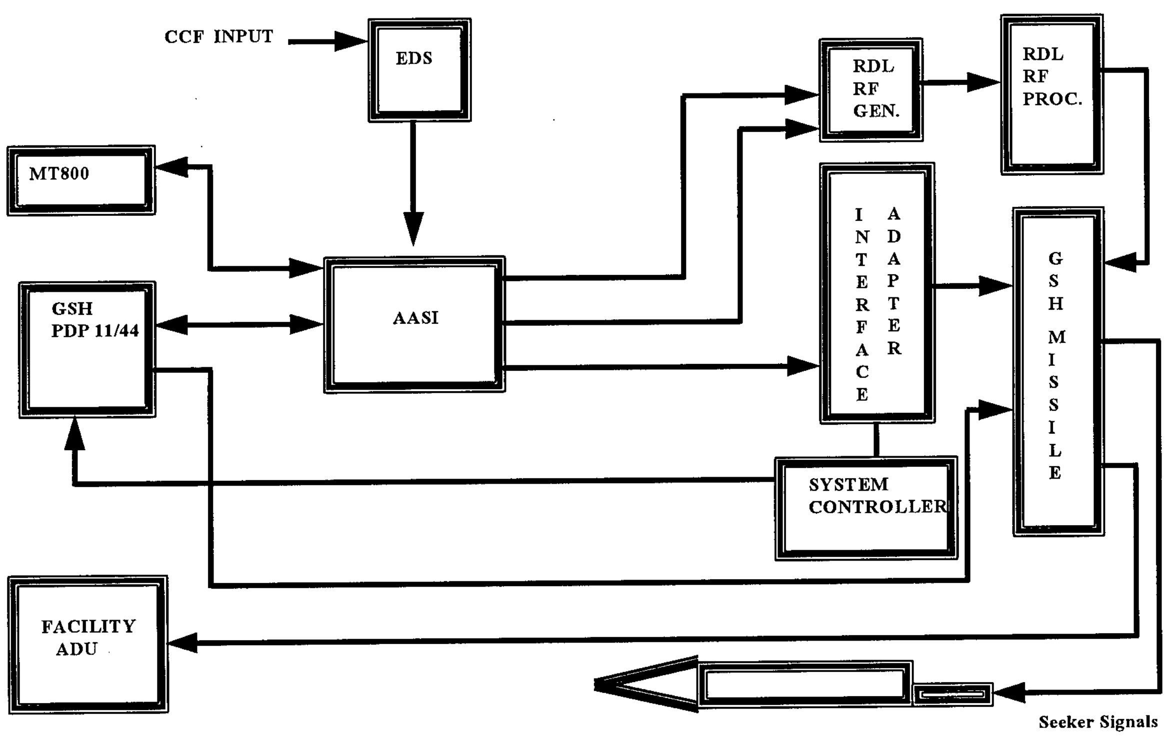

Figure 3 MISILAB Configuration

When defining the essential data required for the MISILAB simulation, it became apparent that standardized data formats were necessary. The interface points for the standardized data formats were designated as the ScramNet memory locations resident in the DEC Alpha 600 in the MISILAB. The result of the discussions among all the participants led to the development of the Interface Control Document (ICD), dated 13 June 1996. The ICD established the standard communication requirements and indicated the CCF would provide a specific set of TSPI data from the shooter aircraft and up to two target aircraft, and would provide the TM data from the launch station.

Visualization

Similar to the training community interactive visualization requirements, the JADS program required the support of 2-D and 3-D visual display for real-time mission and post mission playback and analysis. DIS PDUs from both CCF and the MISILAB were logged on an SGI Indigo 2 running the U.S. Army Simulation, Training, and Instrumentation Command (STRICOM) data logger. The 2-D visualization capability was provided by the JADS SIT Team, and was a product of the JADS Linked Simulators Phase.

