# The System Approach to Spin/Stall Parachute Recovery Systems–A Five Year Update

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## INTRODUCTION

Slightly over 5 years ago, Irvin Aerospace Inc (Irvin) presented to the SETP Symposium our solution to the 'System Approach' for ***Spin/Stall Parachute Recovery Systems*** (**SSPRS**). In general, this involved additional involvement of the parachute manufacturer, to provide the entire suite of components that support the control, deployment and release of the parachute. In our previous experience, several of these components were designed and built by the airframe manufacturer, typically by a flight test organization.

For reasons that will be described, this approach is largely being replaced by the 'one stop shop' approach. The benefits, including highly increased experience and lessons learned, are outlined herein.

This Paper reviews our experiences over the past five (5) years. Having delivered, installed, and operated systems on tens of aircraft, and several classes, we have refined and improved equipment, procedures and processes. Many of these lessons learned are presented, either as general programmatic comments, or as descriptions of detailed changes to critical components. We also present some lessons learned that are directly related to flight-testing this class of system. Finally, we present some system deployment sequences that provide enhanced understanding of the overall system function.

# WHAT IS A SPIN/STALL PARACHUTE RECOVERY SYSTEM?

The parachute approach to Spin/Stall Parachute Recovery System (SSPRS) is rather well defined. It involves a relatively rapid deployment of the parachute from the aircrafts tail. The effect of the parachutes rapid deployment from the aircrafts tail, from which it is attached, is largely that it lowers the aircrafts "Angle of Attack" (AOA). This technique, with a properly sized parachute will produce a recovery from either a spin or a stall.

The applications are typically grouped into two categories:

1) Spin Recovery
    a. General Aviation
    b. High Performance Military Aircraft
        i. Fighters
        ii. Advanced Trainers
2) Stall Recovery
    a. Typically all jet aircraft of the T tail configuration

In the stall recovery application, the "T"- tail configuration is key. As the aerodynamics of the "T"-tail often result in a 'locked in deep stall', where the aircraft elevator becomes virtually useless at high AOA, due to blockage of airflow from the aircraft wing root (and often) engine nacelles. In our experience, virtually all T tail jet aircraft utilize a stall recovery system, while most T tail propeller aircraft do not. This is largely due to the increased airflow over the wing root from the prop wash.

The recovery system is used during flight test only, for exploring the boundaries of the flight envelope. Once these and potential departure points are defined, operational limits are established, such as AOA limiters, Stick Shaker or Stick Pusher. In the case of spinning aircraft, the procedure is similar, but the testing goal is to identify and document recovery procedures for the spin.

# THE BASIC ELEMENTS OF A SSPRS

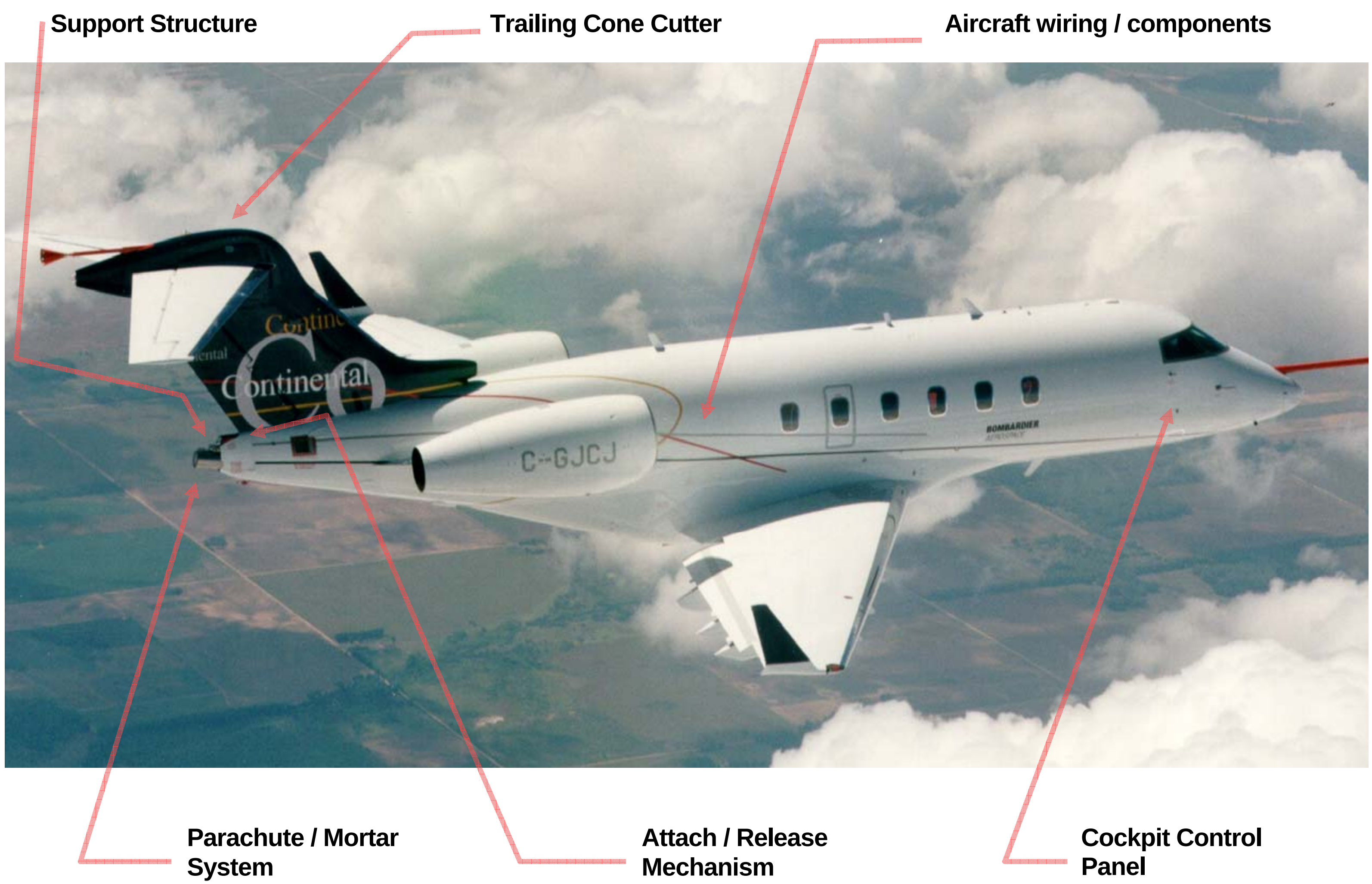
The basic elements of a SSPRS are identified pictorially in Figure 1.
These include:

1) Parachute and Deployment Device
2) Parachute Attach/Release Mechanism (ARM)
3) Pilot Controls or PVI
4) Parachute Attachment Structure
5) System Control Wiring

Also:

i. A cutter to release a trailing static pressure cone – typical in business jet applications
ii. Ground Support Equipment
iii. Used for system installation testing
iv. Periodic Testing
v. Maintenance Diagnostics

Some business jet manufacturers and testers also use a related application. This involves a much smaller parachute for recovery from high-speed events. Where rapid deceleration is required, the events could flutter, or Mach tuck or high-speed loss of control. While this application is not a subject of this paper, the approach, from equipment point of view is rather similar. However never under estimate the complexities that might arise from the addition of ‘just another parachute’.
Figure 1 is a view of the General Components of SSPRS.


