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Paper Session I-B - Development and Operational Applications of a Real-time Range Data Simulator

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Development and Operational Applications of a Real-time Range Data Simulator

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ABSTRACT

Whenever a rocket is launched at any U.S. Space Launch Range, safety systems are in place to ensure that human life, health, and property are protected. These range safety systems rely on accurate knowledge of where flight vehicle debris would land in the event of a mishap. They must precisely process and display data from the rocket and ground sensors, and not react in an unpredictable manner to non-nominal or erroneous data.

ENSCO has developed the Real-time Instrumentation Simulation Environment (RISE) to evaluate and operationally certify real-time range safety critical systems at space launch facilities. Various RISE configurations thoroughly test range safety critical systems by simulating, injecting, and recording up to 40 simultaneous real-time links of nominal and non-nominal vehicle tracking data, including ground sensor outputs and full-rate telemetry data.

RISE simulators include options for the introduction of noise, data dropouts, quality defects, divergent trajectories, single or multiple source latencies, and numerous other data perturbations. By overlaying current timing in the data stream and computing and inserting checksums in real-time, RISE data is indistinguishable from operational mission data. With RISE, launch ranges have the ability to simulate a complete vehicle launch for both nominal and non-nominal conditions. Tests can be carefully controlled to validate range safety display systems, identify defects, or support training of operations personnel.

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Introduction

Assuring the proper operation of range processing systems is critical to launch operations and the protection of life and property in the launch area. For this purpose a broad suite of tracking instrumentation monitors manned and unmanned vehicles launched at launch ranges. The primary requirements for all tracking and processing systems are set forth in the Eastern-Western Range Requirement 127-1 (EWR 127-1), *Range Safety Requirements.* A prime EWR 127-1 requirement for the protection of life and property is the real-time knowledge of where a flight vehicle is and where flight vehicle debris would impact in the event of an anomaly. To accommodate the requirement for debris impact determination, range safety display systems encompass a process known as Instantaneous Impact Position (IIP) processing and display. The IIP process works in conjunction with the present position data by constantly taking the present position data, assuming thrust is terminated, and applying a ballistic trajectory calculation algorithm to the position data, thus determining the ground impact location of the vehicle. This IIP is plotted on the range safety display screens along with the present position of the vehicle. Destruct criteria are based on the predicted location of falling debris, rather than the actual position of the missile.

Range instrumentation used to maintain positive knowledge of the flight vehicle's position includes telemetry reception and processing sites, ground-based radars and optical trackers. Launch vehicles all include a flight telemetry package to report comprehensive vehicle performance parameters including Inertial Guidance (IG) data that is received at a series of telemetry sites throughout the ER. During any particular mission, the launch range systems produce multiple individual reports on vehicle location. This data is processed through real-time systems for input to a set of range safety displays used to monitor the vehicle during ascent. The most critical users of this information are the Mission Flight Control Officers (MFCOs) who perform the critical task of protecting public safety by monitoring the instantaneous vehicle impact position throughout the flight, and terminating the mission when that safety is threatened.

Since the protection of personnel and property safety relies on accurate knowledge of where flight vehicle debris would land in the event of a mishap, range safety critical systems must precisely process and display data from the rocket and ground sensors (e.g., Radar, Optic Tracking Sites). It is imperative that these range safety critical systems properly process the data to produce an accurate IIP, and not react in an unpredictable manner. The RISE simulator allows injection of 40 simultaneous streams of real-time data, including manipulated non-nominal and erroneous data for range safety validation.

The RISE simulator is intended to provide a reliable, efficient and comprehensive instrumentation simulation tool to assure the reliable and accurate operation of and the range safety processing and display systems as required by EWR 127-1. RISE produces data simulations from base trajectory inputs and includes options for the introduction of "noise", data dropouts, quality defects, divergent trajectories and numerous other data perturbations. RISE data is transmitted with current, or user determined, timing overlaid on the data streams. Checksums, based on the data and selected timing reference, are also computed in real-time and inserted into the data streams. This ensures that the system under test cannot distinguish simulated RISE data from operational mission data. With RISE, a launch range is able to simulate a complete vehicle launch for both nominal and non-nominal conditions. Tests can be carefully controlled to validate range safety display systems, identify defects or to support training of operations personnel.