Remotely controlled and local 3-D visualization capabilities were developed. The remote system was located in GWEF, where PDUs were received from the CCF, converted to a 3-D rendering, and transmitted in RGB video format back to the CCF, via a "video switchable" secure fiber-optic link (reference figure 4). The Live Entity Visualizer (LEVR) software provided the DIS visualizer/link capability. This system used an SGI Onyx RE2 computer, and a switchable video extension hardware. The remote 3-D visualization capability was interactive; however, this was limited to a free-fly/tethered "stealth" viewer of the real-time aircraft and missile players. The capability includes, 3-D observation, player trails, selectable motion models, switchable views and playback. Heavy emphasis was placed on using commercial off the shelf hardware and software and DIS standards. The greatest challenge was adapting to software version incompatibility (operating systems, viewers, logger) and scheduling the resources required to develop the visualization tools. The local 3D visualization software uses the Naval Post Graduate School NPSNET 3-D PDU visualization software running on a Silicon Graphics (SGI) ONYX in CCF. Both 2-D and 3-D visualizations were recorded on VHS tape with an overlay for IRIG time and mission audio.

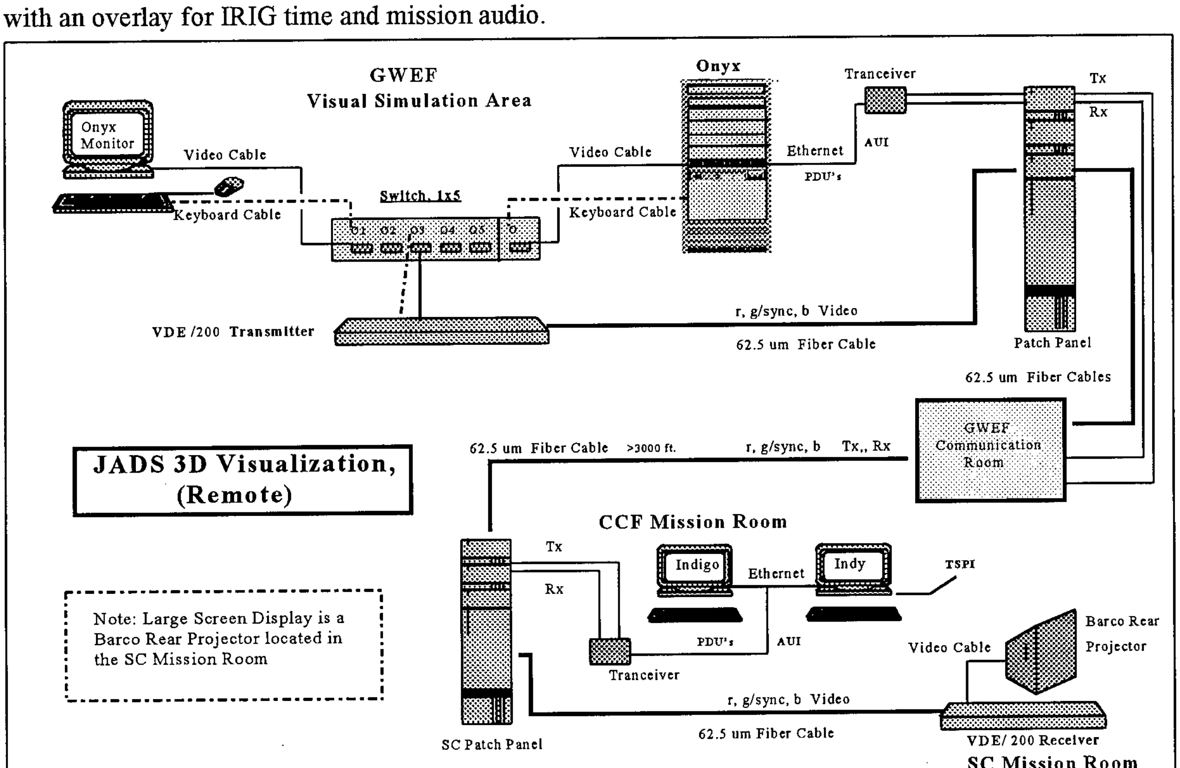

Figure 4 Remote visualization configuration

The MISILAB utilizes a powerful visualization tool, which provides a 3-D view of the missile and target, from the time of missile launch to termination. The Simulation Engagement Display System (SEDS), is shown in figure 5.

