Laser Initiated Ordnance Technology Workshop

Pyrotechnic Devices
Flight Failure History, Reliability Issues, and Current Needs

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Issues of Concern for the Pyre-devices Relative to the Unmanned Spacecraft

- Reliability of the devices
- Reliability of the pyre-devices performance in the spacecraft
- Effects of pyro firings on the spacecraft performance
- Environmental effects on the pyro devices
- Device complexity
- Product assurance practices
- Test and performance requirements

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Pyrotechnic Devices

Devices with Electrically Initiated Ordnance

Favorable Aspects:

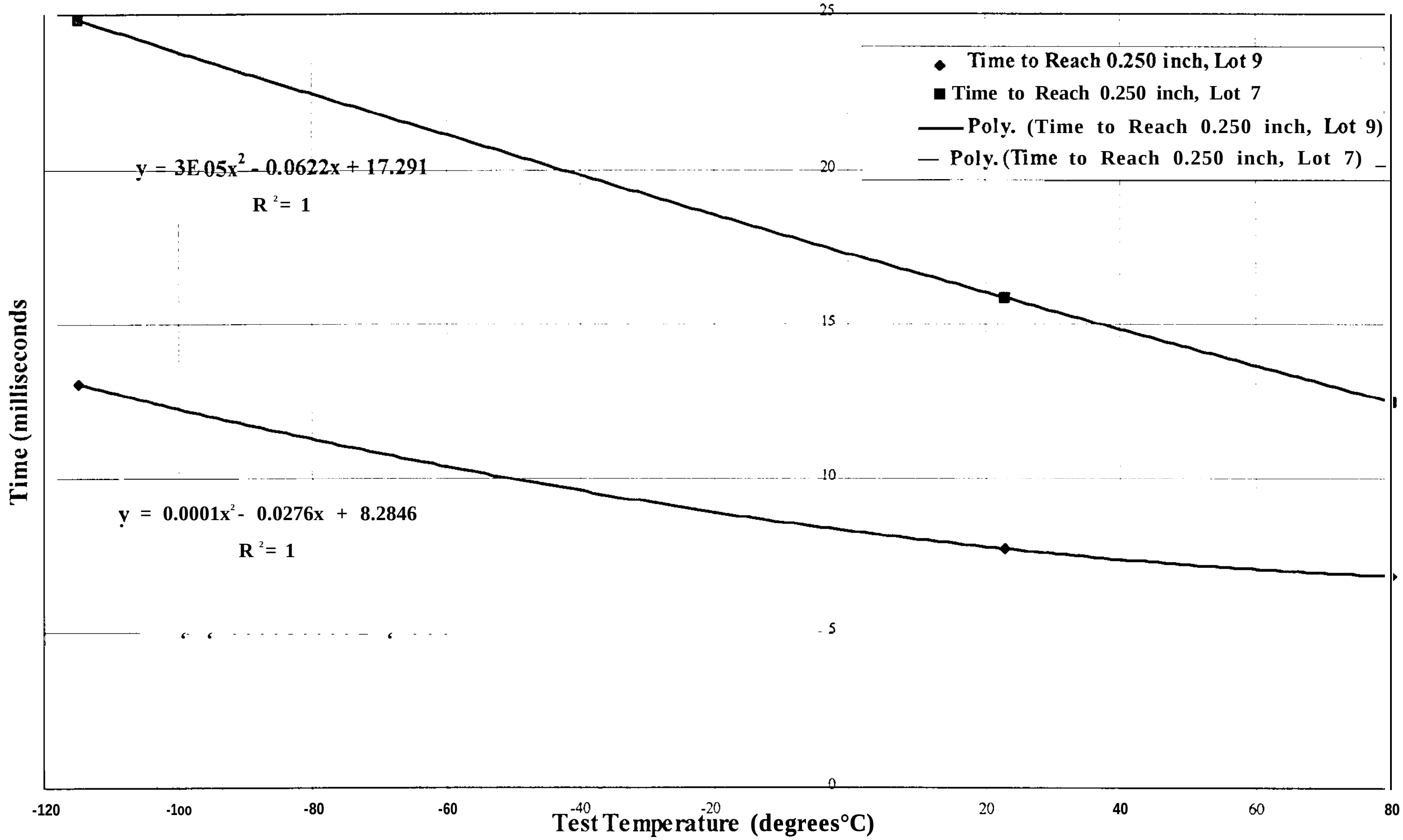
- Reliability of the individual devices is proven throughout the years.
- Large number of the devices flight qualified
- Simplicity of the devices
- Small cost of the electrical initiators and the devices.

Concerns:

- Firing of the devices seems to cause a sneak path between the device high and the spacecraft chassis.
- Spacecraft failures, causing or not causing the vehicle loss, attributed to or associated with the firing of the electrically initiated pyro devices.
- Possible limited shelf life.

Testing of bellows of different production date showed that the bellows that were kept in storage demonstrate longer times for full extension

Bellows Firing Test. Time to Reach 0.250 Inch



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Pyrotechnic Devices

Devices with Electrically Initiated Ordnance. Test and Flight Anomalies.

