

Digital Recovery Sequencer – Advanced Concept Ejection Seats

David A. Ross
Senior Project Engineer
Ejection Seat Engineering
Goodrich Aircraft Interior Products
Phoenix, AZ 85085

David Culhane
Electronics Engineer
CAD/PAD Joint Program Office
Indian Head Division NSWC
Indian Head, MD 20640

Lee Cotter
Engineering Manager
New Business & Product Development
Teledyne Electronic Safety Products
Northridge, CA 91324

Matthew J. Press
Lead Egress Engineer
Aircrew Protection Division
Human Systems Group
Brooks City-Base, TX 78235

ABSTRACT

The Advanced Concept Ejection Seat (ACES) currently uses the Analog Sequencer, designed in the 1960's and 1970's with analog technology, to control ejection event timing and ejection mode selection. Continued usage of the Analog Sequencer is undesirable due to limitations with respect to its installed life, electronic component obsolescence, flexibility to accommodate seat safety improvements, and mode differentiation capability at the Mode 1 to 2 crossover point. The Digital Recovery Sequencer (DRS) program was undertaken by Goodrich, the seat Original Equipment Manufacturer (OEM), and the Cartridge Actuated Device / Propellant Actuated Device (CAD/PAD) Joint Program Office (JPO) to design and qualify a sequencer based on digital technology as a replacement for the Analog Sequencer. The DRS program was established with three phases: Phase I for requirements definition and supplier selection, Phase II for design and qualification, and Phase III for pre-planned production (P³I) improvements. Phase I was completed in 2003. Phase II is complete through design, firmware verification, component qualification, and

sled testing. Phase II is on track to conclude with approval of the Safe-to-Fly certification in October 2005. The DRS is in the early stages of production with deliveries scheduled for the 4th Quarter of 2005 and the 2nd Quarter of 2006. The program progress to-date, the DRS design including its safety related improvements; and results from the DRS firmware verification, component qualification, and sled tests are presented herein.

INTRODUCTION

Currently the ACES family of ejection seats utilizes the A114520 Analog Sequencer to control the timing of their ejection events. The Analog Sequencer, shown in Figure 1, is designed with analog circuit technology and dates to the late 1960's. It functions by selecting one of three modes of operation depending on the seat airspeed and altitude. Figure 2 shows the airspeed and altitude regions for each mode of operation. The airspeed is determined with the delta between the dynamic and static pressures, and the altitude with the static pressure, through pressure switches in the A114310 Environmental Sensor. The open or closed positions of the switches determine which

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mode the Analog Sequencer selects. Once the mode is selected, the Analog Sequencer operates in accordance with the applicable event timings for the selected mode.



Figure 1 Analog Sequencer

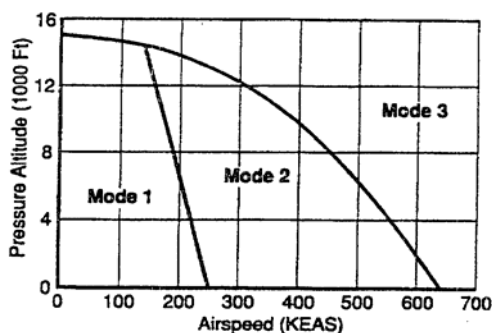


Figure 2 Recovery Mode Flight Envelopes

The Analog Sequencer has limitations with respect to its installed life, electronic component procurement, ability to accommodate seat safety improvements, and mode differentiation at the Mode 1 to 2 crossover point. Its maximum installed life is 7.5 years based on the life expectancy of its thermal batteries and some of its internal electrical components. Due to the aging design of the Analog Sequencer, multiple electronic components are becoming increasingly more difficult and expensive to acquire for on-going production requirements. Due to the inherent

inflexibility of the analog circuit boards, upgrades to accommodate advances in the seat safety systems can only be accomplished by totally replacing the internal electronics. In addition to the above limitations, the Analog Sequencer has experienced two known instances where both Mode 1 and Mode 2 were simultaneously selected. Both incidents occurred during ejection sled tests at velocities near the Mode 1 and Mode 2 crossover boundary. Simultaneous selection of Mode 1 and 2 causes the parachute and drogue chute to deploy together and potentially entangle with each other, which could result in catastrophic injury to the aircrew.

Based on these limitations and the likelihood that the ACES will remain in service for another 30 years, replacement of the Analog Sequencer with a new device is highly desirable. The DRS program was created to develop and qualify a replacement for the Analog Sequencer. The DRS program was established with a phased approach with three phases. Phase I was to identify the DRS performance requirements, configuration, and potential sources of supply. Phase II is to complete the design, verify the firmware, qualify the component, and perform system qualification sled tests. Phase III is for P³I activities.

Key details from the Phases I, II and anticipated P³I items for Phase III are summarized herein. The DRS design and method of operation is described in detail. The test program is summarized and key results are highlighted as well.

PROGRAM SUMMARY

Phase I began in early November 2001 and concluded in March 2003. Following the completion of Phase I, Phase II was placed

on hold due to insufficient funding to complete the DRS design and qualification effort as defined exiting Phase I. Phase II was started in November 2003 and will finish in October 2005. Phase III is currently unscheduled, but efforts for implementation are anticipated to begin in 2006.

The primary objective of Phase I was to define a DRS configuration based upon capabilities of the marketplace, identify potential suppliers, and recommend a supplier based upon capabilities and cost to the US Government for selection into Phase II. A secondary objective of the Phase I program was to establish the Phase II program structure.

The initial DRS configuration was established through responses by five potential suppliers to a Request for Information (RFI). The RFI results supported the preparation of the 1847-053 Performance Based Specification (PBS). All five potential suppliers were solicited through a Request for Proposal (RFP). The RFP and subsequent evaluations resulted in the identification of two viable suppliers based on cost and technical parameters. Following the supplier selection process, the Phase II and III Statements of Work, Program Plans, Schedules, and Cost Estimates were developed. The 1847-053 PBS was reformatted as well to incorporate changes identified during the RFP process.

Phase I concluded with an identified configuration based on market capability for the DRS and two viable suppliers. Both suppliers presented design solutions that were compliant with the 1847-053 PBS and other program requirements, and were recommended to the US Government. The preparatory planning effort for Phase II was completed as well. The results of the

configuration development, supplier evaluation, and Phase II/III planning efforts were captured in the Phase I final report.

Following the completion of Phase I, the funding available for the DRS design and qualification effort in Phase II was found to be insufficient to complete the program as defined exiting Phase I. Due to the funding constraints, the DRS configuration was evaluated for potential requirement changes that would result in cost savings, yet still meet the primary design and performance requirements. Based on the results of this requirement evaluation, the following configuration for the DRS was established:

- Separate Electronic and Power Modules
- Redundant thermal batteries in the Power Module
- Digital based electrical components
- Firmware programmed in a higher-level language per IEEE/EIA-12207
- Airspeed and altitude inputs from the existing Environmental Sensor system
- Survivable Data Recorder with a single set of 3 accelerometers
- Eight Electro-Explosive Device (EED) Interfaces
- External test connector
- Operating temperature range of -40°F to 160°F
- Fixed or removable Cable Assemblies

As an additional cost savings to the US Government, Goodrich decided to internally fund the DRS design task of Phase II, with the US Government providing funding for the qualification tasks. Due to the changes in the technical and program requirements implemented following Phase I, Goodrich issued a Request for Quote (RFQ) to the original eight potential suppliers. The RFQ process resulted in the selection of Teledyne Electronic Safety Products as the DRS Electronic Module Supplier. In addition,

Goodrich elected to be the supplier for the DRS Power Module with Eagle Picher as the thermal battery supplier.

The objective of Phase II is to design and qualify the DRS for use on the ACES family of ejection seats. The Phase II program was established to achieve this objective through completion of the following major milestones:

- System Requirements Review (SRR)
- Hardware/Firmware Development
- Fit-Checks
- Critical Design Review (CDR)
- Hardware/Firmware Verification
- Component Qualification
- System Qualification (Sled Testing)

The SRR was completed in December 2003. Key outcomes of the SRR were a complete review of the 1847-053 PBS requirements, agreements on the methods of compliance to the requirements, development of the tailored approach for compliance with the IEEE-EIA 12207 software development specification, and establishment of the fit-check and component qualification units.

The Hardware/Firmware Development effort was started following the SRR and completed prior to the CDR. The Electronic Module and Power Module designs were completed during this time frame. The Electronic and Power Modules designs are described in detail in the Design Description section.

The Fit-Checks were conducted in parallel with the Hardware/Firmware Development effort from February to March in 2004. Fit-checks of a production equivalent mockup unit were conducted on A-10, F-15, F-16, F-22, F-117, B-1B Fwd, B1-B Aft, and B-2 ejection seats. The fit-checks successfully demonstrated that the DRS could be

installed and removed from all seat platforms without requiring any modifications to the seats. Figure 3 shows the mockup unit installed on an F-16 ejection seat.

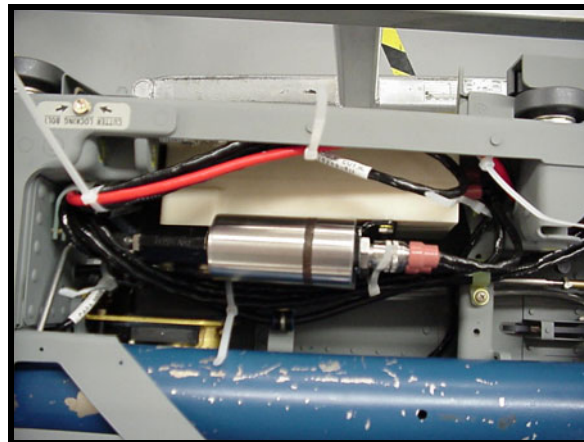


Figure 3 Fit-Check Installation

The CDR was completed in June 2004. The objective of the CDR was to review the DRS detail design and the plan for demonstrating compliance to the 1847-053 PBS requirements. The US Government endorsed the Electronic and Power Module designs and their respective methods of compliance to the 1847-053 PBS following the meeting.