RISE Overview

Utilizing state of the art software and hardware development processes, ENSCO developed the RISE family of range instrumentation simulators for customers such as the Air Force's 45th Space Wing Logistics Group (45 SW/LG) and the Alaska Aerospace Development Corporation (AADC). RISE is a real-time data simulation system currently used to thoroughly and economically evaluate and operationally certify real-time Range Safety critical systems at the United States Air Force's Eastern Range (ER) space launch facility and AADC's Kodiak Launch Complex (KLC), located in Kodiak, Alaska. The RISE system stresses range safety critical systems by simulating, injecting and recording up to 40 simultaneous real-time links of vehicle tracking data, including ground sensor outputs and full rate, RF modulated vehicle telemetry data.

The basic hardware components of a RISE system consist of an Intel-based computer (running under the Microsoft Windows 2000 operating system), a serial interface controller that provides the interface for the serial data streams, a PCM encoder for encoding telemetry data in NRZ or Bi-phase formats, a pre-modulation filter, and signal generators for RF modulation of the full rate telemetry streams. A full RISE III configuration is depicted in Figure 1.

The RISE project was originally initiated to produce a system to simulate launch vehicle tracking data that is generated by range instrumentation and vehicle telemetry during a launch (Figure 2). The current generation (RISE II and RISE III) products build on the original RISE capability delivered to the ER in 1997. The original RISE concept was formulated to address the needs of testing new real-time processing and display systems as well as training operators and performing maintenance on existing systems. Traditional methods of testing and demonstrating range real-time processing systems involved labor-intensive replays of previously recorded mission data. This type of testing required the dedicated and coordinated use of a number of Range personnel and assets. Large-scale tests involving multiple tracking instruments and telemetry sites are therefore very costly. Such replays are also limited to the events that occurred during actual launches and do not completely address the needs of non-nominal situations. In addition, the time stamping on replayed data is based on the original record time, whereas the RISE data uses current time stamping resulting in true real-time data. With RISE simulated data, the systems receiving the data see it as true real-time operational data.