Magellan:

100 devices fired, one problem encountered:

4 K memory lost as a result of the assumed current spike.

Experiment conducted after the Magellan event, 18 pyro devices fired, one spike encountered.

Probability of spike occurrence calculated from the Magellan test:

Point estimate, p = 0.056
90% one sided upper confidence limit: p“ = 0.13

Viking:

After firing of the pyre-device developed an attitude control problem.

Devices with Electrically Initiated Ordnance. Test and Flight Anomalies, cont.

Mars Observer:

The spacecraft lost after the pyre-event.

Experiment conducted after the loss of MO:

12 pyro devices fired. 12 times out of 12 firings, the current was 12 A: 7 A was used for the squib firing, the remaining 5 A had flown through the circuit.

Experiments conducted for Galileo and Magellan showed a current of up to 27A (current limiting is 27 A)

Galileo:

No pyro related anomalies, 220 pyro devices fired to date. Possible reason for no anomalies: grounding is different than on the other S/C.

Possible cause of anomalies: Plasma shorting the high side of the devices to the chassis.

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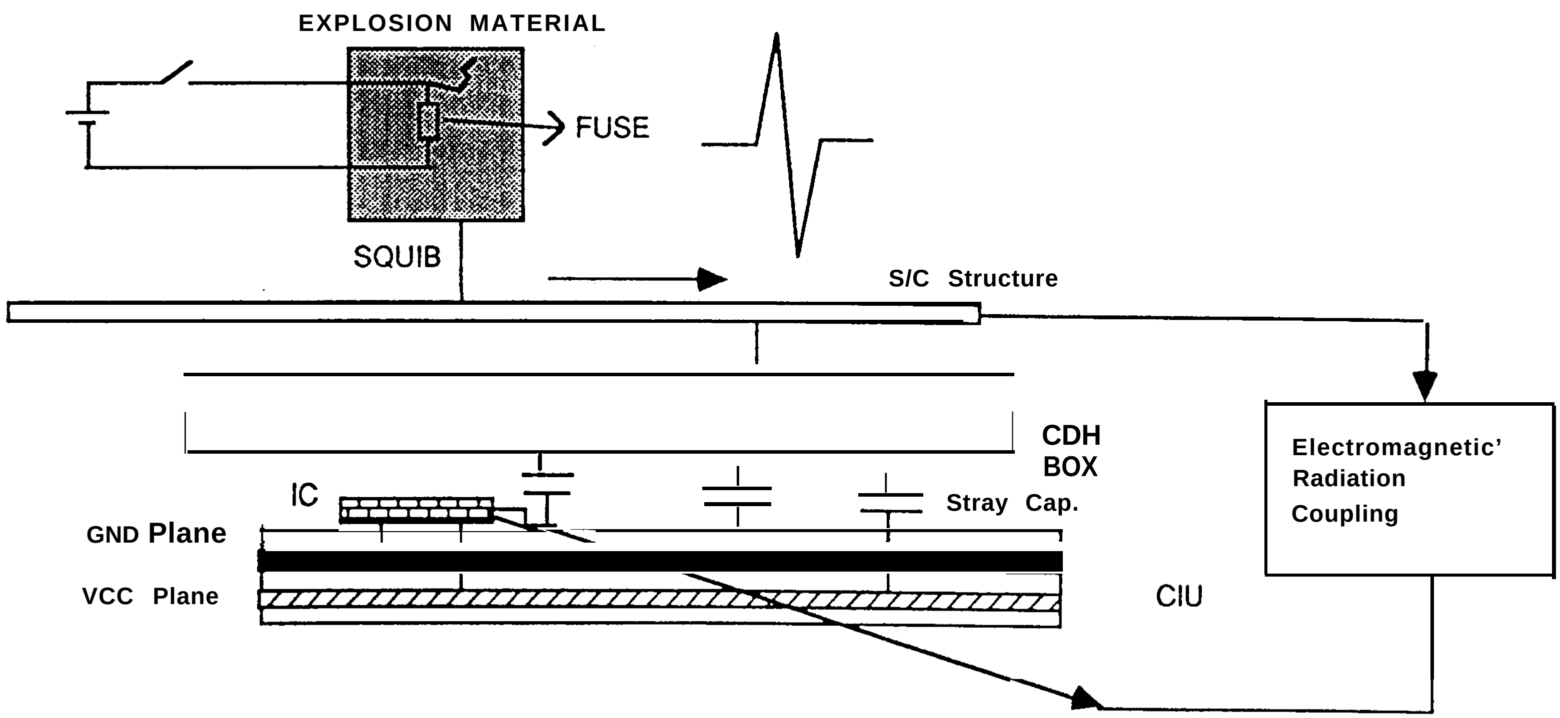
What can cause both CONTROLl and CONTROL2 stuck LO?

MOI was not the first anomaly occurred to **JPL** Spacecraft **after** the **NSI's were fired. One of the failure in MGN after insertion was the loss of 2K Memory. The TCC244 RAM was zapped by the Electrical Spike the after the** pyro fired to release the Solid **Rocket Motor (SRM).**

With the Magellan (MGN) in mine, i.e., the MGN Déjà vous, the following model is speculated: the electrical pyo spike zapped one component to **cause two signals CONTROL1 and CONTROL2 stuck LO.**

Where-is the spike come from? and How does it get to the IC's?