The Hardware/Firmware Verification effort was started following the CDR and testing was completed in December 2004. All firmware verification tests were conducted in accordance to the Firmware Test Plan contained in the 10002127 Firmware Design Description. The tests successfully demonstrated that the Electronic Module firmware meets its specified requirements.

The Component Qualification effort was conducted during fall of 2004 and concluded in January of 2005. The DRS was environmentally tested both as an assembly and as individual components depending on the particular test requirements. All

environmental tests were successfully passed. The Power Module was functionally tested as well for firing pressure and thermal battery output and demonstrated that it met all of its specified requirements. The DRS as an assembly was bench tested prior to sled testing as a risk reduction test. The bench test demonstrated that the Power Module fires by gas pressure through its inlet port and in turn powers the Electronic Module through the ejection event. The bench test showed that the Electronic Module properly executed the expected mode based on the given test conditions within all specified timing requirements.

The sled test program started in February 2005 and ran through April 2005. Four sled tests were conducted with a fully operational production DRS unit. The four tests included a 0 KEAS test with a Lightest Occupant in Service (LOIS) manikin, a 632 KEAS test with a Large Anthropometric Research Device (LARD) manikin, a 197 KEAS test with a LOIS manikin, and a 306 KEAS test with a LOIS manikin. All four tests demonstrated that the DRS properly selected and executed the applicable mode of operation for the given set of test conditions.

Phase II will conclude in October 2005 with completion and award of the Safe-to-Fly certificate. The production of a limited number of design verification units will deliver to the US Government in October for future sled test requirements and other usages as defined by the JPO as part of Phase II.

Phase III is for the P³I items on the DRS. Potential P³I items under consideration include replacement of the environmental and velocity sensors with pressure sensors mounted directly in the DRS, incorporation of active control of the seat during ejection,

expansion of the SDR recorded data to include additional ejection events, and incorporation of additional p-lead capacity. Phase III is not currently scheduled at this time, but efforts for implementation are anticipated to begin in 2006.

The DRS is in the initial stages of production for the USAF with deliveries scheduled for the 2nd Quarter of 2006. Implementation of the DRS in the USAF fleet will be accomplished via attrition replacements of the Analog Sequencer. The initial installation of the DRS will include the Electronic Module, Power Module, and Hot-Gas Tube. Subsequently, the Power Modules will be replaced as time-change items.

DESIGN DESCRIPTION

The DRS consists of two primary components – the Electronic Module and the Power Module. The Electronic and Power Modules, shown in Figure 4 in their assembled configuration, are joined together to function as an integral sequencing unit for control of the ejection events during emergency aircrew egress. The Electronic Module attaches to the interior of the right side panel of the ejection seat using the same footprint as the Analog Sequencer. The Power Module is mounted on the Electronic Module with standard aerospace fasteners. The cable assemblies are permanently attached to the Electronic Module and route to their respective external devices in the identical manner used with the Analog Sequencer. The hot gas supply tube for initiation of the thermal batteries is modified to accommodate the inlet port location change from the Analog Sequencer to the Power Module.



Figure 4 DRS Assembly

The Electronic Module is an assembly of printed circuit boards and associated wiring contained within a housing fabricated from aluminum. It is a derivative of a qualified and fielded design and retains the key architectural and functional features of that design. The Electronic Module uses digital technology with a unique firmware code embedded into its circuits. It has three redundant channels that use a voting scheme for mode determination, which prevents the possibility of multiple modes being simultaneously selected. The Electronic Module has two power input cables, two or three switch input cables, and six or seven EED output cables. The actual number of switch input and EED output cables is dependant on the application. It contains a SDR feature to record data throughout the ejection for post-ejection analyses. The Electronic Module incorporates the input and output cables as an integral part of its assembly, which use a double EMI shield method of construction with potted strain reliefs at the connector and adaptor ends for durability.

The Electronic Module operates by receiving electrical power from the Power Module. Following power initiation, the Electronic Module microcontrollers boot up and synchronize with each other. The

Electronic Module receives the start switch and environmental switch inputs and based on the switch settings, determines the appropriate ejection mode. Once the ejection mode is determined, the Electronic Module controls its outputs to the applicable EED's based on its firmware/hardware circuits in accordance to the specified event timings in the 1847-053 PBS. The SDR feature records the input switch positions, the selected mode, and actual event sequence timing.

The Power Module is an assembly of two redundant thermal batteries, a manifold assembly, and a mounting clip. It is based on the MXU-792A/A Battery Pack and uses the same "green" thermal batteries. The manifold assembly consists of dual firing pins contained within firing bodies screwed into the manifold body. The firing pins are held in place in the firing bodies with shear pins. The manifold body has dual ports and an internal cross channel between the ports. One port contains a standard union fitting and the other is plugged.

The Power Module operates by receiving ballistic hot gas from the Rocket Catapult. The hot gas travels from the Rocket Catapult through a tube assembly into the standard union fitting. The hot gas then flows into the firing bodies and through the cross-channel, causing the firing pins to strike the thermal battery primers. The shear pins used to retain the firing pins in place are designed to withstand 400 psig and completely shear between 400 and 650 psig.

Use of a separate Electronic Module and removable Power Module was implemented to overcome the life-limited aspects of the Analog Sequencer. The thermal batteries are the primary life-limiting component on the DRS and by allowing for replacement of them independent of the electronics, the

Electronic Module can remain installed for over 20 years without removal. By using digital based electrical components with a triple redundant voting architecture, the component obsolescence and mode differentiation issues of the Analog Sequencer are eliminated. Use of firmware written in a higher order language, provisions for an extra EED interface, and capacity for expansion of the electronics within the Electronic Module housing provide the needed flexibility in the DRS for incorporation of future product improvements. The SDR was added to capture data during actual ejections that will be used to develop a better understanding of the performance of the seat. The cable assemblies are permanently attached to Electronic Module for reliability and cost purposes. They replace the method of construction used by the Analog Sequencer cable assemblies with an alternate proven method of construction that alleviates durability issues and still interface with their respective devices without seat modifications. The DRS retains the Environmental Sensor airspeed and altitude inputs for selection of the mode of operation, and activation of the thermal batteries with hot gas from the Rocket Catapult to minimize impacts to the system seat design.

TEST SUMMARY

The test program was conducted on multiple levels to demonstrate that the design complies with its specified requirements in the 1847-053 PBS. The test program included verification of the Electronic Module firmware, environmental testing of the Electronic and Power Modules, functional testing of the Power Module; and bench and sled testing of the complete DRS assembly.

The firmware verification testing was conducted to verify the Electronic Module firmware correctly executed synchronization of the microcontroller time bases, entered into the applicable operational or test states, interpreted the start switch and environmental sensor inputs, recorded the specified data in the survivable data recorder; and determined, synchronized, and implemented the proper mode of operation. The test methodology typically consisted of running a simulated ejection with specified faults introduced into the test article to validate the firmware made the correct choices. The results of the tests were verified through both external data acquisition systems and recorded results by the SDR. The accuracy of the SDR data was independently verified prior to using its data as test results.

One example of a firmware test is a mode synchronization case where two channels are set to Mode 1 and the third is set to Mode 2. The outcome should be that the three channels vote and reset so that they all execute a Mode 1 ejection. The SDR output shown in Figure 5 confirms that all three channels compared their initial mode selections and reset to all execute a Mode 1 ejection.

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P351_TL_B1
[Edit note: MCU1, MCU2, MCU3 in text is equivalent to MCUA,
MCUB, MCUC in O'scope photos and Firmware Design Description
document no. 10002127]

10002137v01.00 DRS Serial Flash Data S/N 2003,UUT1, 1/ 6/2005,13:44:38
Model1 ,Both Start Switches activated in 30ms ,Divergence Enabled

MCU1: DRS MODE Decision Data
Flash page 4
Time From Start: 16
StRt Sw:3 MCU Sync:3 EED Sync Fault:0 Alt:1 Vel:0 Div:1
Selected mode:1 Left mode:1 Right mode:2 Actual mode:1

MCU1: DRS EED Event Times and TO States
Flash page 13
NO Fall Through:
Drogue On: Off: EED Sync:0
Stapac On: 15 Off: 25 EED Sync:2
Parachute On: 32 Off: 42 EED Sync:3
Divergence On: 46 Off: 56 EED Sync:3
Pri Severence On: 182 Off: 189 EED Sync:3
Sec Severence On: 192 Off: 199 EED Sync:3
Harness On: 282 Off: 292 EED Sync:3

MCU2: DRS MODE Decision Data
Flash page 4
Time From Start: 16
StRt Sw:3 MCU Sync:3 EED Sync Fault:0 Alt:1 Vel:0 Div:1
Selected mode:1 Left mode:2 Right mode:1 Actual mode:1

MCU2: DRS EED Event Times and TO States
Flash page 13
NO Fall Through:
Drogue On: Off: EED Sync:0
Stapac On: 15 Off: 25 EED Sync:3
Parachute On: 32 Off: 42 EED Sync:3
Divergence On: 46 Off: 56 EED Sync:3
Pri Severence On: 182 Off: 189 EED Sync:3
Sec Severence On: 192 Off: 199 EED Sync:3
Harness On: 282 Off: 292 EED Sync:3

MCU3: DRS MODE Decision Data
Flash page 4
Time From Start: 16
StRt Sw:3 MCU Sync:3 EED Sync Fault:0 Alt:1 Vel:1 Div:1
Selected mode:2 Left mode:1 Right mode:1 Actual mode:1

MCU3: DRS EED Event Times and TO States
Flash page 13
NO Fall Through:
Drogue On: Off: EED Sync:0
Stapac On: 15 Off: 25 EED Sync:3
Parachute On: 32 Off: 42 EED Sync:3
Divergence On: 46 Off: 56 EED Sync:3
Pri Severence On: 182 Off: 189 EED Sync:3
Sec Severence On: 192 Off: 199 EED Sync:3
Harness On: 282 Off: 292 EED Sync:3

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Figure 5 Typical SDR Output

The firmware testing successfully verified the Electronic Module firmware met the applicable requirements of the 1847-053 PBS. The results of firmware testing are completely documented in the 10002127 Firmware Design Description document.