Support Structure
Trailing Cone Cutter
Aircraft wiring / components
Parachute / Mortar System
Attach / Release Mechanism
Cockpit Control Panel
Continental
C-GJCJ
BOMBARDIER

*SSPRS*

# OTHER APPROACHES

For fairness sake, we mention other techniques that we have observed in the literature, and on occasion in flight-testing. These include:

1) Rapid mass shift forward
    a. Encountered at least once in Business Jet class aircraft
    b. Provides a forward CG shift to lower AOA
2) Rapid mass shift aft
    a. Encountered at least once in GA class aircraft
    b. Idea is to increase aircraft Moment of Inertia and reduce spin rate
    c. Seen in technical presentation – no information on effectiveness
3) Rockets of aircraft wing tip
    a. Technical paper
    b. Reduce spin rate
    c. No history available regarding success
4) Rockets on aircraft tail
    a. Reduce AOA
    b. Same comments as 3
5) Deployable fabric tail mounted on aft fuselage
    a. Reduce AOA
    b. Same comments and 3 and 4

While we have presented these concepts, we have not encountered them in any recent flight test programs, or technical literature.

# HISTORY OF THE SYSTEM APPROACH (AT IRVIN)

Prior to the creation of the ‘system approach’ to SSPRS at Irvin, our typical approach was that Irvin provided the parachute and deployment mortar only. Our customers would design or procure the balance of the equipment listed above. The result was many different organizations pursuing the exploration and design of how these systems might operate.

Circa 1995 or ’96, the recently formed Bombardier Flight Test Center (BFTC) contacted Irvin. At this point, Irvin was a tradition supplier to Canadair, but not to Lear Jet, which dominated the flight test center (in Wichita). In prior years, Canadair had experienced two SSPRS related incidents, where the system did not function as either designed or required for the specific emergency. The details of these events are not important here, but have been thoroughly reviewed in creating the requirements outline below.

The summary of that meeting was BFTC's suggestion that Irvin provide the entire SSPRS solution instead of the traditional parachute and mortar. The full day meeting centered around lessons learned and system requirements that would eliminate those failures.

# BASIC REQUIREMENTS

The basic requirements, listed below, defined system operation and to some extent hardware. The most compelling requirement was that of running continuous Built in Test (BIT) for the SSPRS during flight. While a group was assembled (including the author), a large portion of the inspiration was given by Mr. Pete Reynolds, at that time, Chief Test Pilot. His was the requirement for BIT, to which the author replied 'That's going to be hard, but it will be darn neat when it is done'.

The basic requirements assembled from that meeting include:

1) Dual Power Source
2) Quad Electrical Circuits – Where Possible
3) Reversible Parachute Lock
4) Fast Acting Additional Parachute Lock
5) Large Deploy Handle
    a. Rotate to Lock Parachute
    b. Must Rotate before Pull
    c. Pull to Deploy Parachute
    d. Deployment Sequence
        i. Fast Acting Lock – Immediate
        ii. Trailing Cone Cutter – Immediate
        iii. Parachute Deployment – 0.5 Second Time Delay
6) Smaller Jettison Handle
    a. Covered By Deploy Handle
    b. Electrical Interlock
7) Simple Lights
    a. Green: Parachute Locked and Passing BIT
    b. White: Parachute Unlocked – BIT in this area passing
    c. Green Light Repeater on Glare Shield – Due installation of Control Panel in Business Jet
8) Built In Test
    a. Power Sources
    b. Ptyro Circuits
    c. Position of Reversible Lock

At this point, the basic system design began, with inputs from many at Irvin, Canadair, and BFTC. The basic objective was to field a system that had learned from the lessons of previous programs, and as many other programs as possible. The general system description and individual components are discussed below, and the basic background of this program.

In addition, many-many lessons have been learned in the past ½ decade. A further section provides some of the details of system/component improvement.

## THE GENERAL SSPRS – COMPONENT DESCRIPTION

The general components of a SSPRS are listed above. Many various component combinations exist and their resulting systems have operated very effectively. For instance, the F-16 has operated for decades in many countries and in over a dozen (probably two dozen) aircraft. Their solution for parachute release is a mechanical release, with a pyrotechnic back up. The Irvin/Bombardier solution avoided the mechanical release, as the parachute continues to provide significant force into the release mechanism. Both organizations have had incident experiences with release under load. This is not to criticize the F-16 approach, but rather to illustrate our process of learning the lessons of as many programs as we could find.

Similarly, in the control panel area, the Irvin/BFTC solution provides a single series of operations, which will produce the required parachute results. Improper sequences (in the final version) result in non-functions, which allow for an additional, correcting input.

## PARACHUTE AND MORTAR (OR OTHER DEPLOYMENT DEVICE)

The preferred parachute for this application is clearly the Conical Ribbon Parachute, or a small variation of that design. This design provides a parachute that highly stable, inherently damage tolerant, and high performance.

Figure 02 provides a view of a ribbon parachute.