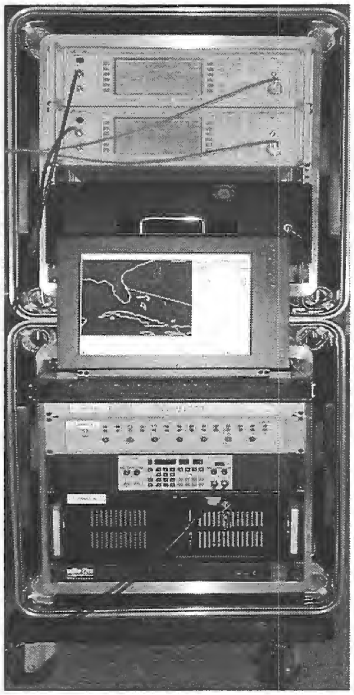

Figure 1 – Full RISE III Configuration

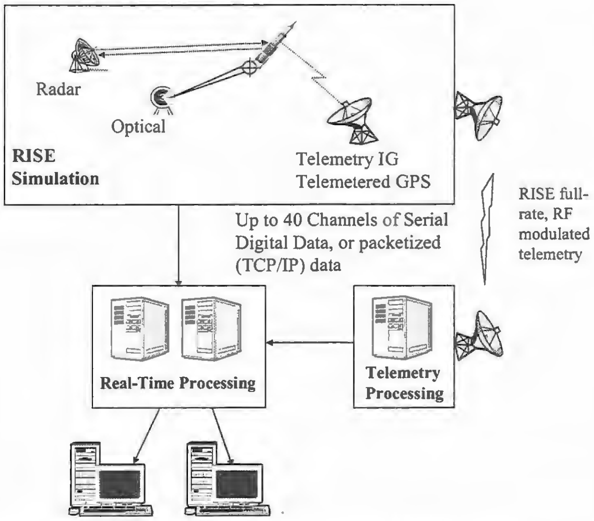

Figure 2 – RISE Concept within Range

The requirements for RISE were formulated during a series of working groups conducted with commercial, Government and Government contractor personnel. Key requirements include:

- 40 data ports capable of simultaneous operation.
- The capability to record up to 40 data streams.
- The capability to replay up to 40 data streams.
- The capability to create and modify vehicle launch trajectories.
- The capability to generate simulated instrumentation data streams from trajectories (both actual and user created) including optical and radar vehicle tracking sites as well as vehicle telemetry data.
- The capability to simulate RF modulated, full-rate telemetry data for launch vehicles.
- The capability to select one or more data sources to simultaneous record and to allow the user to eliminate one or more data sources from a created or recorded file for playback.
- The capability to simulate the ER Multiple Object Tracking Radar (MOTR 1.39) formatted data.
- The capability to introduce defects and “noise” into the data stream including the ability for the user to toggle quality bit(s), the ability to define source latency with a resolution of 100 milliseconds, the ability to drop synchronization.
- The capability to create, edit and manage pre-defined “scenarios” that capture a complete simulation specifying instrumentation, port allocation, programmed data “noise” and other run-specific parameters.
- The capability to replay data with current time or at the time recorded in the data file.
- The capability to set T-0 time for playback.
- The capability to simulate the First Motion trigger to timing.

Sample RISE test and training screens for IIP and telemetry are seen in Figure 3 below.

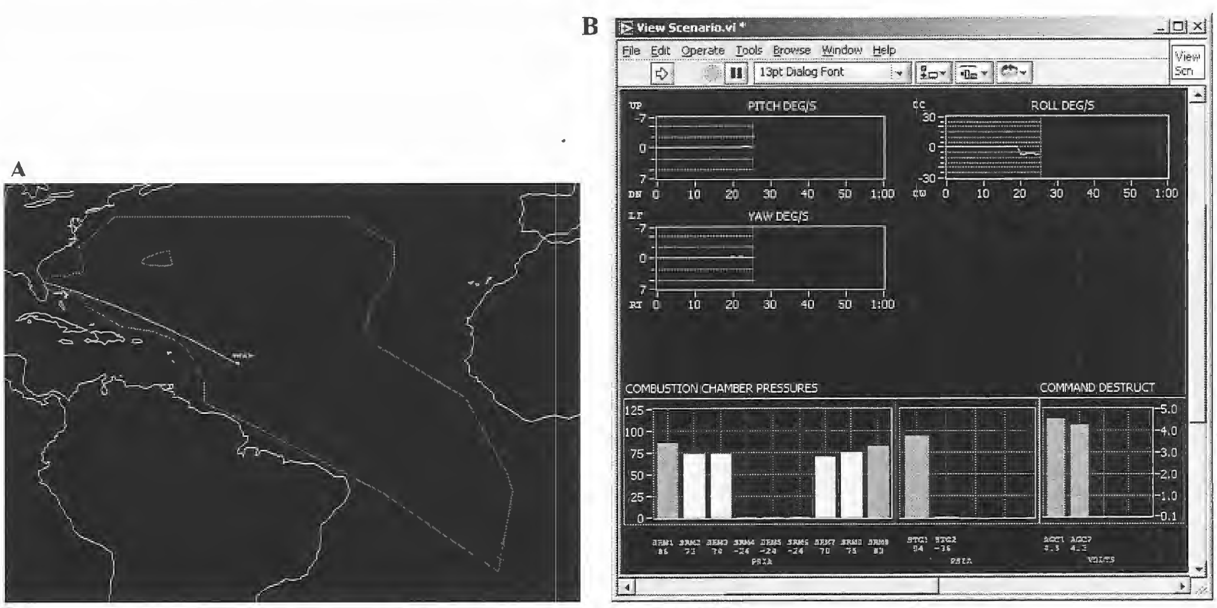

Figure 3 – RISE IIP Screen (A) and RISE Telemetry Screen (B)