Environmental tests conducted on the Electronic and Power Modules included weight, transit drop, mechanical shock, operational and gunfire vibration, and linear acceleration. The weight and transit drop tests were conducted on separate Electronic and Power Modules. The shock and acceleration tests used an Electronic and Power Module assembled together. The vibration tests were conducted with the complete DRS assembly installed in an ACES II seat mounted in rails on a test fixture. The tests were all performed as required and were successfully passed.

Functional testing of the Power Module included initiation pressure, voltage rise time, and activated life tests. The initiation pressure test verified that the shear pin design meets its specified “no-fire” and “all-fire” requirements. The voltage rise time and activated life tests verified the thermal batteries met their specified performance requirements. A typical test setup for the Power Module is shown in Figure 6, a typical shear pressure plot is shown in Figure 7, and a typical rise time vs. voltage plot is shown in Figure 8.

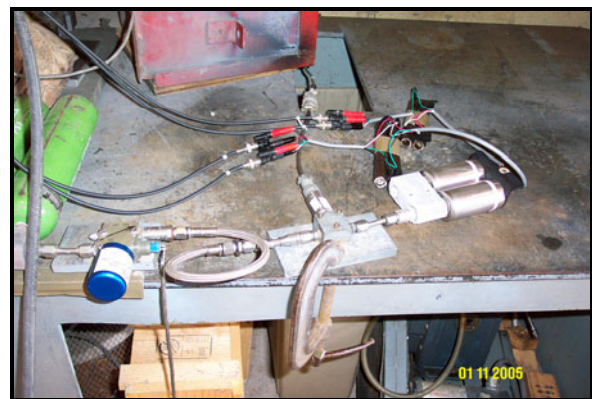


Figure 6 – Power Module Functional Test Setup

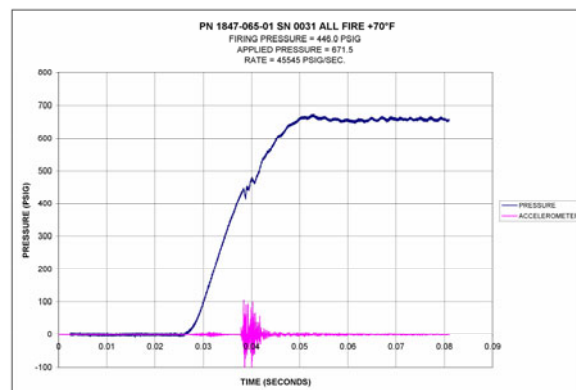


Figure 7 – Power Module Shear Pressure Test

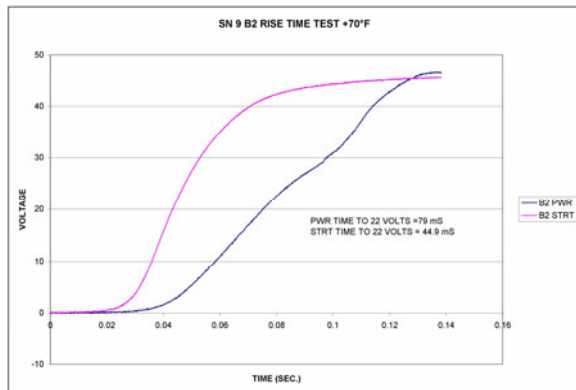


Figure 8 – Power Module Rise Time/Voltage

Bench level testing on the complete DRS assembly was performed to demonstrate that it would execute the correct mode of operation in its operational configuration. Conducting this test confirmed the DRS could properly operate exactly as it is installed on the ejection seat. The Power Module was initiated with a pneumatic source similar to the operational Rocket Catapult bleed gas. The Power Module then provided electricity to power the Electronic Module through its P12 and P13 p-leads. The Electronic Module outputs were connected to light emitting diodes (LED) and a Data Acquisition System (DAS). The DAS system recorded the current pulses on the p-leads than would normally fire the EED bridge wires. The LED's provided a visual backup system to verify the event times. The LED operation was captured on high-speed video. The Electronic Module was connected to an environmental sensor with open ports. The start switch input was left open allowing the Electronic Module backup timer to execute. The bench tests successfully demonstrated the operation of the DRS. The setup for the test is shown in Figure 9. The event current pulse plot is shown in Figure 10.

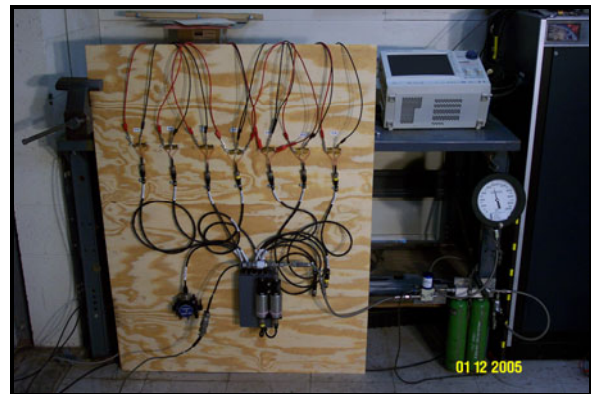


Figure 9 DRS Bench Test Setup

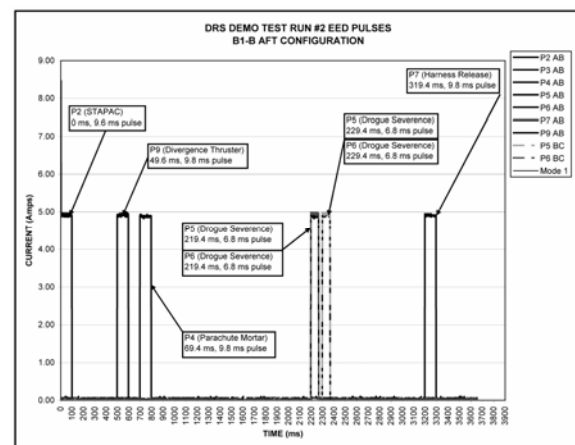


Figure 10 DRS Bench Test Current Pulses

Four sled tests were conducted with the DRS installed in an ACES II at Goodrich's Hurricane Mesa Test Facility. The objective of the test program was to verify that the performance of the DRS installed on an ACES II met its specified requirements. The four tests spanned the operational velocity range of the ACES II and covered all three DRS modes of operation. The first test ejected a LOIS manikin in an F-16 seat at 0 KEAS, the second test ejected a LARD manikin in a B1-B Aft seat at 632 KEAS, the third test ejected a LOIS manikin in an F-15 seat at 197 KEAS, and the fourth test ejected a LOIS manikin in an F-15 seat at 306 KEAS. The first and third tests verified that the DRS selected and executed a Mode 1 ejection in the Mode 1 performance envelope. The second test verified the DRS

selected and executed a Mode 3 ejection, and inhibited the B1-B divergence thruster based on input from the velocity sensor. The fourth test verified the DRS selected and executed a Mode 2 ejection when exposed to the Mode 2 performance envelope. The third and fourth tests also verified the DRS selected the correct mode of operation at ejection conditions near the mode cross-over region. Verification of the selected mode was accomplished through visual observations and data recorded by the test DAS. The events times recorded by the DAS and SDR were compared and were found to be reasonable and relatively equivalent. A typical DAS and SDR data comparison is shown in Figure 11.

Test 03 (HMTT 000)									
SDR EED Event Timing (T0 from Start Switch Detection)	1847-053 Fighter Requirement for EED "On" timing (ms)	SDR EED "On" (ms)	SDR EED "Off" (ms)	SDR EED Time for Fall Through ^a (ms)	DAS Connected (DAS Time to Start Switch Detection) (ms)	Delta Between SDR and DAS (ms)	SDR Delta Between one event to the next (ms)	DAS Delta Between one event to the next (ms)	SDR to DAS Delta Variation Between one event to the next (1.00 - No Variation)
Insensitive by Design									
Dropout	15	15	25		44	19			
STAPAC	32	32	42		54	12	17	10	1.70
Parachute	46	46	56						
Divergence	182	182	189		200	11	147	146	1.01
Pri Severance	192	192	199						
Sec Severance	232	232	292		302	10	103	102	1.01
Harness									

^aNo "Fall Through" time for Mode 1 ejection

Figure 11 Sled Test Data Analysis

Photos of the pre-test and post-test DRS installation are shown in Figures 12 and 13. A photo of the DRS in action during the third test is shown in Figure 14.



Figure 12 Pre-Test DRS Installation



Figure 13 Post-Test DRS Installation



Figure 14 – DRS in Mode 1 Ejection

The DRS test program comprehensively tested its firmware, physical design, and operational performance integrity. All tests were successful and clearly demonstrated that the DRS meets all of its specified requirements in the 1847-053 PBS. Consequently at the conclusion of the test program, the DRS was determined to be qualified for use in the ACES II.