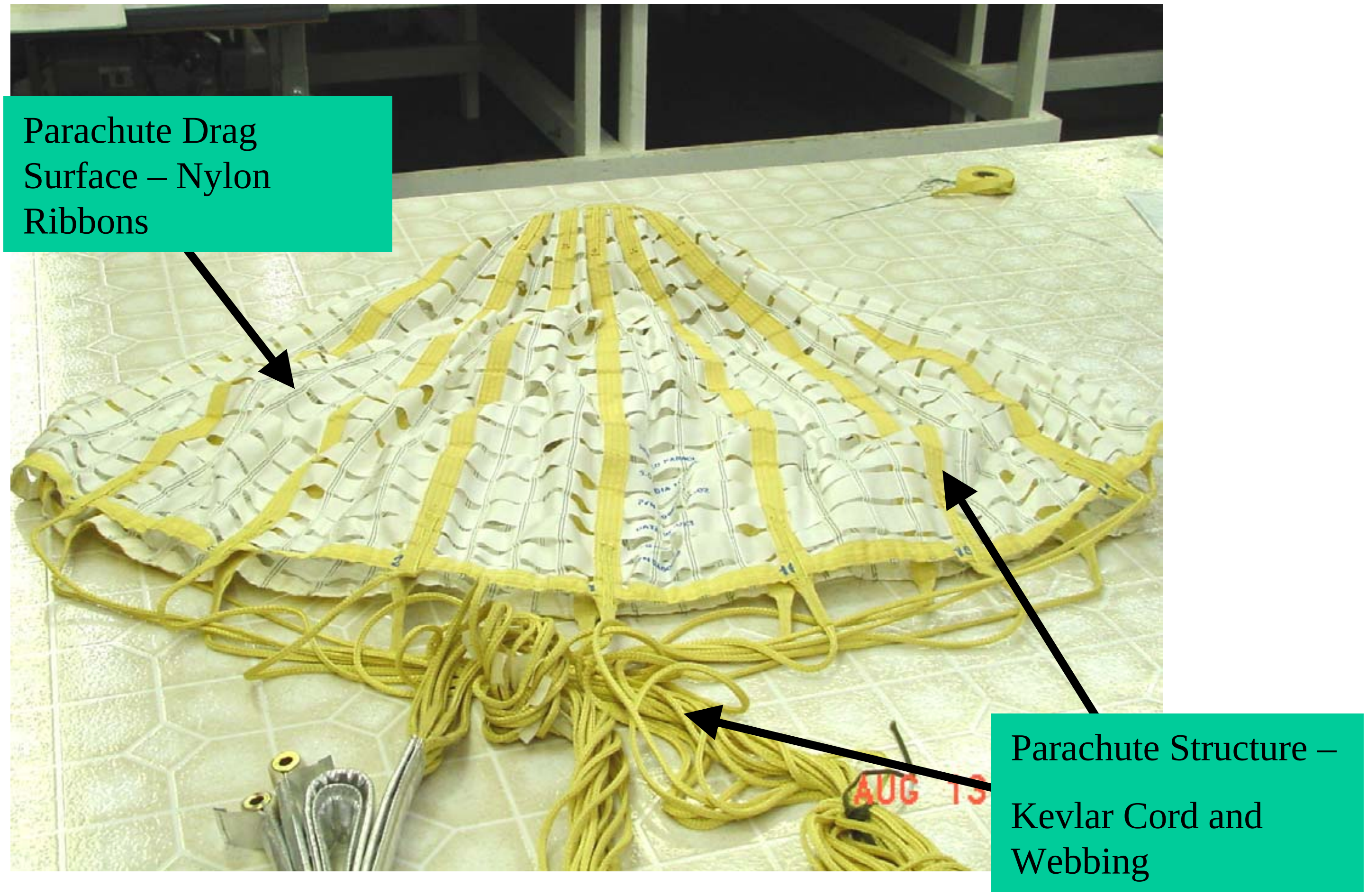



*Figure 2 – Ribbon Parachute during Inspection*

Several parachute deployment mechanisms exist. However, our favorite is deployment using the mortar deployment mechanism. This approach provides the parachute with the highest energy to penetrate the base of the aircrafts low energy flow field. and when compared to tractor, rocket, or other approaches, it is relatively forgiving in cross flow deployments,. Finally, the parachute mortar provides a relatively simple compartment for the parachute installation. Figure 03 provides a view of a couple of aircraft installations. The silver colored parachute mortar is due to a thermal protection system that is bonded to the outside of that mortar. That particular installation is very close to an APU compartment and exhaust. Figure 04 provides a view of the family or parachute mortars available to Irvin. These span a range from small parachutes of a few pounds to very large parachutes with pack weights in excess of 100 lb.

*Figure 3 – Sample Installations of Parachute and Mortar*

*Figure 04 – Family of Parachute Mortars.*

# ATTACH/RELEASE MECHANISM (ARM)

Our Attach/Release Mechanism (ARM) has evolved from a number of programs and technologies. The basic approach includes a structural frame that transfers the parachute load through direct contact with the system installation structure. Mechanical fasteners provide fixity of the device, but do not transfer the parachute related loads.

The parachute riser is installed around a swing arm within the ARM. The swing arm is held in place by a lightweight (roughly 1000 lb) shear pin. If the device is unlocked and parachute forces (such as un-commanded deployment) were to develop in excess of 1000 lb, the parachute is immediately released. This feature has been confirmed in development testing, and performed as planned during an operational event mentioned below.

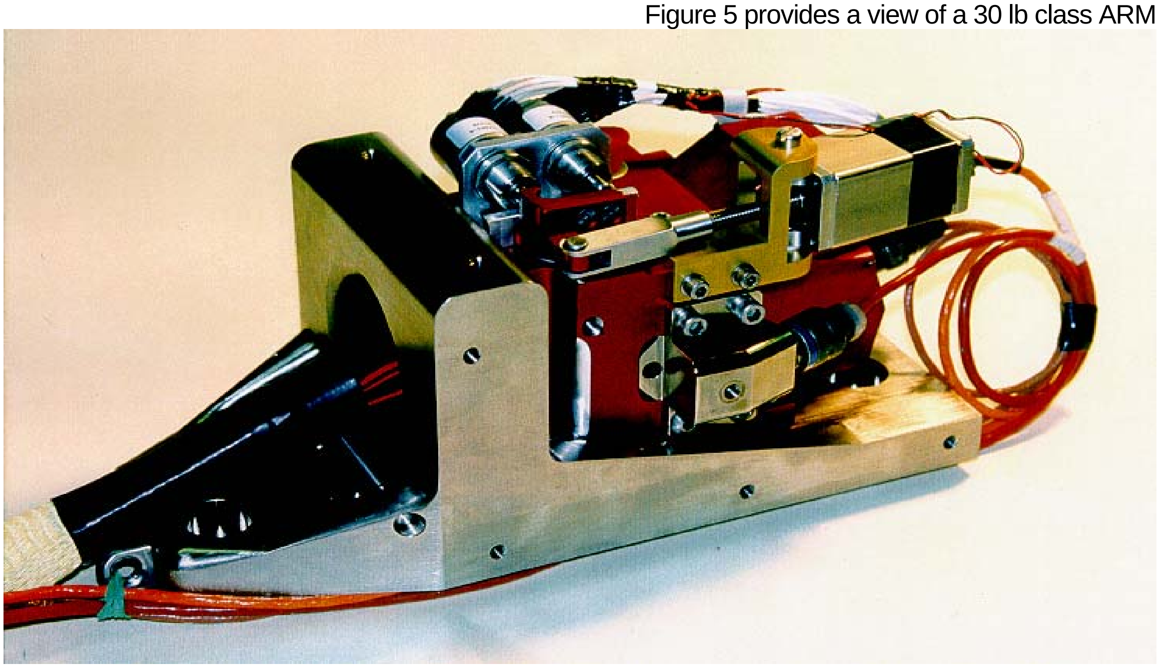
The servomotor and position switches control an interference bar, which locks the swing arm in place. This approach provides a reversible lock, which allows securing the parachute prior to hazardous maneuvers (spin or stall testing) and allows the parachute to remain unlocked during other testing.

A fast acting lock is also provided through a pyrotechnically activated pin. This pin is fired by the control system 0.5 seconds before parachute deployment. The pin embeds in the end of the swing arm, completing the additional locking function.

Parachute release is provided through two blade type cutters, also pyrotechnically activated. Our experience has shown that cutting of fabric elements is far more reliable than the mechanical release, thus the approach described.

Figure 5 provides a view of a 30 lb class ARM, while Figure 6 provides a view of the larger device used on the F-22 Raptor and Hawker Horizon.