Major Challenges

From the outset the RISE development project faced several challenges to a successful delivery. Large-scale range instrumentation simulation as would be done by RISE had not previously been accomplished. Although ENSCO had successfully developed the RISE I prototype, the RISE II/III program included a number of additional challenges.

Challenge 1: Interfacing to Range Systems

The communications demand was the first critical problem to solve. The availability of synchronous communications interface hardware capable of meeting RISE requirements was a major technical issue for project success. The communications environment currently operational at many ranges utilizes a number of specially developed synchronous serial protocols. These protocols have been rigorously tested and validated over many years and many have been in use before the High-Level Data Link Control (HDLC) was implemented as an ISO standard (ISO 3309 and ISO 4335). Nearly all currently available serial interface cards operate exclusively under HDLC and would not work with instrumentation data streams. The large number of ports was also problematic, as interface cards typically provided no more than eight ports each. A 40-port configuration would then require five cards within a single computer, added to that was the need for a timing synchronization card to support the required interface the common range timing source. With a minimum requirement of six internal data bus slots our options were extremely limited. Few available internal data buses offered that number of ports.

The solution to this problem was to utilize an external serial interface unit. This unit provided eight serial interface ports that could be configured to be synchronous or asynchronous. Ports used for synchronous connections could be configured to run with or without HDLC. This interface unit is accessed through a conventional 10/100 base-T network using the vendor supplied Applications Programming Interface (API) and supports various operating systems including different versions of the Microsoft® Windows™ family as well as several Unix variants.

There were also a significant number of questions regarding time synchronization (IRIG) and data clock distribution (for the synchronous connection). In order to reduce this risk and facilitate a seamless transition of the RISE system into the ER Range Operations Control Center (ROCC), team members coordinated with the Government to obtain a number of Data Buffer Units (DBU) on loan. The DBUs, which are used at the ROCC for data interface, were configured into a single rack along with associated time code and signal generators and provided an effective ROCC simulation environment (Figure 4).