SUMMARY

The Digital Recovery Sequencer program was initiated by the US Government to design and qualify a replacement to the Analog Sequencer currently used on the ACES family of ejection seats. The Analog Sequencer, designed in the late 1960's with analog technology, has several design limitations that make it highly desirable to replace it with a new design based on currently available digital technology. These design limitations include a short installed life, electronic component obsolescence, inflexibility to accommodate seat safety improvements, and the potential to select both Mode 1 and 2 when the seat airspeed is near the crossover point.

The DRS program started in 2001 with the Phase I effort to evaluate design requirements, industry capability, costs, and

potential suppliers. Phase I concluded in March 2003 with a configuration defined for the DRS, two potential suppliers identified, and the necessary program planning for Phase II/III completed. During the transition from Phase I to Phase II, the US Government determined that the available funding for the DRS design and qualification effort was insufficient for DRS configuration established at the conclusion of Phase I. Subsequently, the configuration was rescope to introduce potential cost saving measures and the 1847-053 PBS was updated accordingly. As an additional cost savings to the US Government, Goodrich decided to internally fund the Phase II design effort with the US Government providing funding for the qualification tasks. Due to the changes in the technical and program requirements, Goodrich issued a new RFQ to the original eight potential suppliers and selected Teledyne Electronic Safety Products as the DRS Electronic Module Supplier. Goodrich retained the design responsibility for the Power Module. Phase II of the DRS program started in November 2003 and will conclude in October 2005 with the award of the Safe-to-Fly certification. Key accomplishments completed during Phase II include establishment of the DRS baseline requirements, completion of the DRS design, successful fit-checks of the DRS mockup unit, verification of the DRS performance and design integrity through multiple phases of testing, and production of design/verification units. Phase III of the DRS program is under consideration, but is not scheduled at this time.

The DRS consists of separate Electronic and Power Modules joined together at the seat installation to function as an integral sequencing unit. The Electronic Module attaches to the seat using the same footprint as the Analog Sequencer. The Power

Module mounts to the Electronic Module. The Cable Assemblies are permanently attached to the Electronic Module and a new hot gas tube is used to accommodate the Power Module inlet port. The Electronic Module is a derivative of a qualified and fielded design and uses three redundant channels with digital components. The Power Module is based on the MXU-792A/A Battery Pack and uses two redundant thermal batteries with a common firing manifold assembly. The DRS overcomes the life limitation of the Analog Sequencer by enabling replacement of the thermal batteries independent of the electronics, which have a significantly longer life expectancy. It eliminates the obsolescence and mode differentiation issues, and creates design flexibility by using a firmware based design approach with digital components. It includes a Survivable Data Recorder to capture live ejection data for use in determining future product improvements.

The DRS test program comprehensively tested its firmware, physical design, and operational performance integrity. The firmware was extensively tested to ensure the correct mode of operation would be selected and executed properly based on the conditions at the time of the ejection. Environmental tests were performed to validate the structural design of the DRS. Performance tests on the Power Module were conducted to verify the shear pressures and battery outputs met their requirements. Bench and Sled tests were conducted on the DRS assembly to verify its performance as a system. All tests were performed successfully and clearly demonstrated that the DRS meets all of its specified requirements in the 1847-053 PBS. Consequently the DRS was determined to be qualified for use in the ACES II ejection seat at the conclusion of the test program.

The DRS is currently in production for the USAF with initial deliveries scheduled for 2nd quarter 2006. The DRS will be implemented into the USAF fleet via attrition of the Analog Sequencers starting in 2006.

REFERENCES

“JESP ACES II Description,” Goodrich, 29 January 2001.

1847-053, “Specification - Digital Recovery Sequencer,” Revision E, Goodrich

10561, “Power Module Qualification Test Report,” Revision N/C, Goodrich

10583, “DRS Demonstration Test Report,” Revision N/C, Goodrich

10611, “DRS Sled Test Report,” Revision N/C, Goodrich

10002127 “Electronic Module Firmware Design Description,” Revision A, Teledyne

BIOGRAPHIES

Mr. David A. “Andy” Ross is a senior project engineer for the ACES II Program at Goodrich-UPCO with more than 4 years experience in the escape system industry. Mr. Ross is the lead engineer for the Digital Recovery Sequencer (DRS) Phase II design, development, and qualification program. Mr. Ross was a project engineer at The Boeing Company on commercial aircraft platforms for over 10 years prior to his Goodrich employment. Mr. Ross graduated from Arizona State University with a BS in Aerospace Engineering in 1988.

Mr. David Culhane is the Electronics Engineer for the CAD/PAD Joint Program Office (JPO). Mr. Culhane has been with the Indian Head Division, Naval Surface Warfare Center for over 14 years, and has provided engineering support to the Digital Recovery Sequencer Program for the past 48 months. Mr. Culhane graduated from the Marine Corps Communications and Electronics School in 1987, and received a BS in Electrical Engineering from Capitol College in 1996.

Mr. Matthew J. Press is the Human Systems Group Lead Egress Engineer for the Aircrew Protection Division at Brooks City-Base, Texas. Mr. Press' diverse experience includes employment with Raytheon at Johnston Atoll Chemical Agent Demilitarization Facility; US Filter Blastrac in Oklahoma City, Oklahoma; and the Air Force Research Lab at Wright Patterson Air Force Base, Ohio. Mr. Press graduated from Oklahoma Christian University with a Bachelor of Science in Mechanical Engineering and completed his Master of Science in Astronautical Engineering at the Air Force Institute of Technology with a thesis on multi-satellite control theory

Mr. Lee Cotter is the Engineering Manager at Teledyne Electronic Safety Products. Mr. Cotter is also responsible for New Business and Product Development. Mr. Cotter has over 20 years of experience in the escape system industry and was involved in the development of nearly all of their escape related and other products. Prior to that, Mr. Cotter had 16 years of engineering and management experience in the inertial instruments, flight control and navigation, and electronic warfare worlds. Mr. Cotter has a B.S. in Mathematical Physics from Cal. State Northridge.

Digital Recovery Sequencer

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BROOKS CITY BASE

David A. Ross
Senior Project Engineer
Ejection Seat Engineering
Goodrich

David Culhane
Electronics Engineer
CAD/PAD Joint Program Office
Indian Head Division NSWC



Lee Cotter
Engineering Manager
New Business & Product Development
Teledyne Electronic Safety Products

Matthew J. Press
Lead Egress Engineer
Aircrew Protection Division
Human Systems Group
Brooks City-Base, TX 78235

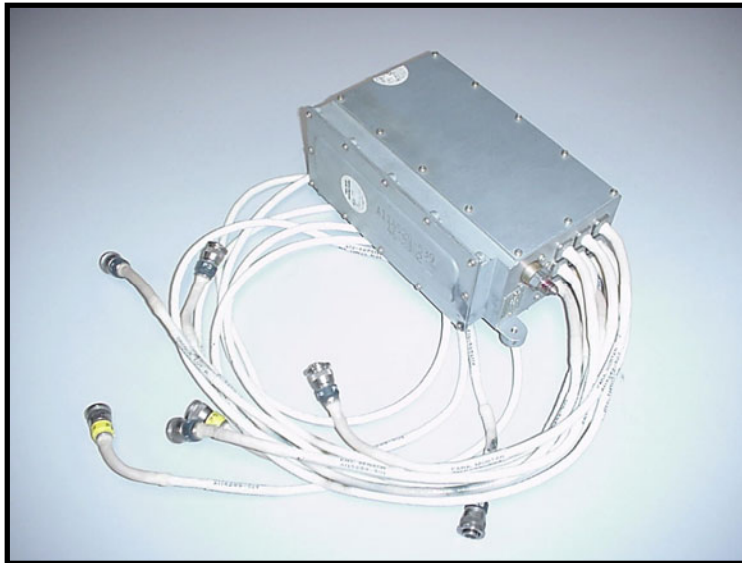
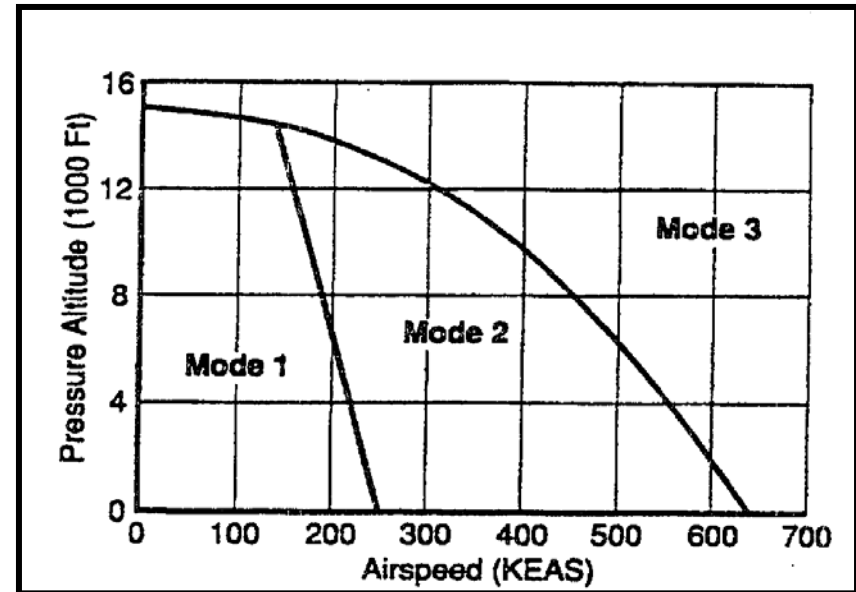
- Introduction
 - Why is DRS necessary
- Program Summary
 - Where is the program today
- Configuration & Installation
 - What is it and how is it installed
- Tests
 - What was done to verify the DRS works
- Summary