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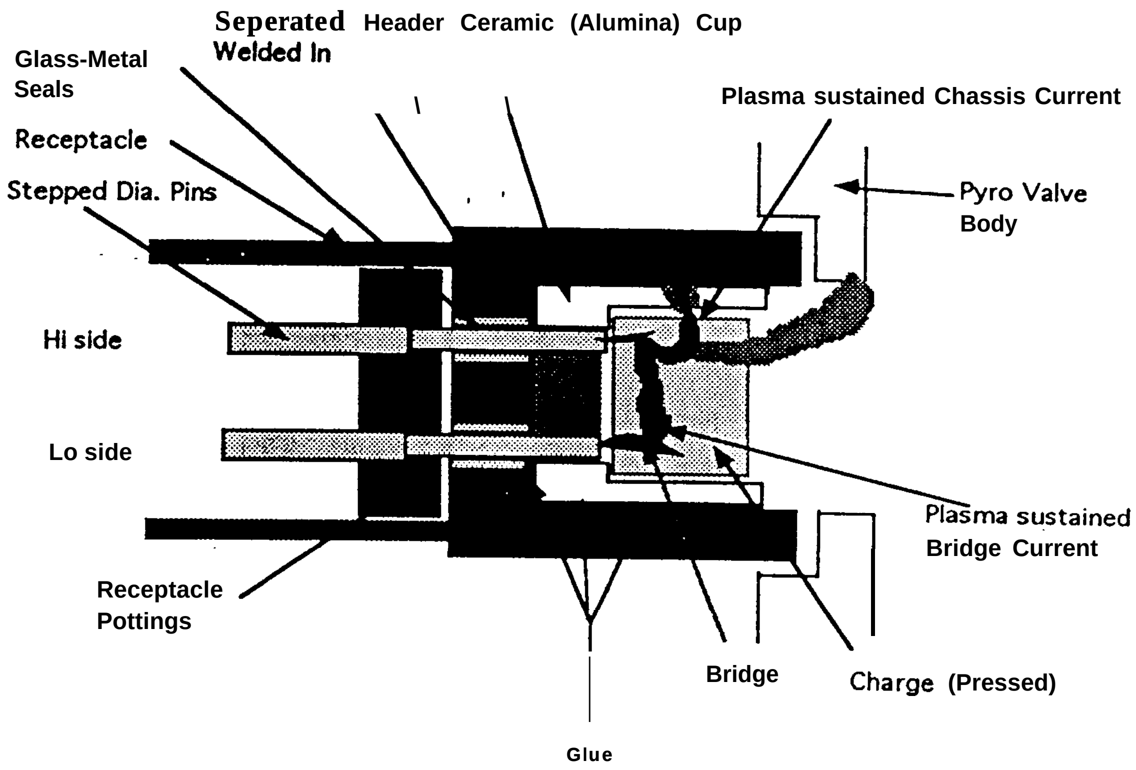
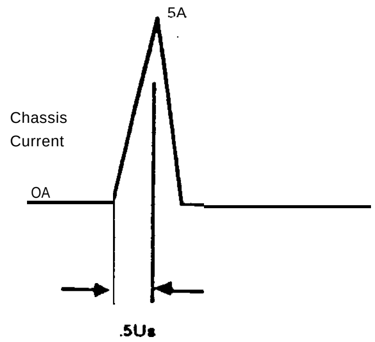
The ignition in the squib is created by blowing the fuse. Per JPL Experiments during the explosion process in the EED chamber, plasma is generated. This conducts current to the chassis.





A model of current flow inside a NSI: After the closure cup is poped out.

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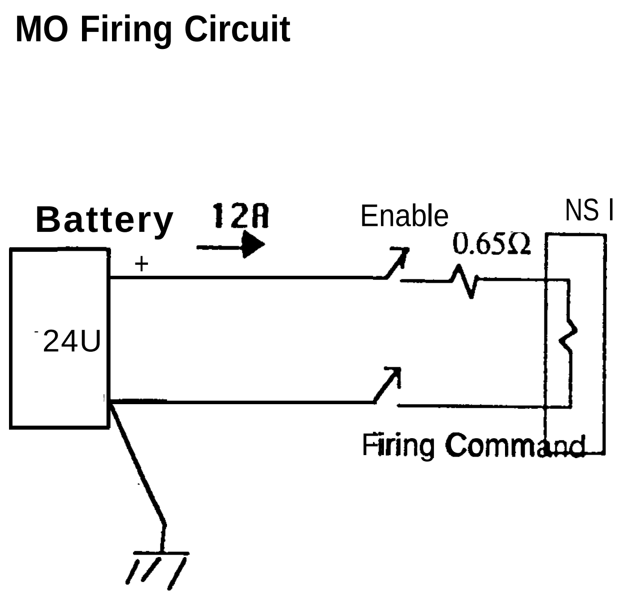