Figure 5 provides a view of a 30 lb class ARM



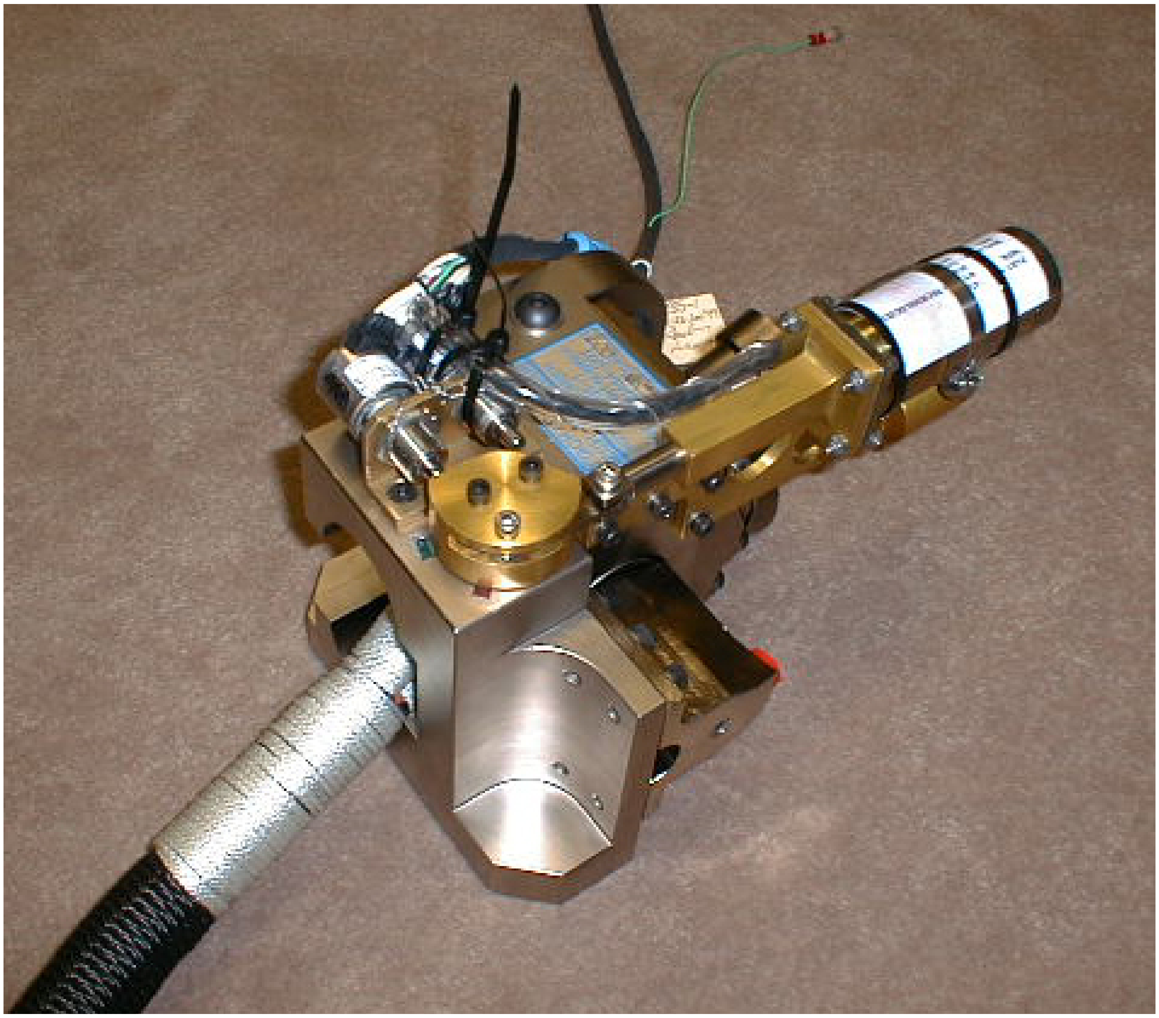


*Figure 6 -larger device used on the F-22 Raptor and Hawker Horizon*

## CONTROL SYSTEM

The control system provides the Pilot Vehicle Interface (PVI), the deployment control and sequence, and Built in Test (BIT) for the entire SSPRS.

## PILOT VEHICLE INTERFACE (PVI)

Our original effort was in the area of Business Class aircraft, where a center console is a primary location for switches and controls. As the location of the control handles is the center console andare likely to be non-line of sight, intuitive and simple actions were required. We settled, rather quickly on the rotate to arm and pull to deploy concept. Developing the mechanical assembly to complete this was the next challenge and The Southern California Switch Manufacturer, Janco was selected.

The Jettison switch was designed to be smaller and further aft, making the deploy switch the likely first contact. A palm aft for deployment and palm facing forward for Jettison is suggested and provides a simple and effective procedure, with minimal direct observation of the handles.

Both switches and the control panel faceplate (which mounts the switches) are designed for significant pull forces, on the order of 100 lb. This recognizes the realities of stress under the conditions of departure from controlled flight. Both switches require approximately 10 lb pull force and have a travel of approximately 1 inch. Both of these provide positive feedback that the activation has occurred.

In the lessons learned, we will present a significant adjustment to the Jettison handle operation, which removed concerns about operational scenarios and potential improper sequences.

In military aircraft, such as fighters and trainers, the T handle configuration, is often problematic and is regularly replaced with push and lever switches. In the Korean T-50, the T Handle configuration was adopted due to schedule constraints and the availability to mount a control panel in a Multi Function Display (MFD) location. Figure 7 presents an example of the final control panel and activation switches. The handle chamfers were required for remove intrusion into the safe ejection envelope, a good example of the challenges with this approach.


*Figure 7 final control panel and activation switches*

.We are currently working on defining the installation for the F-35, which will use yet another mounting geometry due to the cockpit details and large MFD in that aircraft.


*Figure 8 - the control installation for the F-22 Raptor*

# BUILT IN TEST (BIT)

The incorporation of Built in Test (BIT) has been a great success in flight safety. Examples of real world failures are detected and reported are presented in the lessons learned section. Additionally, the BIT test and maintenance-reporting feature has helped to isolate and quickly identify reported errors during installation or maintenance.

An independent microprocessor completes the BIT testing. This circuitry is un-related to the proper execution of the deployment sequence. A complete BIT processor failure will not inhibit proper SSPRS system activation, this is by design and confirmed by testing.

In flight BIT error indications are simple to interpret. With the Spin System armed, a green light indicates that all BIT tests are passing. These tests are repeated at a cycle of approximately 1 second. The absence of the green light indicates a BIT failure and is latched after three concurrent occasions. As simple cycle of the Deploy Handle Arm function (rotate back and forth) will reset the failure if it has cleared. Similar procedures exist for the higher performance aircraft installations. In the larger cockpit installations, a repeater light is available to repeat the BIT (green light) indication in a readily visible location such as the glare shield. In the T-50 installation, these same signals were linked to the Flight Test Data System, to provide system status verification (via telemetry) to the Flight Test Control Room.

The test completed during a normal BIT cycle include the following:

1) Continuity Check of All Ptyro Circuits (10 to 12)
    a. At a Resistance Level
    b. Identifies Opens, Shorts and ‘Dirty Pins’
2) Input Voltage to the Control System
    a. Dual Channel
    b. Customer defined range
3) Position of the ARM
    a. Through redundant position switches on the ARM
4) Operation and Time Delay of the Deployment Sequence Relays
    a. Provides 0.5 second delay between deployment command (handle pull) and parachute deploy
    b. Allows time for Ptyro Lock firing and Trailing Cone Cutter (if installed)

Figure 9 provides an example of the maintenance computer displays, which provide circuit isolation of declared faults. There is also ability, though rarely implemented, to record these same data in-flight and isolate alerts that are only occurring during flight test.

```
▪OPEN CIRCUIT - FSC1A (Deploy 1A)
▪
▪
▪
▪Fail/1  FTCA    FMLA    FSCR1A  FSCR2A  FSC1A   FSC2A   CALIBA
ij's-off
▪        Pass    Pass    Pass    Pass    Fail    Pass    Pass
Pas
▪       2.247   2.163   2.172   2.215   31.85   2.18  4.768   0.0
```

*Figure 9 – Sample Output from the maintenance computer during BIT testing*

## ADDITIONAL EQUIPMENT

There is some level of additional equipment required for the installation of an SSPRS, ranging from wiring and structural modifications to the test aircraft, to adaptive installation equipment such as mounting structure and thermal protection systems. The last two will be presented with examples.

In the case of internal aircraft wiring, we typically work in concert with the aircraft flight test organization to provide the appropriate requirements. In this area, our experiences, such as those presented in the Lessons Learned section, regarding the requirements for twist and shielding are shared both eagerly and with a rather compelling example.

In one case, we have provided the actual aircraft wiring harnesses for installation into the flight test aircraft. This approach has allowed full testing of the complete system, prior to any wiring installation. While not the ‘common’ approach, this does provide an interesting perspective.

# STRUCTURAL ATTACHMENT ELEMENTS

Modification of the airframe structure to absorb the parachute deployment and inflation loads is clearly the realm of the airframe manufacturer and its flight test organization. In this area, we provide support with detailed definition of parachute deployment/inflation loads and equally important, the force application angles during those load events.