Introduction

Introduction

Analog & Digital Recovery Sequencers

- Select the ejection mode based on the Environmental Sensor velocity and altitude switch positions
- Control the ejection event timing based on the selected ejection mode



Mode Selection	Switch (Sv) (Velocity)	Switch (Sa) (Altitude)
Mode 1	Closed	Open
Mode 2	Open	Open
Mode 3	Open or Closed	Closed

Introduction

Analog Sequencer Issues	
<u>Installed Life</u> Installed life limited to 7.5 years by thermal batteries and some electrical components	
<u>Component Obsolescence</u> Difficulty in procuring electrical components for 1960's technology based design	
<u>Design Inflexibility</u> Fixed circuit board design requires total replacement to accommodate seat safety improvements	
<u>Mode Differentiation</u> Two known instances during sled tests near the mode crossover point where Mode 1 and 2 were simultaneously selected	

Introduction

Analog Sequencer Issues	DRS Solutions
<u>Installed Life</u>	Separate Electronic and Power Modules
	PM life is limited by thermal battery operational life
	EM life is over 20 years
<u>Component Obsolescence</u>	EM uses current technology digital COTS components
<u>Design Inflexibility</u>	EM contains provisions for an additional EED device
	EM housing has room for an additional printed circuit board
	Firmware allows future upgrades without hardware changes
<u>Mode Differentiation</u>	EM has a triple redundant voting architecture that does not allow for simultaneous selection of multiple modes

Program Summary

Program Summary

DRS Program

- Phase I
 - Began in November 2001 and concluded in March 2003
 - Defined the initial DRS configuration
 - Program placed on hold due to limited available funds at end of this phase
- Phase I to Phase II Transition
 - DRS configuration was modified to decrease design & qualification costs
 - Goodrich decided to internally fund the DRS design
 - USAF/JPO funded the component qualification and sled testing
 - Teledyne was selected as the Electronic Module supplier
 - Goodrich was selected as the Power Module supplier
 - Thermal batteries for the Power Module would be from qualified suppliers

Program Summary

– Phase II

- Started in November 2003 and will finish in October 2005
- Is complete pending grant of Safe-to-Fly certification
- Completed Electronic Module, Power Module, and Hot-Gas Tube Assy Designs
- Conducted fit-checks of DRS Assy, including Hot-Gas Tube Assy
- Tested DRS components and assembly:
 - Firmware proven out through extensive verification testing
 - Mechanical design aspects validated through environmental testing
 - Power Module performance verified through actuation and operational tests
 - DRS Assy demonstrated via bench testing
 - DRS System verified through system level sled tests
- On-track to deliver Design/Verification Units in October 2005

Program Summary

– Phase III

- For Pre-Planned Product Improvement items including
 - Replacement of the Environmental Sensor
 - Replacement of the B1-B Velocity Sensor
 - Incorporation of active control of the seat during ejection
 - Expansion of the Survivable Data Recorder capacity
 - Incorporation of additional p-lead capacity
- Not currently scheduled
- Implementation efforts are expected to begin in 2006

– Production

- Initial Production Orders placed with deliveries scheduled for 2nd quarter 2006
- Spares kits include
 - Electronic Module
 - Power Module
 - Hot-Gas Tube Assy
 - Power Module attachment hardware

Configuration & Installation

Configuration & Installation

Firmware written in "C"
per IEEE/EIA-12207

Qualified
Batteries

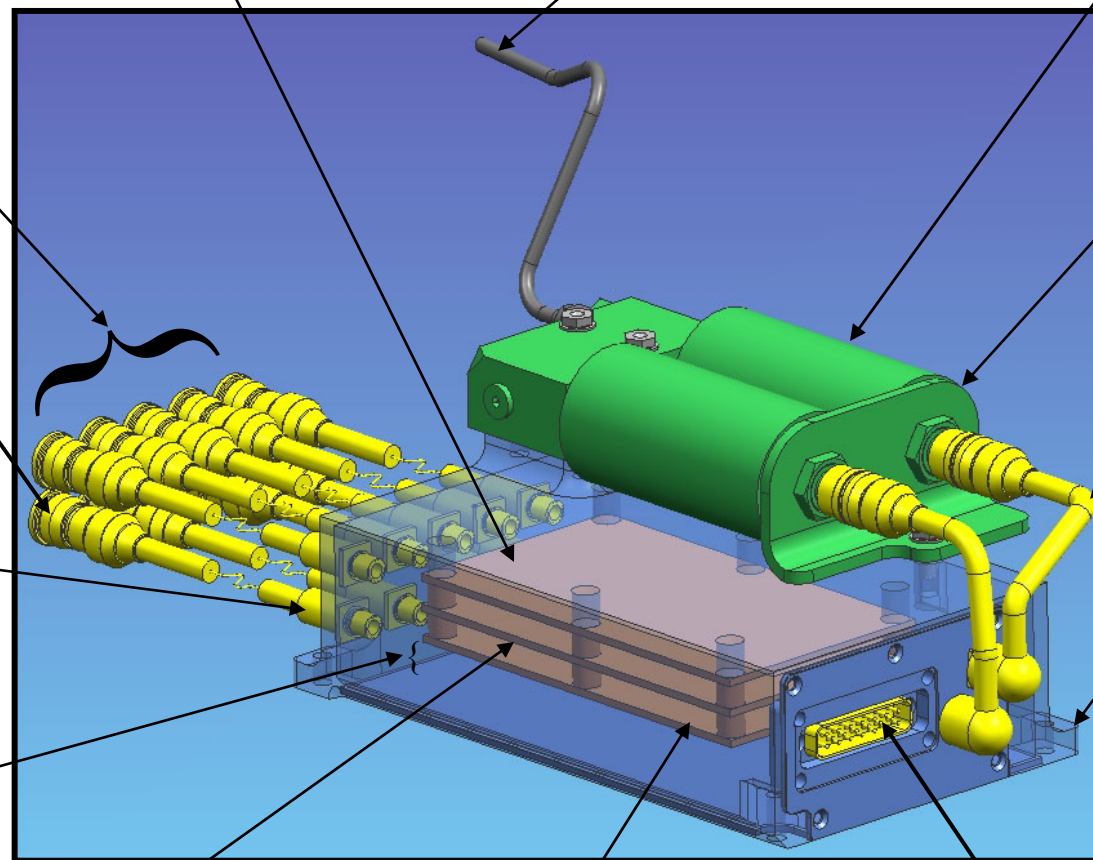
Removable
Power Module

Battery
P-Leads

Electronic
Module

External Test
Connector

Hot-Gas Tube Assy



7 EED
Interfaces w/
provisions for
an 8th

S_a and S_v inputs
from Env. Sensor

P-Leads

Growth room
for additional
Circuit Board

COTS Digital
Electronics

SDR with
Accelerometers

Configuration & Installation

Electronic Module

- Based on a qualified and fielded design
- Unique firmware code embedded into the DRS electronics
- Four configurations – Fighters/B2, A-10, B1-B Fwd, and B1-B Aft
- Three microcontroller units (MCU's) that vote to determine the mode
- Double EMI shielding with potted strain relief for the P-Leads
- Survivable Data Recorder with accelerometers