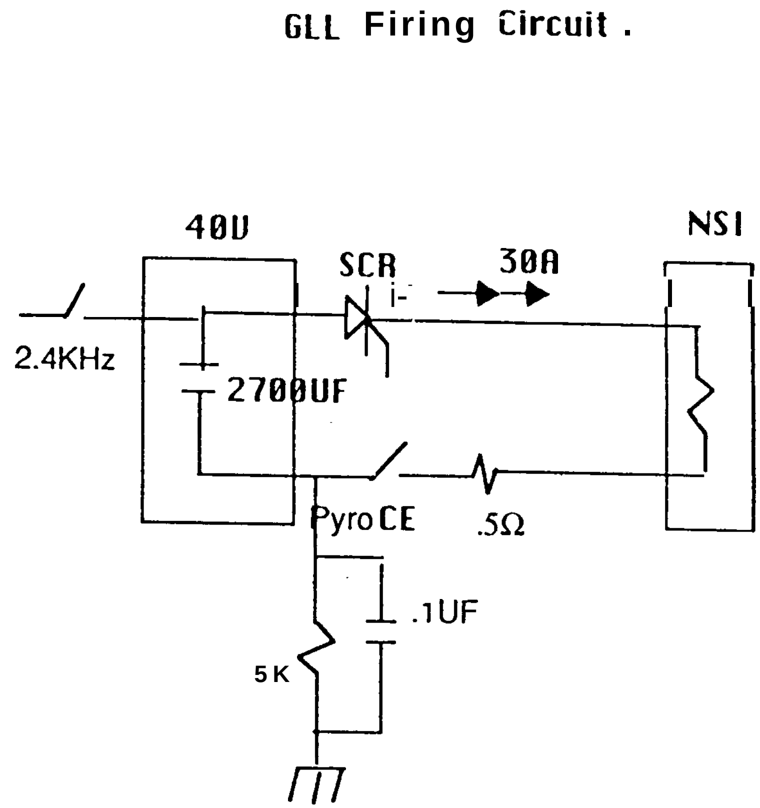

Firing Circuits: GLL vs. MO

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Approach

From pevious studies at JPL:

During the firing of the NSI, there are currents:

Hi side to LO side

Hi side to chassis and shield

These currents caused by the Plasma in the NSI chamber.

The main current of interest is:

The Hi side to Chassis current.

The value of this current is 5 A

The energy of the current flowing in the chassis can couple to the victim loop in the following mechanism:

Loop to Loop magnetic coupling

High Voltage spike caused by inductive kick

Resonance of long ground cable

From previous studies, the Loop to Loop magnetic coupling is the most severe mechanism. It will be used in this analysis.

The others cause negligible effects.

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MO: Pyro *Induced Chassis current Model*

Pyro valve Firing Command:

One of the critical event in the MOI is the mixing fuel between the NOT tank and MMH tank. To perform this task, SCP sent commands through CIU, SCU, and PRA. The power connected directly from the BATTERY, 24V, to the EED via the relay of PRA.

EED Event;

The current flowing through the bridge wire in the EED generates heat to the charge (explosion material) in the EED chamber creating explosion. This in turn creates pressure in the Booster to push the ram down to open the valve.

Short Caused by Plasma:

By normal expectation, this will be the finishing step of an pyro event. But from the study in ref. (3), when the charge in the EED is ignited, plasma formed by ionization of the charge material creates a short path between the high side of the bridge (+24V) to the case of the EED.

Tubing Current;

The pyro valve support is a plastic strap which cannot directly conduct the current from the high side of the bridge to the chassis. It has to go through the tubing. (Figure 4)

The current continue flowing through the tank and spreading in the chassis of the S/C. Figure 4 shows the normal current paths and the pyro short induced current path.

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MO: The chassis current by Pyro Short: MO Firing