In some applications (F-16, T-50) we believe that the internal aircraft structure is largely not changed, and external adaptive structure distributes the loads over a portion of the internal structure. However, in some cases – such as business jets – the internal structure might be highly modified. At this point, the parachute mounting and load carrying structure can be completed as additional equipment provided by Irvin.

Examples include the adaptive structure presented in Figure 10 and Figure 11, which show adaptive structure, which mounts to relatively rigid tail structure for the flight test aircraft. Figure 12 provides a view of external structure for a military installation.

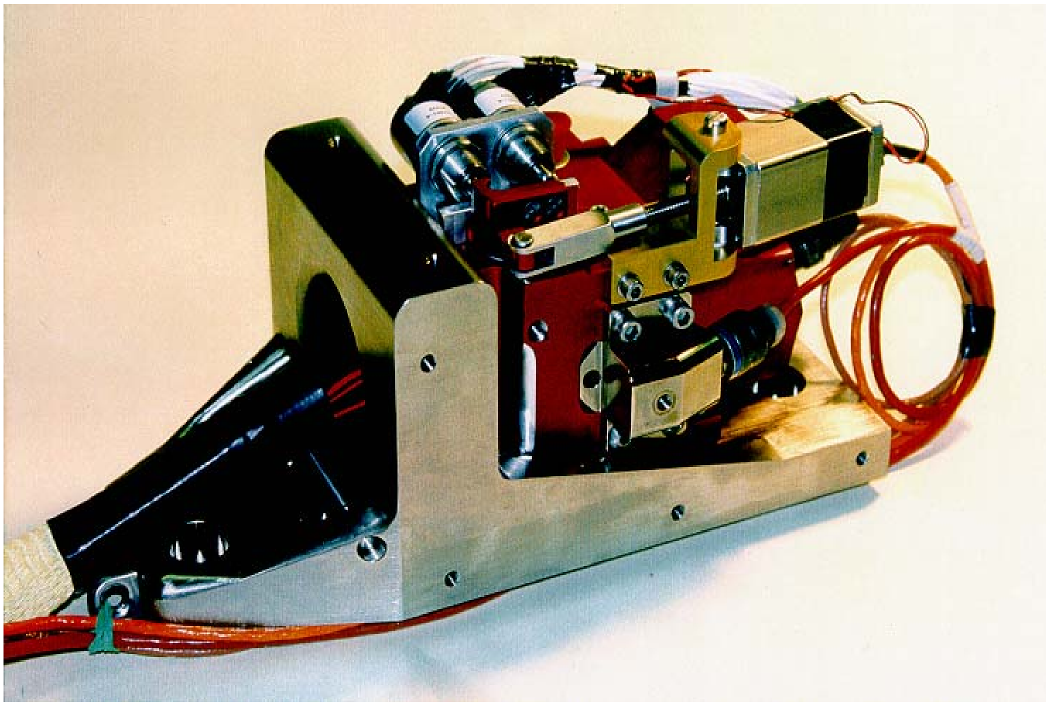


*Figure 10 – Structural Bridge Unit for External Tail Cone Installation*


*Figure 11 – Structural Element for Aft Bulkhead Installation*


*Figure 12 – F-16 Quadrapod for External Installation on a High Performance Aircraft*

## THERMAL AND STRUCTURAL PROTECTION SYSTEMS

Thermal protection, primarily of the Parachute and Mortar installation is often an issue. For high performance aircraft, protection of the parachute container and riser can also be an issue. In addition, in some installations, Structural contact and loading between the parachute attachment riser and the aircraft structure need to be reviewed. Issues in this area include:

## GROUND SUPPORT EQUIPMENT

The development of adequate Ground Support Equipment (GSE) to support both component and complete aircraft testing has progressed, however, it could also be viewed as a work in progress. With two generations of aircraft test sets having been designed and fielded, these are relatively mature; however, we believe that one more generation is required to become a truly mature system.

In general, we have learned that both laboratory and on-aircraft testing can be completed with a single System Breakout Test Box (SBTB). However, there are significant differences in wiring harnesses for this approach, and the laboratory cables should not be neglected. Additionally, some additional test boxes are also often required for component testing. For some customers we have found it convenient, for instance, to have the ability to test an ARM when not installed in the aircraft. Additional test boxes have been designed for these purposes.

In general, our approach to laboratory or on aircraft testing includes two phases:

1) Intentional insertion of simulated failures to assure that the BIT system is operating properly
2) Simulated Operation of the SSPRS to assure that the control system is operating properly
    a. Sufficient current to activate the pyrotechnic device
    b. Proper sequence of all pyrotechnic devices

Our general approach has included a breakout box that allows the failure insertion in item 1). These include a series of open and short circuits, which the BIT system must detect. This portion of the SBTB design has been relatively stable for many years. In the area, of system operation, a great deal of effort has been expended related to simulation of the electrical characteristics of pyrotechnic initiators (squibs). These devices are very rapid acting and relatively current selective. Our typical device will not ignite at 1 amp of current for a duration measured in minutes. This feature allows the safe testing of these devices, as is described in the BIT testing section. This same device is assured to ignite in milliseconds, when a current of 3.5 to 4.0 amps is applied. This close range of performance presents challenges in designing affordable and re-usable simulators.

In our first approach, our breakout box included a resistor and automotive class fuse to simulate the squib. However, wishing to prove that we had generated 4 amps of current through the circuit, we quickly learned that 4 amp fuses would carry that load for minutes, if not hours. This was not consistent with our test approach, and led to difficult discussions with those reviewing our results. We also found ourselves scouring the local Auto Parts and Electronics Stores in search of more fuses!

Our current approach uses circuitry specifically designed to simulate a Ptyro device. While this circuitry is not current aware, it is designed to open quickly following the application of current. Additio
nal circuits and an internal data logger record current traces through the simulated PyroE devices.

This approach allows full monitoring of device current and deployment sequence, during the on aircraft testing. Figure 14 provides an example of current traces and sequence from a typical test procedure. The review of on aircraft testing (we call a Functional Test Procedure), requires that each device achieve a desired current and duration, as well as in the required sequence.

Future GSE development will seek to eliminate maintenance operation errors. The lessons learned section discusses ongoing, accidental deployments. We believe that we have a design concept to reduce of eliminate these, and are working for an opportunity to introduce these updates.