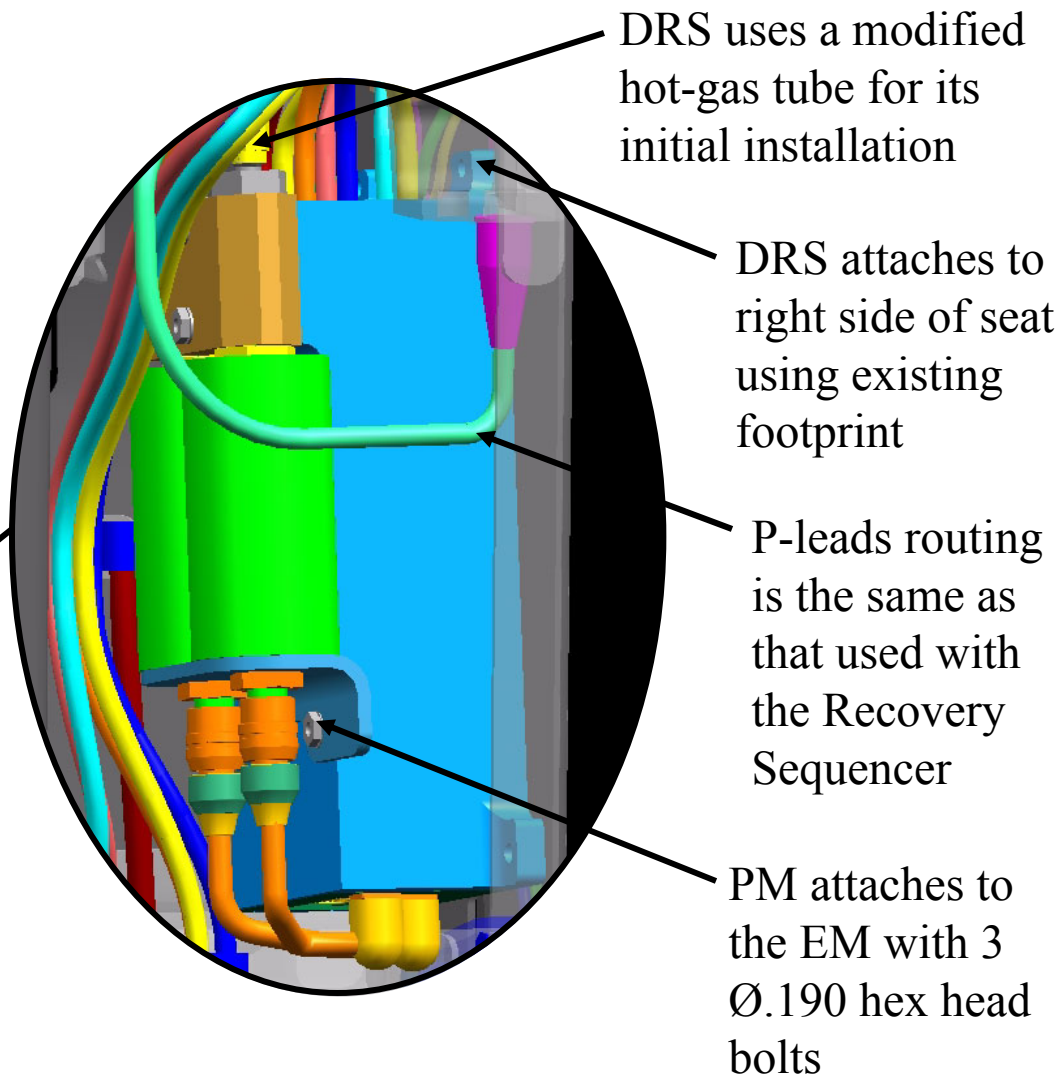
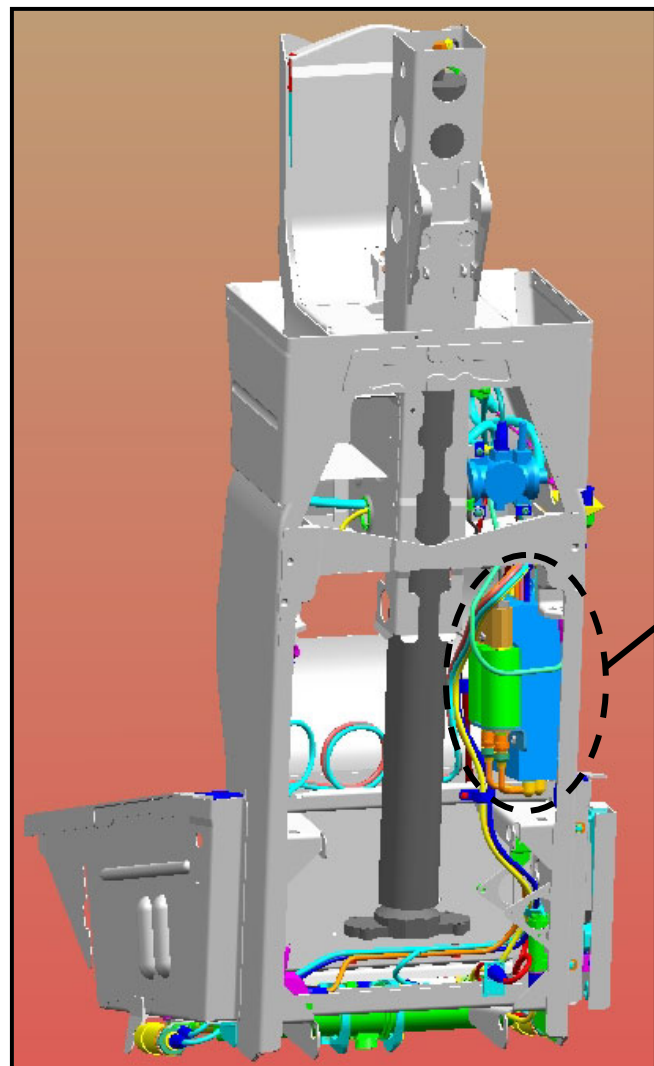
Configuration & Installation

Power Module

- Qualified thermal batteries
- Single source of gas to fire batteries
- Two inlet ports
 - Standard union in one port
 - Plug in other port
 - Union & Plug can be replaced by check valves for dual gas sources
- Dual firing pins held in place with shear pins
- Gas from either port can fire both batteries through the internal cross-port



Configuration & Installation



Tests

Tests

DRS Test Program

- Electronic Module Firmware Verification Testing
 - Proper selection and execution of modes of operation
- DRS Assembly and Component Environmental Testing
 - Weight, Transit Drop, Shock, Vibration, Linear Acceleration
- Power Module Functional Testing
 - Firing Mechanism Performance, Voltage Rise Time, Activated Life
- DRS Assembly Bench Testing
 - System Performance in static conditions
- DRS System Sled Testing
 - System Performance in dynamic conditions

Tests

Firmware Verification Testing

- Tested Parameters
 - MCU time base synchronization
 - Flight or Test Modes as commanded
 - Start Switch detection
 - Environmental/Velocity Sensor input
 - Survivable Data Recorder
 - Mode selection and execution
- Test Example - Mode Synchronization
 - Two channels set to Mode 1
 - One channel set to Mode 2
 - Outcome is all three channels vote & agree on Mode 1

```
MCU1: DRS MODE Decision Data
Flash page 4
Time from Start: 16
Start SW:3 MCO Sync:3 EED Sync Fault:0 Alt:1 Vel:0 Div:1
Selected mode:1 Left mode:1 Right mode:2 Actual mode:1

MCU1: DRS EED Event Times and TO States
Flash page 13
NO Fall Through:
Drogue      On:      Off:      EED Sync:0
Stapac      On: 15 Off: 25 EED Sync:2
Parachute   On: 32 Off: 42 EED Sync:3
Divergence  On: 46 Off: 56 EED Sync:3
Pri Severence On: 182 Off: 189 EED Sync:3
Sec Severence On: 192 Off: 199 EED Sync:3
Harness     On: 282 Off: 292 EED Sync:3

MCU2: DRS MODE Decision Data
Flash page 4
Time from Start: 16
Start SW:3 MCO Sync:3 EED Sync Fault:0 Alt:1 Vel:0 Div:1
Selected mode:1 Left mode:2 Right mode:1 Actual mode:1

MCU2: DRS EED Event Times and TO States
Flash page 13
NO Fall Through:
Drogue      On:      Off:      EED Sync:0
Stapac      On: 15 Off: 25 EED Sync:3
Parachute   On: 32 Off: 42 EED Sync:3
Divergence  On: 46 Off: 56 EED Sync:3
Pri Severence On: 182 Off: 189 EED Sync:3
Sec Severence On: 192 Off: 199 EED Sync:3
Harness     On: 282 Off: 292 EED Sync:3

MCU3: DRS MODE Decision Data
Flash page 4
Time from Start: 16
Start SW:3 MCO Sync:3 EED Sync Fault:0 Alt:1 Vel:1 Div:1
Selected mode:2 Left mode:1 Right mode:1 Actual mode:1

MCU3: DRS EED Event Times and TO States
Flash page 13
NO Fall Through:
Drogue      On:      Off:      EED Sync:0
Stapac      On: 15 Off: 25 EED Sync:3
Parachute   On: 32 Off: 42 EED Sync:3
Divergence  On: 46 Off: 56 EED Sync:3
Pri Severence On: 182 Off: 189 EED Sync:3
Sec Severence On: 192 Off: 199 EED Sync:3
Harness     On: 282 Off: 292 EED Sync:3
```

Tests

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Environmental Testing

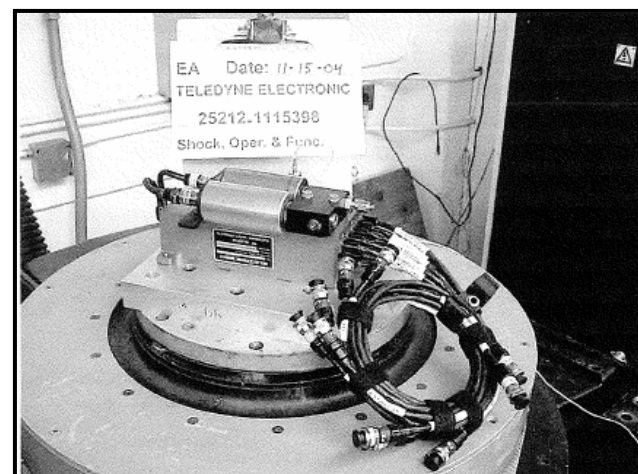
- Weight
 - Electronic Module: 4.85 lbs
 - Power Module: 2.54 lbs
- Transit Drop on separate Electronic & Power Modules
- Shock & Acceleration on DRS Assy
- Operational & Vibration on a DRS Assy installed in a seat
- All Tests were successful in demonstrating the structural integrity of the DRS