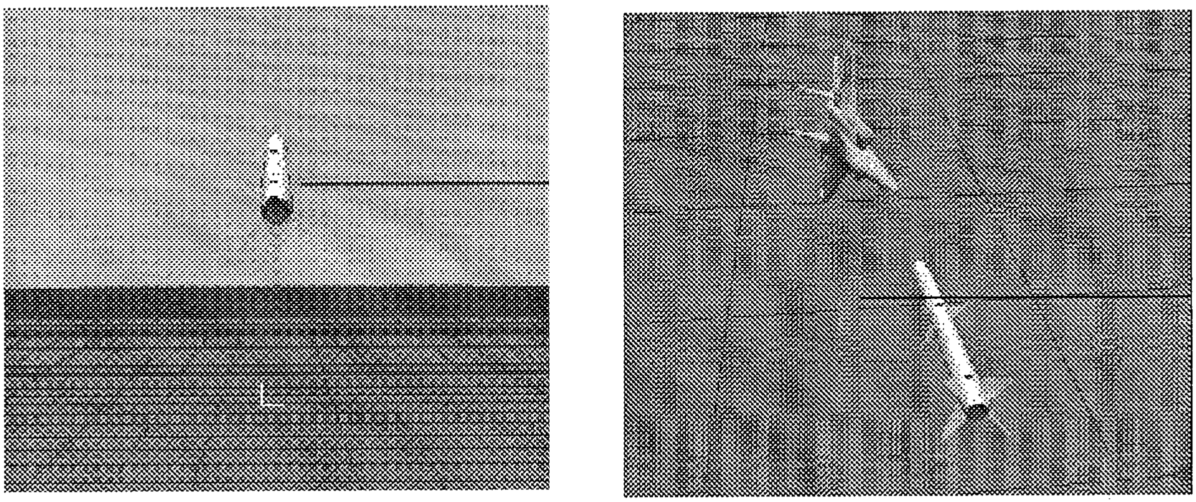

Figure 5 SEDS Display

Summary of Facility Upgrades

Each facility involved in the JADS program modified legacy systems to meet the requirements for the JADS SIT. The major upgrades required during the development phase of the program are summarized in Table 1.

Table 1 Major Design Issues for Each Facility.

CCF	GWEF/MISILAB	PRIMES
Develop Network Infrastructure-procure hardware, integrate facilities, test hardware	Develop Real Time Interface to seeker (AASI)	Develop TSPI simulation and integrate with existing 6-DOF simulation
Encrypt Network hardware	Design and implement the bridge between the secondary and primary ScramNet rings	Design real-time control programs for GPS simulators
Develop Data collection and display Capability	Development of interface between MISILAB and CCF	Installation fiber optic drivers, for connection to CCF network antennas to communicate with CCF
Aircraft INS telemetry setup and processing	Addition of IRIG-B time to saved data in MISILAB	Installation of antennas and cables to transmit GPS/MTACS data to CCF
AMRAAM telemetry processing	Software to support updated Euler angle rates, and increased cycle rate of input data	Installation of hardware to allow voice communication with outside facilities
Software processing for multiple GPS inputs	Removal of file driven target/shooter data, and software to support use of real-time aircraft data from ScramNet	Develop flight profiles to meet mission requirements
Develop data transfer capability	Calculation of required coordinate transformations	
Develop Data logging and replay software	Writing missile kinematics data to the ScramNet for the outside world	
Develop smoothing software	Integration of the pre-table driver software	
Develop DIS PDU generation software	Incorporation if IRIG-B time in HIL data products	
Develop visualization tools	Develop Visualization Tools	
Develop operating procedures for communications between facilities		