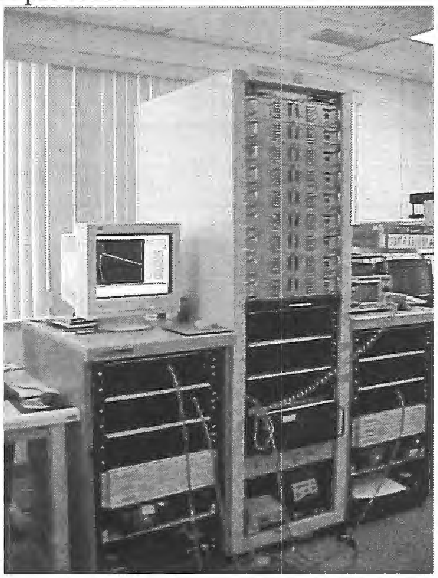

Figure 4 – ROCC Simulation Rack

Challenge 2: Implementation Environment

The next challenge involved the selection of the implementation environment (both operating system and development tools). RISE would have a fairly complex Graphical User Interface (GUI) and would also exercise control over both the communications interfaces, time synchronization interface and first motion signal interface. Customer preference and security requirements led to the selection of Microsoft® Windows 2000™ as the operating system. Next the team considered the development tool set and selected the two most plausible candidates for comparison using the primary criteria of technical merit, sustainment and staff capabilities. The two leading candidates were C++ and LabVIEW®. The advantages of C++ included full low-level control of all aspects as well as significant staff experience. Utilization of C++ had been the assumed approach at the project's start but an investigation of LabVIEW® demonstrated several key advantages. The ease and rapidity of interface construction was a major benefit. LabVIEW® also interfaced with the specific timing synchronization card that was selected. The final concern involved the serial interface unit. Using sample code from the vendor the development team was able to construct a compact and efficient Data Link Layer (DLL) interface using C++ that provided a robust mechanism and also effectively abstracted the communications interface. The evaluation concluded that LabVIEW® would provide the best implementation tool coupled with a C++ interface layer.

Challenge 3: Telemetry Simulation

RISE adds a number of vehicle telemetry formats that include fairly complex and varied encoding schemes (Table 1). Within the telemetry stream are fields that list individual vehicle performance items such as chamber pressures for propulsion systems, internal electrical system voltages and Inertial Guidance (IG) data. While RISE inserts realistic values for all telemetry items the most important simulation is the IG data; it is used to determine the vehicles self-reported position and uses a specific coordinate system. Each coordinate system must be researched to determine its definition and any variation in the actual implementation. The non-standard nature of IG implementations in telemetry data streams requires considerable effort for proper simulation. An additional consequence is the limited re-use of algorithms and code possible when such variation is present.

Table 1 - Vehicle Telemetry Elements

	Bit Rate	Bit Order	Coordinate System	Data Representation
Atlas II AS Centaur TRSB	4.8 KBps	LSB 1st	UVW	MIL STD 1750A
Delta II TRSB	4.8 KBps	LSB 1st	XYZ	Twos Compliment
Optics (ER)	4.8 KBps	LSB 1st	AER	Twos Compliment
Radar - C & S (NASA)	2.4 KBps	LSB 1st	AER	Twos Compliment
Radar - MOTR (ER)	56 KBps	LSB 1st	EFG	Twos Compliment
Radar - On Axis (ER)	2.4 KBps	LSB 1st	EFG	Twos Compliment
Radar - ON Axis (WR)	2.4 KBps	LSB 1st	AER	Twos Compliment
STS MILA (ER)	2.4 KBps	LSB 1st	XYZ	IBM Floating Point
STS TRSB (ER)	4.8 KBps	LSB 1st	XYZ	IBM Floating Point
Titan IV/ Centaur	4.8 KBps	LSB 1st	XYZ/UVW	MIL STD 1750A
Trident D5 POSIP	4.8 KBps	LSB 1st	UVW	Twos Compliment
Trident D5 TRSB	4.8 KBps	LSB 1st	UVW	Twos Compliment
Trident TGRS	19.2KBps 128KBps	LSB 1st	EFG	Twos Compliment

Challenge 4: Simulation of the Multiple Object Tracking Radar (MOTR)

The AN/MPS-39 Multiple Object Tracking Radar (MOTR) is a general purpose, self-contained, phased array C-band radar. It provides highly accurate position and velocity data for up to 40 targets simultaneously; however, the data format is only capable of transmitting 10 targets. The 56 kilobits-per-second High-level Data Link Control (HDLC) format is a combination of hardware and software that is unique to the Eastern Range.

Developing this simulation component was very challenging due to the MOTR file structure, which interlaces 10 track files into a single data stream. The format also employs a complicated word rotation, truncation and inversion encoding scheme requiring a non-trivial effort to properly define and simulate. The RISE software updates the E, F and G coordinates, overlays the current time, and recalculates the checksum for each track, and interlaces the data in real time.

Current Status and Implementation/Use

A RISE III generations system, including the telemetry RF modulation option, was delivered in 2003, and three RISE II generation systems were delivered to the in 2004. Both of these systems are currently being used to verify and validate real-time range safety systems.