Vibration Test Setup



PM Transit Drop

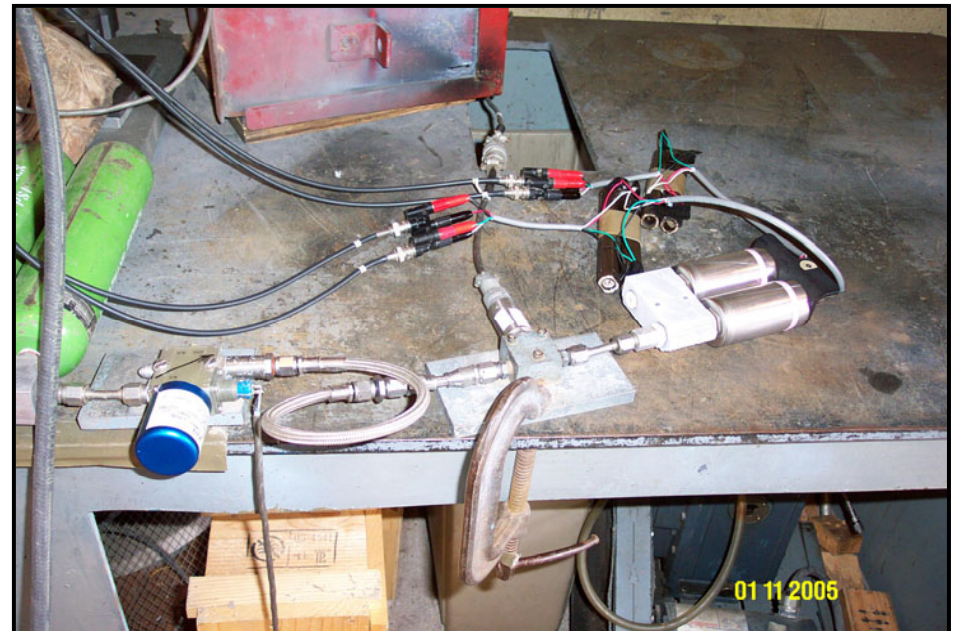


Shock Test Setup

Tests

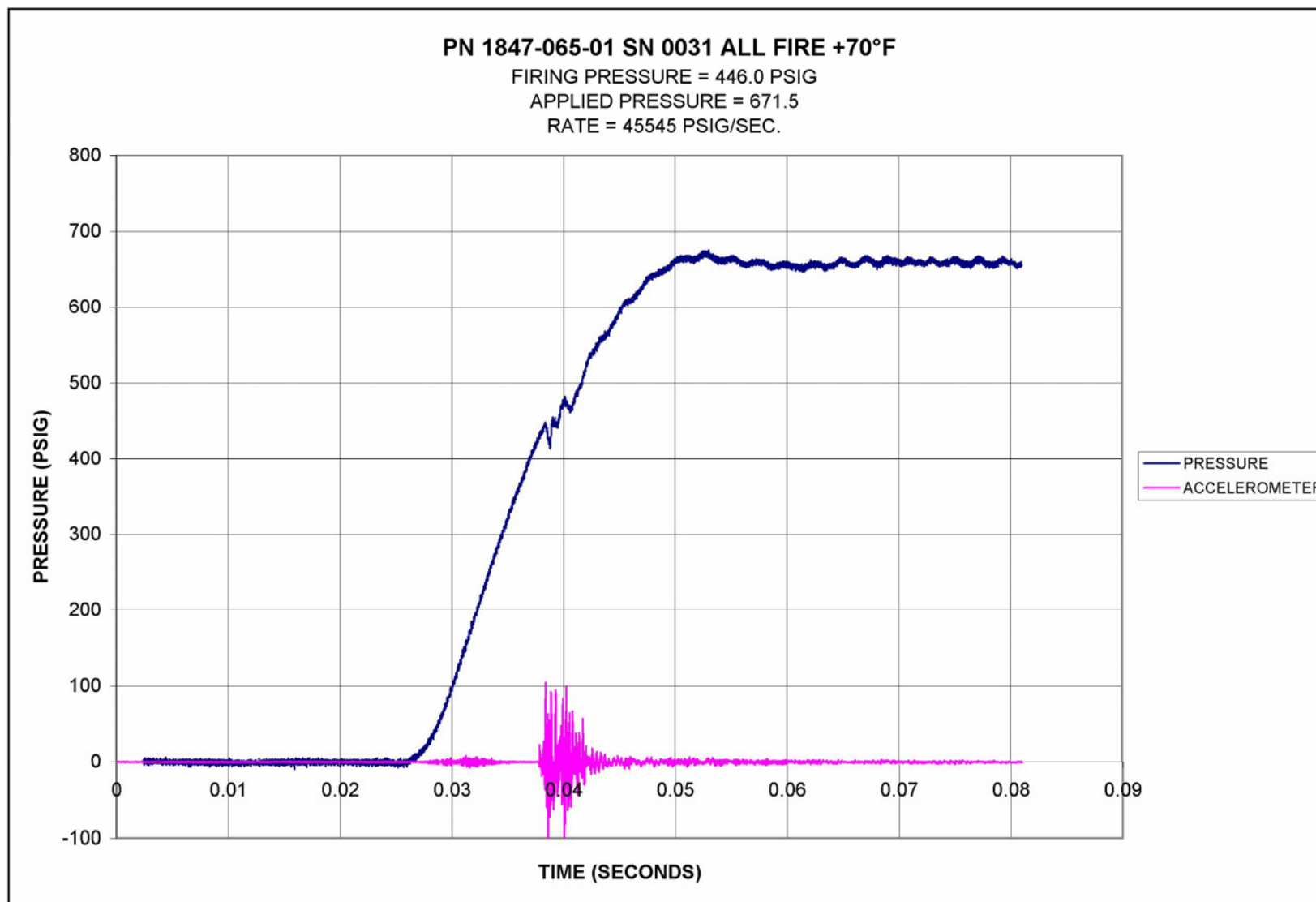
Power Module Functional Tests

- Tests:
 - Firing Mechanism Initiation Pressure
 - Thermal Battery Voltage Rise Times
 - Thermal Battery Activated Life
- Tests performed at -40°F, 70°F, and 160°F.
- Testing verified Power Module meets its performance criteria
 - Shear Pressure between 400 and 650 psig.
 - Rise time to 22 volts < 80 ms
 - Activated life > 5 minutes