System Integration

The identification of each system and function is beyond the scope of this paper. However, a block diagram describing the process flow required to meet the communications requirements is provided in figure 5. The link from the CCF to the MISILAB utilizes a high speed 45 MB DS-3 network encrypted using KG95-2 encryption devices. The connection between CCF and the MISILAB facilities utilizes 62.5 um multi-mode dedicated fiber optics. A separate fiber optic link to the GWEF is used to pass PDU's for 3-D visualization. A secure T-1 link to Kirtland AFB, Albuquerque NM connects to the JADS SIT Test Control and Analysis Center (TCAC) for remote monitoring and coordination of the test mission. Early in the development process, consideration was made to synchronize cryptographic units. Cisco routers were chosen due to the ability to perform pulse synchronization, in the event garbled packets were received. The incorporation of resynchronization signals was not required due to the fact that out of sync conditions were not experienced. FDDI, Ethernet, and reflected memory networks comprise the majority of intra-facility networks. A sophisticated digital voice communication system is used to establish voice networks between various participants. Extensive voice networks are required to coordinate mission directors, A/C controllers, range instrumentation operations, TCAC, GWEF, CCF, and the MISILAB participants.

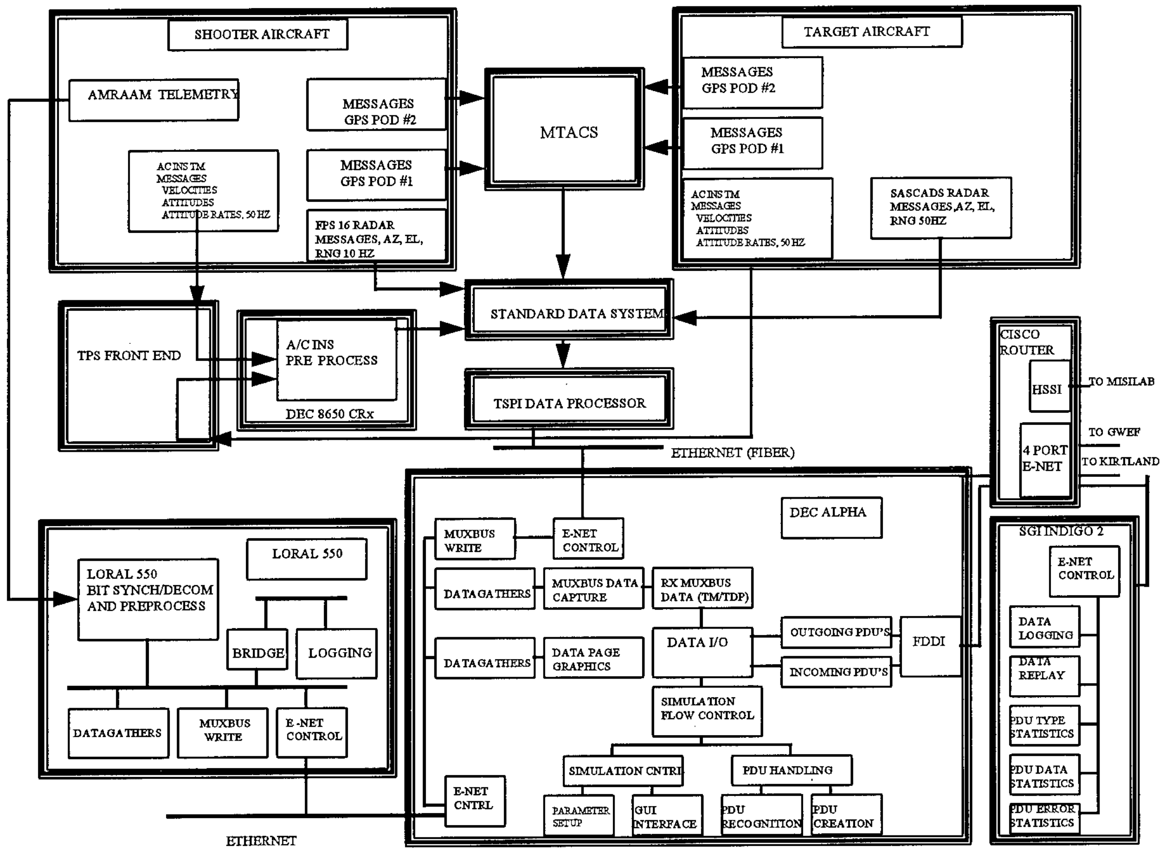

Figure 5 CCF Segment of JADS Process Data Flow Diagram

Time synchonization of the MISILAB environment to the time of day progression occurring in the open air test environment required special algorithms. Two techniques, phase lock loop and a master slave configuration, were analyzed. The master slave configuration was chosen due to the complexity of incorporating a software based phase locked loop. The master slave configuration requires the MISILAB to generate an accurate 600 Hz clock pulse that can be used as a time reference for presenting data. The time of day is established on the next occurrence of an integer second. At that point, the CCF provides TSPI updates at a 600 Hz rate. This technique requires the data to be buffered to accommodate bias and instability in the reference clock frequency. The buffering of data is also required to synchronize the missile launch event.

Results and Analysis

As of this writing, 4 risk reduction flight tests have been completed, and the plan is to execute three additional flight tests. The resultant performance of the AMRAAM HIL simulation will provide the primary performance metrics for the JADS LFP. Statistics associated with AMRAAM variables of significance throughout the flight as well as missile parameters obtained during JADS LFP missions will be compared to

Monte Carlo simulation trials performed in the AMRAAM HIL. The JADS SIT Team will be providing a complete report for this program, based on data collected during the flight testing phase.