RISE is currently being used to support acceptance/certification testing of a customer's range safety system. The formal development test program verified specification performance and would be considered Development Testing and Evaluation (DT&E) under the traditional certification flow for Major Range and Test Facilities Base (MRTFB) range safety critical systems. To be considered for DoD certification subsequent operational tests equivalent to DoD Operation Test and Evaluation (OT&E) needed to be accomplished. The OT&E phase needed to include tests designed to emulate non-nominal mission conditions and dynamics. In that the number of opportunities for shadow operations of actual flights is relatively few over the period desired for certification a RISE III test program was devised to exercise the system to as much as possible to characterize the system's performance in an operational environment. The RISE simulations developed for this test program include:

- Data Loss: The objective of this test case is to determine the response of the RSTS system to a loss of data in one link midstream, followed by a resumption of nominal data flow a few seconds late.
- Zero Position Data: The objective of this test case is to determine the response of the RSTS system to a period of zero position data, followed by a resumption of nominal data flow a few seconds later.
- Zero Velocity Data: The objective of this test case is to determine the response of the RSTS system to a period of zero velocity data, followed by a resumption of nominal data flow a few seconds later.
- All Zero Data with Valid Time: The objective of this test case is to determine the response of the RSTS system to a period of zero positional and zero velocity data, followed by a resumption of nominal data flow a few seconds later.
- Small Time Fluctuations: The objective of this test case is to determine the response of the RSTS system to a corrupted or noisy SV time at intermittent intervals and durations, followed by a resumption of nominal data flow a few seconds later.
- Large Time Fluctuations: The objective of this test case is to determine the response of the RSTS system to a corrupted or noisy SV time at intermittent intervals and durations, followed by a resumption of nominal data flow a few seconds later.

- Data Hold: The objective of this test case is to determine the response of the RSTS system to a period of static data. Time, position, velocity and all other vehicle parameters will be static for a period of 0.1 to 5.0 seconds.
- Slightly Noisy State Vector (SV) Data: The objective of this test case is to determine the response of the RSTS system to "slightly" noisy SV data. Noise, on the order of 5 – 10%, will be integrated into the vehicle SV data. Following the period of noisy data, nominal data flow will be resumed.
- Very Noisy SV Data: The objective of this test case is to determine the response of the RSTS system to "very" noisy SV data. Noise, on the order of 10 – 30%, will be integrated into the vehicle SV data. Following the period of noisy data, nominal data flow will be resumed.
- Varying Data Rates: The objective of this test case is to determine the response of the RSTS system to a varying data rate that is, at times, both greater than or less than the nominal data rate.
- Time Drop Out: The objective of this test case is to determine the response of the RSTS system to a period of zero time data, followed by a resumption of nominal data flow a few seconds later.
- Wild Points: The objective of this test case is to determine the response of the RSTS system to "wild point" data in each component of the state vectors (position, velocity and time), followed by a resumption of nominal data flow a few seconds later.
- Frame Slip: The objective of this test case is to determine the response of the RSTS system to a randomly, periodic slip in the telemetry frame by single and multiple data words.
- Corrupted Sync Pattern: The objective of this test case is to determine the response of the RSTS system to a period of time where the data stream contains bad sync patterns that cause loss of frame lock, followed by a resumption of nominal data flow a few seconds later.
- RF Doppler Shift: The objective of this test case is to determine the capability of the telemetry tuners and demodulator to receive and provide telemetry data in the presence of shifts in the telemetry link frequency caused by Doppler shifts in the telemetry frequency or from variations in the vehicle transmitter.

For each of the proceeding test cases the RISE III simulator will be set to play two channels of data simultaneously. Side A will play the unperturbed data stream as a baseline reference and Side B will play the perturbed stream. In each case, the range telemetry processing systems and Range Safety displays will be evaluated as to the continued availability of valid data from the good stream and the ability of the system to recover back to normal operation and display after the stream has been restored.

Significant interest has been generated from a broad set of organizations and agencies in response to the current RISE programs. Additional deliveries to other entities are in progress or under negotiation.