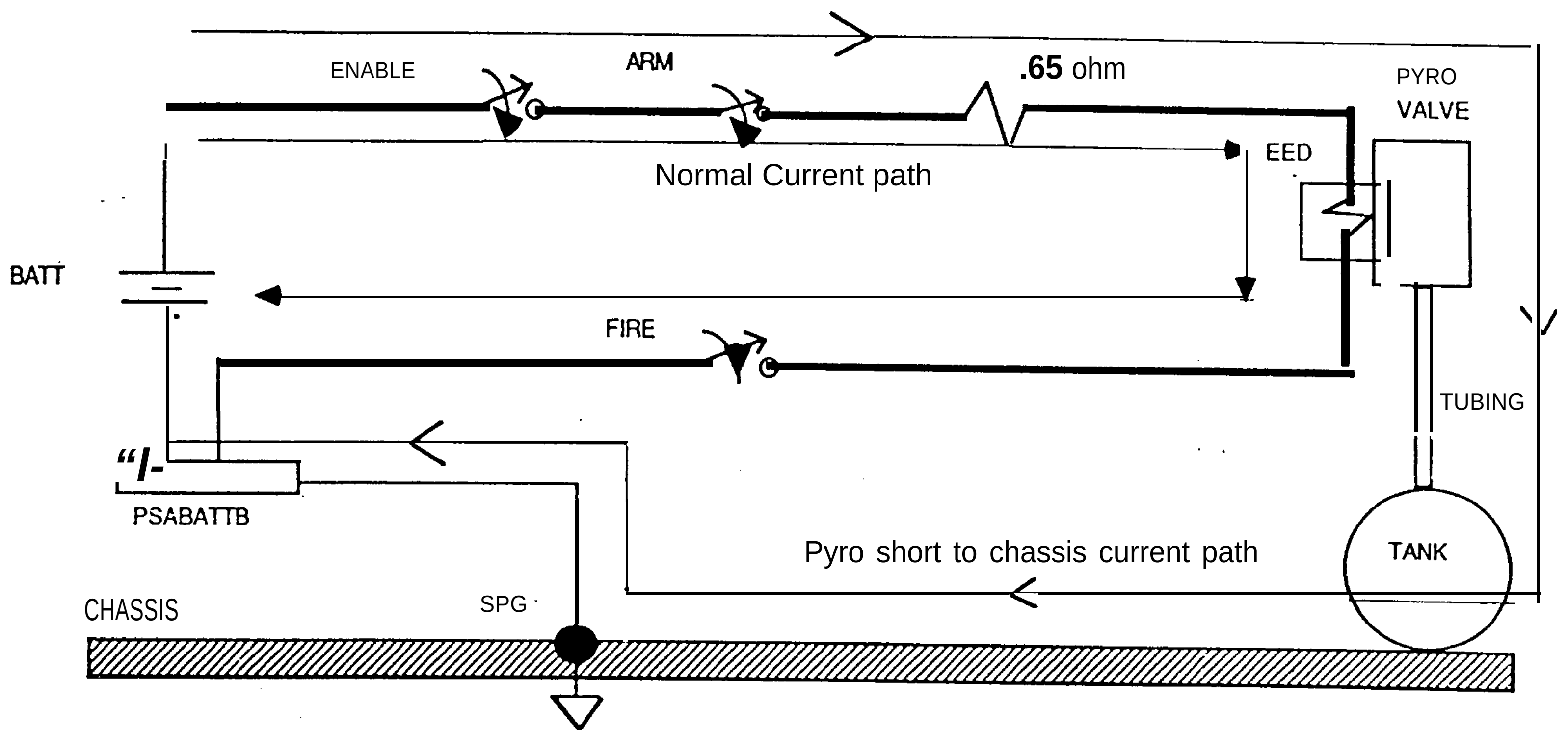

Figure 4

MO

The Culprits and Victims in This EMI Phenomena:

The Culprits are the paths conducting the pyro short current:

1. The Giant Loop: Figure Cable-3
   - a. The Tubing section: (pipe from Pyro Valve to Tank)
   - b. The Power Cable
   - b. The RTN Cable: (wire from SPG to Negative Pole of Battery),
   - c. The Chassis

The Victims:

1. The ground loop created by the 10V I/F circuit
2. The CIU Ground Cables
3. The SPG Cables

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Pyrotechnic Devices

Additional example events extracted from the database:

Slc	Date	Symptom	Cause	Effect/CA
Voyager 2	August 20, 1977	At pyro command "S/C-LV SEP A' an indication was received of TLM pyro amps A&B. Only pyro amps A should have been received	The TLM pyro amps indication was a false indication determined to be caused by a combination of unbalanced grounding design in the PSU in conjunction with the characteristics of the superzip detonator squibs which shorted the frame to ground	No recovery effort was initiated because it was determined that the problem had an insignificant effect on the mission.
Voyager 1	September 5, 1977	At pyro command "S/C-LV SEP A' an indication was received of TLM pyro amps A&B. Only pyro amps A should have been received	The TLM pyro amps indication was a false indication determined to be caused by a combination of unbalanced grounding design in the PSU in conjunction with the characteristics of the superzip detonator squibs which shorted the frame to ground	No recovery effort was initiated because it was determined that the problem had an insignificant effect on the mission.
Gemini	March 1, 1966	S/C had docked with Agena when violent roll occurred and orbital attitude maneuvering thrusters fired wasting fuel. Vehicle status: failure. Mission effected.	Short; grounded the circuit to the valve driver on no. 8 orbital attitude maneuvering (OAM) thruster and energized it, at first intermittently and then continuously while S/C's attitude control and maneuvering electronic system was powered down	Recovery method: undecked, but roll continued, then used re-entry control system thrusters.
Nuclear Detector	October 1, 1963	At orbit injection the S/C load current increased by 0.25 A. Vehicle status: anomaly; Mission affected	Short circuit in APOGEE kick motor fire circuitry after rocket motor fired.	Removed ordnance from busses
CL1	April 1, 1984	With Solar Array deployment, the S/C bus current was observed to show a 5 second transient spike to a peak value of 13A	Firing current induced by the deployment ordnance squib bridgewire.	Redesign the ordnance circuitry

Positive Aspect of Classical Electrically initiated Ordnance

➔ **Proven reliability.**

A report on NASA initiator reliability contained information on initiator testing:

- **A total of n = 30,000 initiators fires, no failures.**

From this information, the following calculation is made:

With 90% upper confidence limits, assuming binomial distribution, the probability of no failures in a sample size n is $\beta = 0.1$:

$$\beta = \sum_{i=0}^{0} \frac{n!}{i! \cdot (n-i)!} \cdot p^{i} \cdot (1-p)^{n-i} \qquad \beta = (1-p)^{n}$$

p = percent non-conforming or one unit probability of failure

The 90% one sided upper confidence limit on probability of failure of one unit:

$$P_{max} = 1 - \beta^{\left(\frac{1}{n}\right)} \qquad p_{max} = 7.675 \cdot 10^{-5}$$

The upper limit on reliability is 0.99992325

The well known value of 0.999 is too conservative and not defensible.

The nominal reliability value is: 0.99996624

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Pyrotechnic Devices

The spacecraft industry needs an ordnance igniting device that is:

- Simple
- Inexpensive
- Robust
- Reliable
- Compatible with the surrounding electronics
- Interchangeable dimensionally with the electrically igniting devices, so that the design of existing pyro devices need not be changed.

Pyrotechnic Devices

Review of up to date accomplishments on the LIO indicates that:

- **The device design is simple**
- **Insulates the explosive from the stray electrical ignition sources. It removes the bridgewire and the conductive pins from the igniting devices and thus creates a Faraday cage to (ref. John A. Merson and F. Jim Salas "Safety Analysis of Optically Ignited Explosive and Pyrotechnic Devices", presented at the Applications of Laser Initiated Ordnance Technology Transfer Workshop, April 26, 1995).**
- **The predicted failure rate (MIL-HDBK-217) is rather low, $\lambda = 4.06$ failures/10^6 hours, yielding a reliability of 0.996 for its mission (ref. Craig J. Boucher, Lawrence M. Richards, "Reliability Prediction Method for Laser Diode Initiated Ordnance Systems", presented at the Applications of Laser Initiated Ordnance Technology Transfer Workshop, April 26, 1995).**
- **Several devices are flight-qualified (Norman Shulze, Craig Boucher, and Bonita Maxfield, "First Flight Application of Semiconductor Laser Initiated Ordnance, LIO", presented at the Applications of Laser Initiated Ordnance Technology Transfer Workshop, April 26, 1995).**

Comments and Conclusions

The Electrically Initiated Ordnance

The flight and test history shows that that there were many anomalies and failures apparently caused by the activation of the pyro devices.

It requires special design considerations for the surrounding electrical circuits and grounding.

Problems also related with aging: bridgewire corrosion, penetration of moisture or other agents into the explosive.

Has a good reliability record (better than normally assumed) and is flight proven over many decades.

Is very simple, and thus the cost is not excessive.

Comments and Conclusions, cont.

Laser Initiated Ordnance

Eliminates electrical problems associated with electrical imbalance, sneak circuits etc.

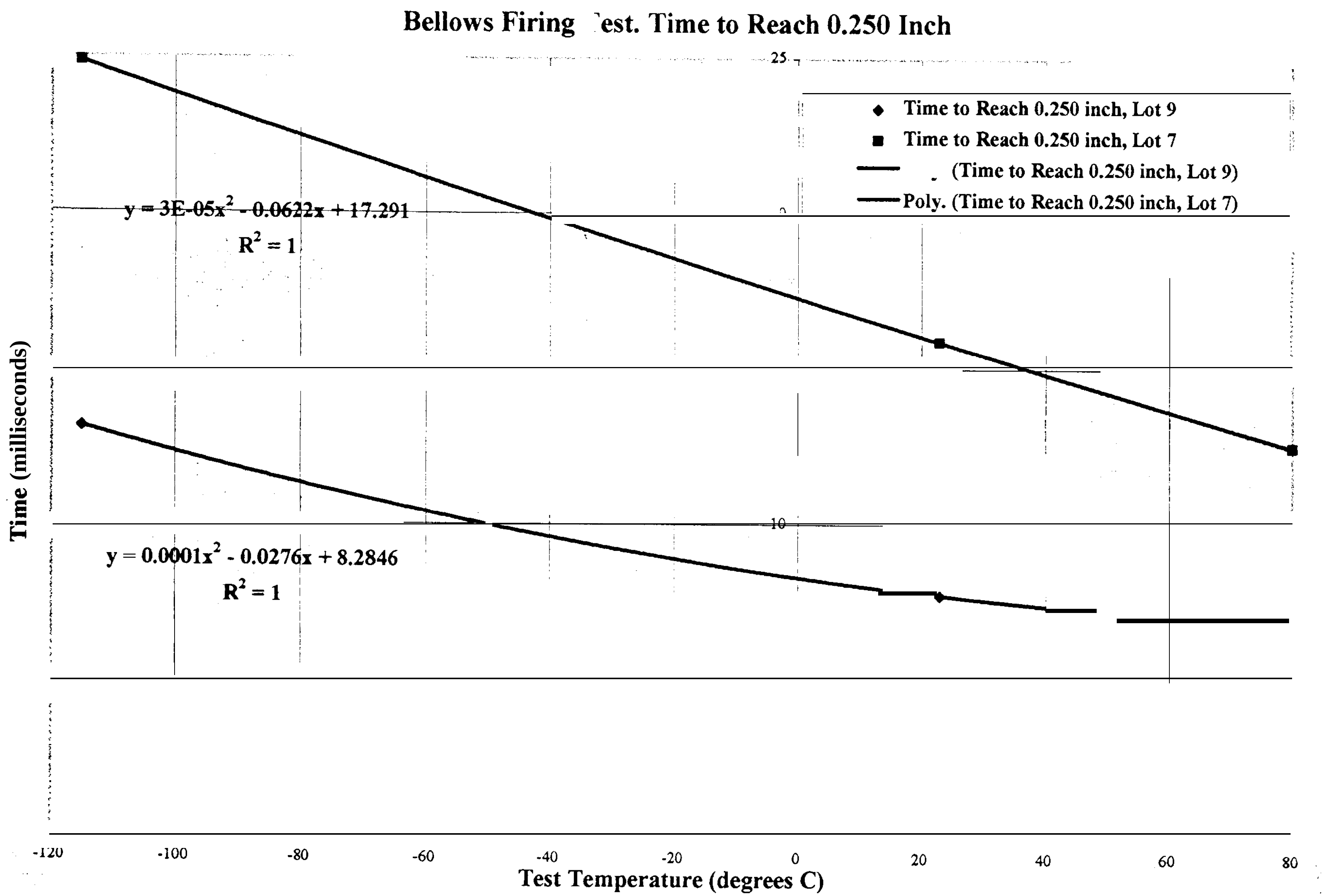
Is technically advanced, however, complex.