Telemetry dropouts from the aircraft and the ITV have been the primary source of error during the execution phase of this program. In order to reduce the problems associated with TM dropouts, the F-16 jets fly without external fuel tanks in the W-151 airspace over the Eglin Gulf Range. Preliminary results from the flight test conducted on July 11, 1997 indicated that the anomalies discovered during previous risk reduction efforts were eliminated, resulting in successful launch data link and termination and data link at the MISILAB.

Lessons Learned

Scheduling all the facilities and resources required to support advanced distributed simulation activities is extremely difficult. When a test range and multiple test facilities are involved, additional effort is required to ensure everything happens at the appropriate time. All the players involved in this program worked these issues to make this difficult task possible.

Another element which was critical in the development of this program, was the team effort required for the JADS concept to become operational. Individuals from at least 7 different companies and military and civilian personnel from multiple organizations were involved in the development and operational phase of this program. Early on, it was evident human factors played a key role in the success of the project. For example, communications between all the players during a live mission was crucial for the successful execution of the engagement profiles. The engagement profiles were "rehearsed" prior to the live missions to make sure that all players understood the procedures they needed to follow during a run. A series of checkout lists was developed by CCF and MISILAB beginning at T-24 hours up to T-1 hour before the live mission. These checklists provided the confidence required that all systems were operational before aircraft take-off.

The leadership provided by the JADS SIT Team proved to be extremely beneficial during this program. With the number of personnel and organizations involved during the development phase, keeping the final objectives in mind was difficult at times. However, the SIT team leadership and analysis tools gave the Eglin group insight on which direction to take when problems arose.

Summary

The linking of distributed simulations with flight testing enhances the fidelity of the simulations and provides greater insight into the performance of the actual systems in the operational environment. Significant technical challenges were successfully addressed during the JADS LFP, and the results are proving that ADS can be an effective adjunct to existing test and evaluation methodologies.

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D. Currently Applicable Classification Level: Unclassified

E. Distribution Statement A: Approved for Public Release

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