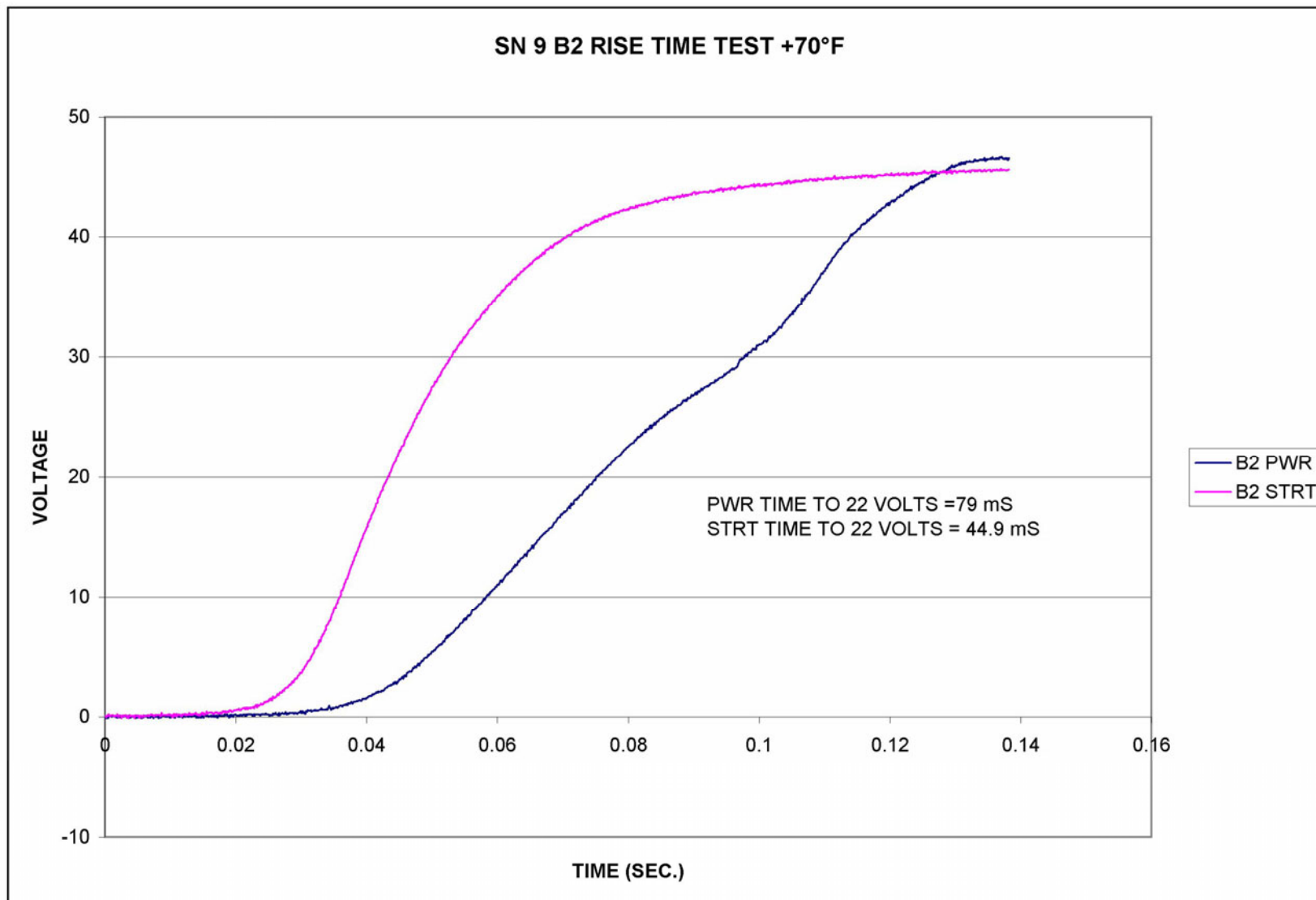


Power Module Test Setup

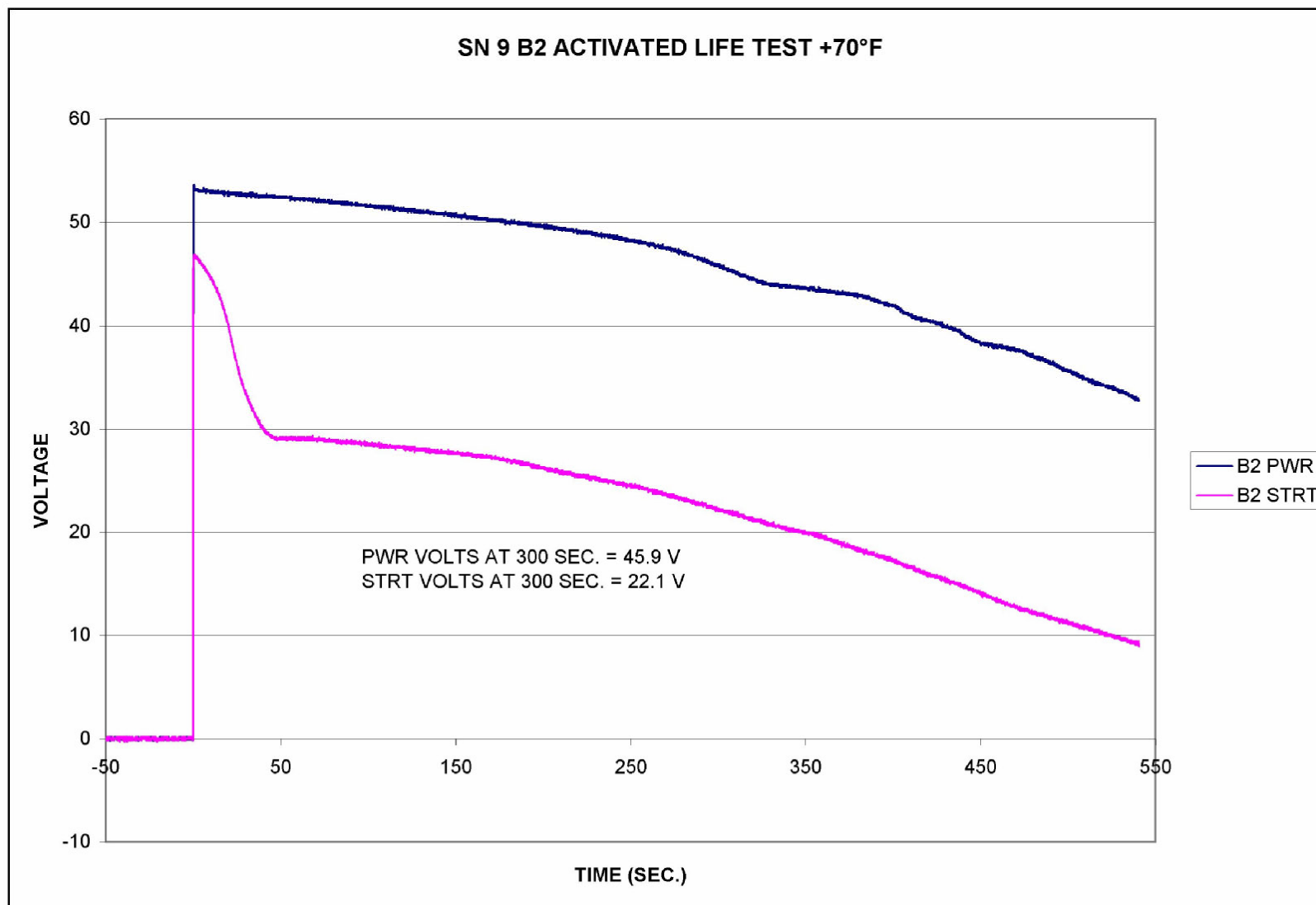
Tests



Tests



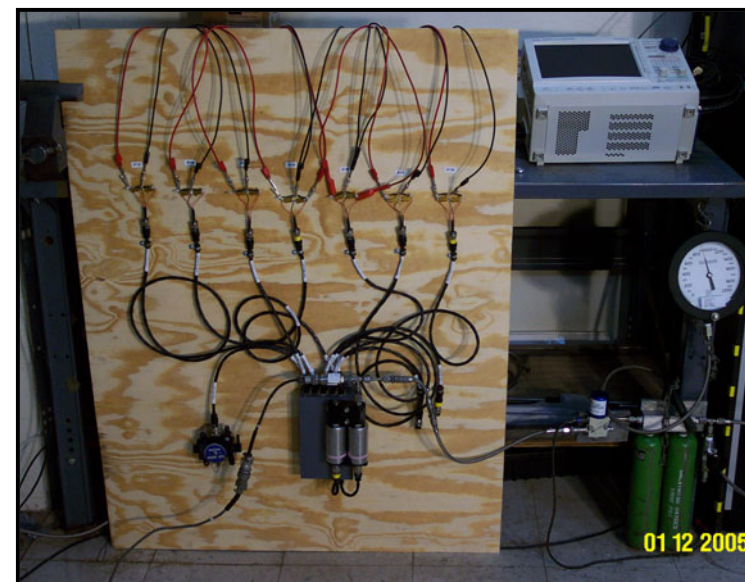
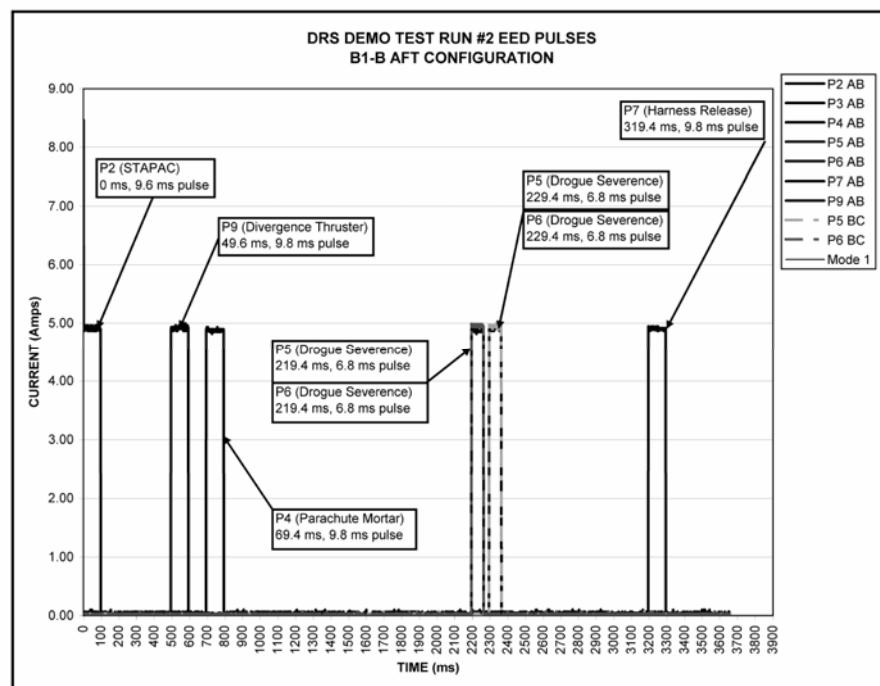
Tests



Tests

Bench Tests

- Static test of DRS Assembly
- Electronic Module EED outputs connected to LED's
- Start Switch left unconnected to test 180 ms backup timer
- Environmental Sensor connected with open ports to simulate Mode 1 ejection
- Tests successfully demonstrated the DRS performance



Bench Test Setup

Tests

Sled Tests

- 0/0 with LOIS in F-16 seat ejected from F-15 Sled at the F-16 Rail Angle
- 632 KEAS with LARD in B1-B seat ejected from F-15 Sled
- 197 KEAS with LOIS in F-15 seat ejected from F-15 Sled
- 306 KEAS with LOIS in F-15 seat ejected from F-15 Sled
- Tests successfully demonstrated the DRS performance
- Data Analysis Example

Test #3 (HMTF800)									
SDR EED Event Timing (T0 from Start Switch Detection)	1847-053 Fighter Requirement for EED "On" timing (ms)	SDR EED "On" (ms)	SDR EED "Off" (ms)	SDR EDD "Off" + Time for Fall Through ¹ (ms)	DAS Corrected (DAS Time Time to Start Switch Detection) (ms)	Delta between SDR and DAS (ms)	SDR Delta between one event to the next (ms)	DAS Delta between one event to the next (ms)	SDR to DAS Delta Variation between one event to the next (1.00 = No Variation)
Drogue	Inoperative by Design								
STAPAC	15	15	25		44	19			
Parachute	32	32	42		54	12	17	10	1.70
Divergence	46	46	56						
Pri Severance	182	182	189		200	11	147	146	1.01
Sec Severance	192	192	199						
Harness	282	282	292		302	10	103	102	1.01

¹No "Fall Through" time for Mode 1 ejection

Tests

Sled Tests

- DRS Pre & Post-Test Photos (From 0 KEAS Mode 1 Test)



Pre-Test



Post-Test

Tests – 0 KEAS

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ACES Digital Recovery Sequencer Program

Tests – 632 KEAS

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October 25, 2005

ACES Digital Recovery Sequencer Program

Tests – 197 KEAS

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October 25, 2005

ACES Digital Recovery Sequencer Program

Tests – 306 KEAS

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October 25, 2005

ACES Digital Recovery Sequencer Program

Summary

Summary

The DRS provides a significant advancement in aircrew safety by...

- Overcoming the design and performance limitations of the Analog Sequencer
- Creating the foundation for incorporation of future safety improvements
- Enabling actual ejection event data to be recorded

Phase II of the DRS Program is...

- Complete pending award of Safe-to-Fly certificate in October 2005
- Culminating with the production of Design Verification Units

Phase III of the DRS Program is...

- Intended to incorporate pre-planned product improvements
- Not currently scheduled, but implementation efforts are anticipated to begin in 2006

Summary

DRS Design

- Separate Electrical and Power Modules
- Four unique configurations for Fighters/B2, A-10, B1-B Fwd, and B1-B Aft
- Verified through firmware, component, assembly, and system level testing

DRS Production

- DVT units in October 2005
- Initial Production Spares Orders in 2nd Quarter 2006

DRS Implementation

- Fleet via attrition as spares to the Analog Sequencer
- Production via replacement of the Analog with the DRS on future seat orders
- Initial Spares Kits include Electronic Module, Power Module, and Hot-Gas Tube Assy
- Power Modules replaced as time-change items