The design is flight qualified.

The reliability, as predicted, is lower than for the classical devices. For a multitude of these devices on a spacecraft, the difference could be even more significant. Prediction needs to include dormant reliability and factors such as alignment and optics.

Lack of the multitude of test data does not permit reliability verification through test/experience. Organized and well planned environmental/reliability testing and data analysis will permit a more resourceful information on reliability.

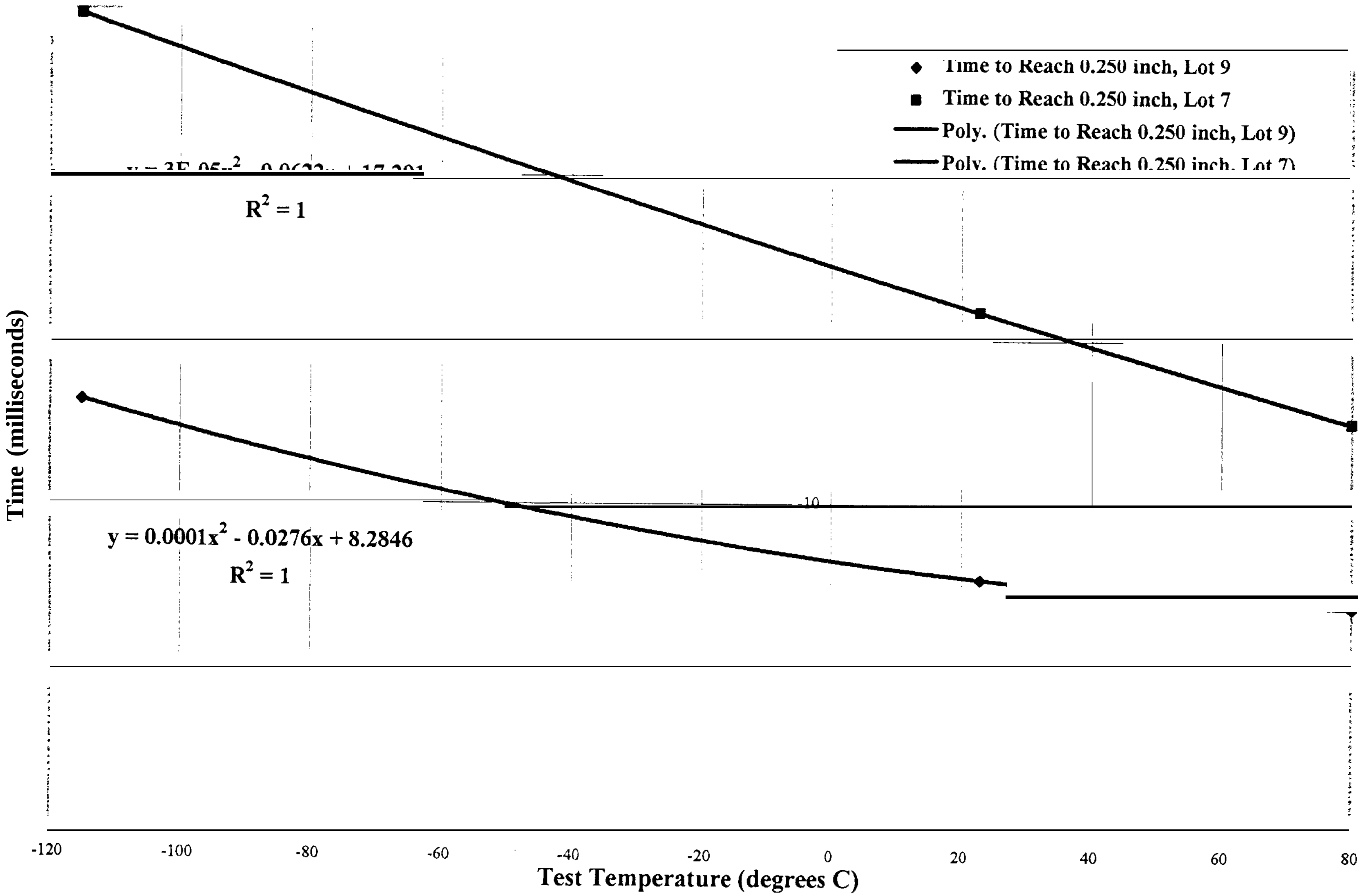
The project has a lot to offer. The design refinements and a good reliability program will provide assurance in the supreme quality of the LIO devices.