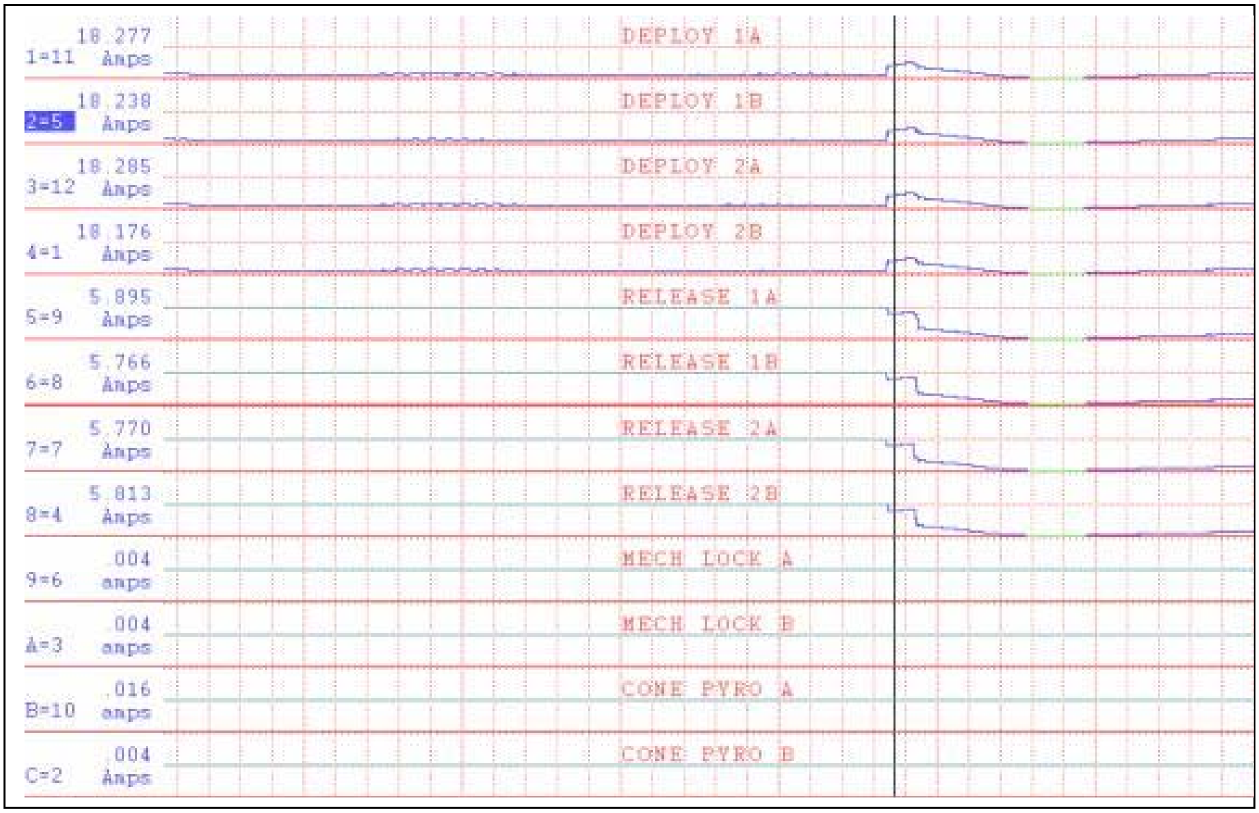



*Figure: 14 – Example of Current Traces from GSE Equipment*

*Figure .15 – Current SBTB GSE device*

# MANUALS AND PROCEDURES

The preparation of clear and complete manuals and procedures is not nearly as simple as the statement appears. However, due to our experience with multiple programs over the past 5-6 years, our manuals have matured to a state of sophistication. Installation, operation, maintenance and de-installation are all described in these manuals.

Surprisingly, de-installation has possibly been the most significant area for improvement. The value of this cannot be understated, as a significant amount of component damage has occurred in the past during the de-installation process.

These procedures have matured to typical airframe manufacturer level documents, with industry standard illustrations, warnings and cautions. Figure 16 provides examples of figures from a typical manual.

**BEFORE CONNECTING THE AIRCRAFT WIRING TO THE MORTAR CARTRIDGE, ESTABLISH A SAFETY ZONE AT THE REAR OF THE AIRCRAFT.**

The switch settings must be as follows:

Key inserted in the Key lock
Key lock in the 'LOCKED' position
Deploy Switch Handle in the 'UNLOCKED' position
Contact Breakers ('BUS A' and 'BUS B') 'pulled'

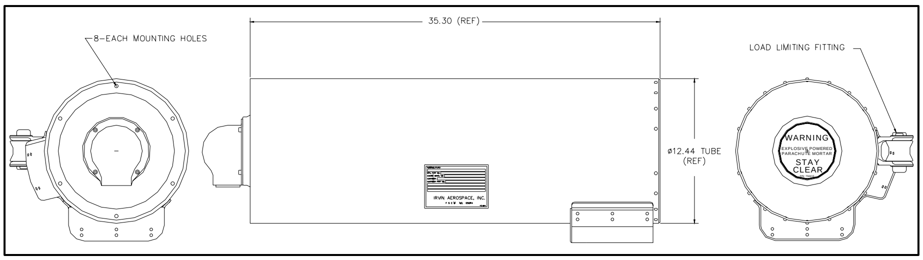



*Figure 16 – Illustrations from a Typical Operating Manual*

# LESSONS LEARNED

This section presents a variety of lessons learned, which can be generally categorized as follows:

1) General Lessons Learned
2) Equipment Specific Issues and Device Improvement
3) Operation Events and Lessons from these
4) Flight Test Planning – Things to Consider Early

# General Lessons Learned

## THE CRITICALITY OF SPIN SYSTEMS TO FLIGHT TEST PROGRAMS

While we have always clearly understood the criticality of such equipment, the tremendous impact of a non-operational SSPRS was probably not fully realized at Irvin until we became more closely integrated with the flight test organizations. In these instances, if the spin system is not available, flight test plans and schedules can be greatly altered or delayed. In the case of the latter, serious dollars begin to flow.

Because of this improved coordination and understanding, response to Aircraft on Ground (AOG) situations has become a portion of the Irvin culture. We can and do provide support in a rapid manner to resolve the situations, and several engineers and technicians are typically available to assure a strong base of support.

Additionally, a greater focus on the importance of spare equipment has evolved. In the past, budget pressures had force us to accept limited or no spare components. However, history has shown that when issues arise with a lack of spares, the cost can greatly exceed the original equipment price. While we continue to work with customers to fashion programs that meet both their technical and budget needs, we do share this experience and our serious concerns regarding spares.

Some unique solutions in this area include at least one customer where Irvin retains a spare unit. This allows Irvin a laboratory unit to support trouble shooting from several time zones away, and supports a rapid response in the case of a complete component failure.

## THE VALUE OF THE SYSTEM PROVIDER AND THE ABILITY TO LEARN THE LESSONS

Perhaps the biggest lesson learned is the value of the system approach to SSPRS. Having established this approach – with strong prompting as described above – we are now in a unique position to continue to enhance the performance and safety of such systems. We have learned what works and what doesn't and have both incorporated that into current components, but can equally articulate those lessons to customers. This hopefully allows us to avoid (at least some of the) mistakes of the past.

Several of the valuable lessons learned are presented below in the descriptions of required upgrades to the individual components.

## ARM CHANGES AND ENHANCEMENTS

## SERVO MOTOR

The original servo-motor, while successful in the first design became far too difficult to procure. While component price was high, but acceptable, the motor delivery was unacceptable, with lead times of 9-12 months. This schedule delay is unworkable in almost every Spin System program.

In response Irvin identified a commercial motor, which while available and meeting performance specifications, could not meet altitude performance in its delivered state. We further defined a cleaning and lubrication process that allows the device to perform at high altitudes and related temperatures.

This system has been qualified for F-22 and also flies on T-50 and many commercial jet applications.

### LOCK POSITION WITNESS SWITCHES

The original position switch design assumed that both arms of a two-arm plunger switch would move simultaneously. Late in the Global Express program, we began to experience in-flight nuisance trips. Monitoring during flight test indicated the ARM was the source of the problem. A visit was arranged for an Irvin engineer, and as luck would have it, the issue was isolated on the aircraft, on the ramp following a flight.

Once the issue was understood, a simple software update was created. This has now been incorporated into all Irvin provided SSPRS control systems.

### FASTENERS

Fasteners is the ARM are largely specified as Stainless Steel, due to the rather severe flight and ramp environments, particularly at some of the commercial aircraft flight-test facilities. Humidity, rain and altitude cycles are all potential issues.

To our recent surprise, we have experienced a level of corrosion on these fasteners. Reviews with the manufacture have identified that they cannot certify the quality of the items. Thus, we have switched to military specification class items only. A notification and replacement program is currently in work.

## Control Panel Changes

### JETTISON SWITCH OPERATION

Our original Jettison Switch design (on the Pull Handle Class Systems) included a design that remained extended following activation of the switch. This, as the Jettison Switch followed the design of the more complicated Deploy Switch, which need to remain extended following activation.