M. Krasich

12/7/95

Bellows Firing Test. Time to Reach 0.250 Inch



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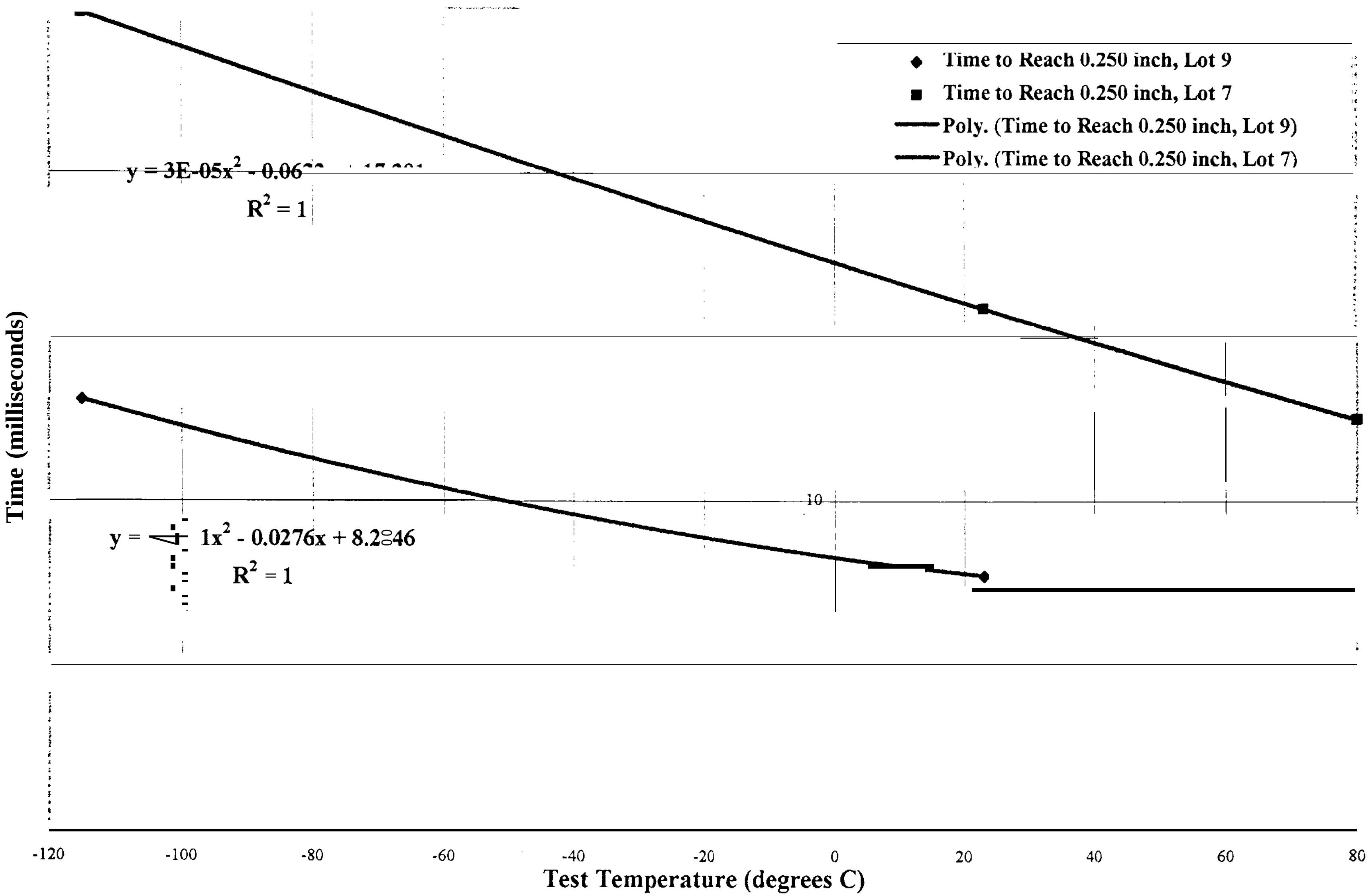

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