During initial fielding of the system, we realized that this approach created an if not critical, at least avoidable flaw. In the case of improper sequence activation – that is pull the Jettison, wait, no result, pull Deploy handle – is that sequence were followed without first stowing the Jettison Handle, the parachute would both be deployed and released from the aircraft nearly simultaneously.

It was concluded that this is not a desired result.

A system upgrade program was undertaken that replaces the Jettison handle with a spring return design. In this case, an improper sequence – Pull Jettison – will have no result, as the Jettison handle is electrically isolated until the Deploy Handle pull occurs. The spring return to the neutral position assures that improper activation will not result in any sequence errors when a proper activation sequence is performed immediately following.

This improvement has been incorporated into all control systems that Irvin provides, both past and new deliveries.

## BIT ENUNCIATION ALGORITHM

As described above, the control panel BIT implementation runs on approximately a 1 Hz cycle. Our original implementation assumed that a single frame error was worth reporting, and as a result, would enunciate the error to the pilot.

Aircraft installation and flight-testing experience indicated that this approach was far too sensitive for practical results. The result was too frequent BIT nuisance trips and pilot reset requirements, and related irritation. The primary cause of these trips was isolated to minor ground plane potential changes, and we expect that these are rather typical of all aircraft.

The design solution was to require a fault to occur of three computational frames (approximately 3 seconds) before pilot enunciation. This approach has nearly eliminated nuisance related events. The maintenance BIT results, when monitored continue to provide the individual computational frame results, thus allowing for significant diagnostic ability.

## INTERNAL SWITCH LOGIC

During one review of the internal control sequence in the original control panel, it was concluded that another potential fault existed. The original design focused on assured deployment and as result did not consider the consequences of a single deployment switch failure, (there are four in the Deployment Switch Assembly).

In the case of a single switch arm failing to the closed position – a rather unlikely event – we identified some cases, where the parachute could be both locked to the aircraft (through the ARM Ptyro Lock) and then deployed. While this failure remains unlikely (and has not been experienced), we agreed that a modification was in order.

The result was a circuit modification that requires two closed switches (from the available four) to complete parachute deployment. We believe that this is an effective compromise to balance the assured deployment concern of our original design, versus the issues identified above.

## AIRCRAFT WIRING REQUIREMENTS

During our earliest installations, perhaps our biggest lesson learned is in the aircraft wiring area. Largely due to the large tolerance of the pyrotechnical devices, which can receive 1 amp of current (or higher) without activation, the need for wire pair shielding and twisting was not full appreciated,

However, during one flight operation, in the vicinity of electrical storms, an un-commanded deployment occurred. Prior to this event, the author often referred to this class event as ‘pilot superstition’. However, faced with a real world event, we (Irvin) were forced to respond.

The good news is that the SSPRS system performed exactly as designed. As the parachute was not armed at the moment, the parachute departed the aircraft with no effect. Having spoken to the pilot, we can report tha t his only clue was an impulse that felt much like an engine compressor stall. Only upon return to the aircraft hanger, was the missing parachute discovered.

An Irvin team was dispatched to the flight test facility, and was largely and AOG class response. The ensuing analysis indicated the need – now from hard experience – for further shielding of the wire pairs related to the pyrotechnic devices. For reference, this aircraft was flying near storm fronts, searching for particular flight test environments – a significant lesson for commercial class aircraft.

As a result of this experience, we now recommend Twisted Shielded Pair (TSP) for all wiring installations for the pyrotechnic actuators. Additional enhancements include location of the ground termination points, and related adjustments to the overall system. These adjustments have been made for all current operational aircraft, and we recommend them in current programs.

## SUPPORTING EQUIPMENT

Additional lessons learned and process improvements have been discovered during this period. In the area of Supporting Equipment, these include additional safety equipment such as load limit fittings, ground support equipment for installation checkout, and a tracking system to alert customers of required parachute inspection and re-packing requirements.

## PARACHUTE RE-PACKING AND MONITORING

We currently require a three (3) year inspection and re-pack cycle on all SSPRS parachutes. This is due to the extreme UV and thermal conditions as well as moisture pumping through altitude cycles that is typical of most system installations. In general, our customers are proactive with the scheduling of this important inspection service.

However, the realities of flight test programs, particularly for mature aircraft, can create the occasion surprise. This often requires either the customer or Irvin to complete 'schedule magic' to fulfill the inspection requirement and support the flight test program.

To provide additional planning support to our customers, we have recently implemented a tracking database for these class systems. This database will allow Irvin to notify our various customers of upcoming inspection requirements, well in advance to the due date. We believe that this approach will allow our customers to more routinely schedule such inspections, for equipment that is still in use or planned for future use.

## LOAD LIMIT FITTING

Load Limit Fittings (LLF) is a feature that several of our customers require. These are fittings in the parachute riser that are designed to release the Spin parachute at a prescribed total force. Several designs for these devices exist, and a testing process has been defined that assures a very tight tolerance on the parachute release force.

In one particular design, the release mechanism is designed for release (metal failure) in a tensile loading environment. After fielding a few of these devices, additional technical reviews indicated that a potential bending load on the tensile member, might exist during parachute deployment. While this load case was very conservative, we could not eliminate it from a technical point of view. Irvin therefore, issued notices to all involved customers, and completed a design solution that eliminated the bending load during deployment.

We have since retrofitted all identified devices, at no cost to our customers.

## SYSTEM BREAKOUT TEST BOX DESIGN

Our test equipment for on aircraft installation and maintenance testing, often referred to as a Functional Test Procedure (FTP), has evolved greatly over the past few years. Original approaches included a series of resistors and common Buss fuses that would simulate the Ptyro devices. These are used to complete simulated firing of the SSPRS, to confirm required current levels for assured Ptyro activation. Additional switches allowed insertion of simulated failures, allowing exercise of the BIT system.

Much experience has indicated that the fuse approach, while a very common one, is far from optimal. More recently, we have designed and fielded integrated circuits that more closely simulate pryo devices. An integrated data collection system, in the basic GSE box, provides monitoring of current through all pyro circuits. This approach allows monitoring of all current levels as well as the sequence of operation, thus confirming the entire system sequence. We continue to test simulated failures to assure proper BIT operation.

Future upgrades may include a fail safe system to prevent parachute deployment during system testing. These errant deployments occur only with mistakes in system testing, but can delay a test program. Additionally, we are contemplating a more automated series of testing, which would speed the BIT failure insertion portion of the test regimen.

## OPERATIONAL INCIDENTS

It is not our desire or intent to document operational incidents, as these are largely the purview of our customers, who remain relatively sensitive to the details of such events. However, we would like to provide some indication of the success of these systems with regard to their intended purpose, and when properly designed, the success rate is significant.

Military aircraft, especially the F-16, rely on these systems to a very large degree. The C-17, only recently quit flying its Stall parachute. The F-22 (we believe) continues to fly with this system, and the T-50 has just begin operations, but intends to continue the use of the SSPRS system into flights of the A-50 variant and store loadings.

The F-16, however, is clearly a case study. The USAF continues to fly with the SSPRS system on a routine basis, this we understand is from the continued installation of new, external stores to the aircraft. Additionally, the sale of additional airframes to other countries creates additional requirements for F-16 SSPRS. There may be as many as 15 operational systems throughout the world.
We are also, at least anecdotally aware, of one 'non-recovery' during the F-14 program, but have not had time to fully research this report. In the verbal report, the parachute was deployed successfully, with no resulting recovery. The pilot then ejected, and later watched, as the aircraft appeared to fly without the spin. Again, this is anecdotal information. However, this data is somewhat consistent with parachute sizing data presented in Reference 1, both of which would suggest that the parachute for that aircraft was somewhat undersized. Irvin now takes a partnership role with our customers in reviewing and selecting design criteria for a SSPRS.

In the case of business and commercial class aircraft, the we are aware of several recoveries with both stall and high-speed class parachute systems. However, limited we do not have, and cannot report on these details.

Since devising the 'System Approach' to these systems, we can report that one successful recovery has occurred in a large business jet class aircraft. Having reviewed the data, Yoke position had limited to no effect for a period of many seconds. After parachute deployment, recovery was completed in 5-8 seconds.

## MAINTENANCE INCIDENTS

Maintenance incidents are generally classified into two areas, the first is the early and quick detection of system faults and here we will provide some examples. The second is the rare but not rare enough, unintentional operation (deployment) of the parachute system.

## FAULTS DETECTED AND ISOLATED

A series of BIT faults have been detected during installation in function (pre-flight) testing. These include;

1) Bad Power and Open Circuit Breakers
    a. Seemingly obvious, with most cases being incorrect aircraft of test setup. However, some instances of supply current out of range have occurred, leading to further system testing and acceptance of larger acceptable voltage ranges.
2) Poor ground connections
    a. In the most interesting example of this kind of failuree case, ground connectors were loosening from flight vibration loads. In this case, a minimal number of ground locations (2) were involved in the entire SSPRS. This could have lead to operational incidents with the SSPRS, but were corrected quickly due to the BIT reporting system.
3) Connectors not properly connected
    a. Another simple item and easily fixed when preparing the aircraft for flight or functional test. However, this simple reporting leads to elimination of this error and improved flight test efficiency.
4) Bent connector pins
    a. Several cases of poor connection or bent pins have occurred.
    b. In the most severe case, the author bent the pins during connector installation, while hurrying to complete system checkout. The realization of the mistake occurred half way between the aircraft cockpit – where the BIT information was displayed – and the aircraft tail – where the connector was. The result was a rush (counter-to-counter), weekend shipment of a new pyro device.
    c. The above incedent has lead to a greater appreciation of spare requirements, as we are certain that counter-to-counter shipment of explosives, no matter how small, is not an option in the current times.

## OCCASIONAL HANGER INCIDENT

Despite our significant efforts, un-intended deployments of the parachute and possible firing of the lower energy cutters, continues to occur on an infrequent, but more than desired basis. This is largely because our rigorous testing techniques, which include both, BIT testing, which tests all aircraft wiring, including the Pyro 0devices. The simulated firing test isolates the aircraft tail and the pyro devices, and exercises the entire system including the cockpit controls. We believe that both of these tests are desired and required for a highly available and reliable system.

However, this approach can lead to confusion between test configurations and has on one occasion resulted in a 'hangar firing' of the parachute. Fortunately, additional safety procedures have resulted in no injuries and minimal damage to other aircraft or structures.

We maintain highly developed procedures and train customer personnel during installation. However, during the evolution of a 2-8 year program, that training (and the reading of procedures) can become hand to hand training. No incidents have occurred with Irvin personnel on-site.

We are currently reviewing designs for a new test set, which would provide another level of foolproof control. Essentially this design would isolate the high-energy parachute deployment circuits at the detection of any incorrect system operation (in the test mode). This approach would not eliminate all operation of SSPRS (and resulting refurbishment requirements), but would prevent any danger to personnel, other aircraft, or facilities.

## FLIGHT TEST PLANNING

Lessons learned for flight test planning have arisen both in the period discussed, and on past programs. Two of these lessons are however, so basic, that we take the chance to point these out at every opportunity. This as failure to observe these lessons can have grave effects on SSPRS system development, or the overall flight test program.

## IN FLIGHT DEPLOYMENTS

When developing a SSPRS and related flight test program, an operation test of the Parachute system, particularly new designs, is mandatory. However, we leave the operational environment to the flight test planners. Static firing, on the aircraft, high-speed taxi test deployment and in-flight deployment are all options. Irvin requires one of these class tests to support new installations, however, the decision to pursue in-flight deployment is left to the airframe manufacturer, as there is some risk to the aircraft with an in-flight deployment.

However, having decided to include an include an in-flight deployment; this test must be included in all design load calculations for the parachute and related structure. Depending on overall system envelope, the flight test parachute loads may be higher than the parachute loads in the recovery envelope. This due to the higher airspeeds related to level flight as compared to locked in stall, or spin modes.

Figure 17 presents the C-17 approach to this problem. During the in-flight deployment, the Stall Parachute was permanently reefed, to reduce its drag area and related loads. This allowed a successful operational demonstration at higher, level flight airspeed, without exceeding structural limits. It should be noted that the incorporation of reefing is common, but non-trivial, and should be planned throughout the system development as well.

*Figure: 17 – C-17 during In-Flight Deployment – Parachute is Reefed to Control Flight Loads*

## TAXI TEST DEPLOYMENT

In the case of taxi test deployments, loads are typically not an issue, as airspeeds are generally lower than the departure envelope. Here, however, two considerations for the test airfield should be remembered.

The first is balanced field length for the test. The test planning should include the runway distances for the planned test, as well as a similar calculation for a failure of parachute deployment. In this case, the field length calculation should include:

1) Acceleration to the test airspeed
2) Generous time in the cockpit to complete the deployment procedure, typically;
    a. Throttles to idle
    b. Deploy Parachute
3) Time to realize that the parachute has not deployed
4) Safe braking to full stop.

Additionally considerations for runway Foreign Object Damage (FOD) should be considered during these tests. Several items are expelled with the deployed parachute, in a mortar-deployed system, these include the mortar cover, mortar sabot, and parachute deployment bag. These are all rather large and easy to identify. However, multiple rivets that are sheered in half during mortar deployment retain the mortar cover. While we have had reasonable success in retaining the rivets with metallic tape, this detail also requires some planning and depends on the particular mortar design. In some cases a post-test FOD walk, inspection or related cleaning mat also be required.

## OPERATIONAL EXAMPLES

The presentation of this paper includes several videos of operational flight tests of these systems including planned deployments and an actual recovery of an F-5E during early Spin Testing. These videos are relatively instructive, but clearly cannot be presented in this format. However, to provide some level of completeness, we include the collage presented in Figure 17. These are clearly taken from the F-22 Raptor Taxi Test Deployment, and have been provided courtesy of the US Air Force.


*Figure 17 – Parachute Taxi Deployment Test – F-22 Raptor*

# CONCLUSIONS

- During the past 8 or 9 years, we believe that the introduction of a system approach to Spin/Stall Parachute Recovery Systems has created a significant change in the way the industry approaches these highly specialized and important flight test safety systems.

- During the development, we learned from some of the flight test incidents of the past. We continue to collect this data, with some additional experiences of the F-16 program being a recent addition. However, most significantly, we have somewhat standardized the approach to these systems. While no one design or product fits all customers, a family of products is beginning to fulfill the needs of the majority. In addition, this family approach allows the continual incorporation of past lessons, as product enhancements. When these lessons are at a level of affecting safe operation, the lessons are flowed back into operational systems as well.

- We believe that this approach to SSPRS has significantly enhanced flight test safety for our customers and the existing community at large.

- Challenges remain, particularly with smaller organizations (and aircraft), where budgets are often inconsistent with the sophisticated equipment presented here. We remain open to discussions on how to achieve such a goal, and suggest that a flight test center that would support these customers, and provide the related equipment on a time use basis, rather than purchase, might be one solution.