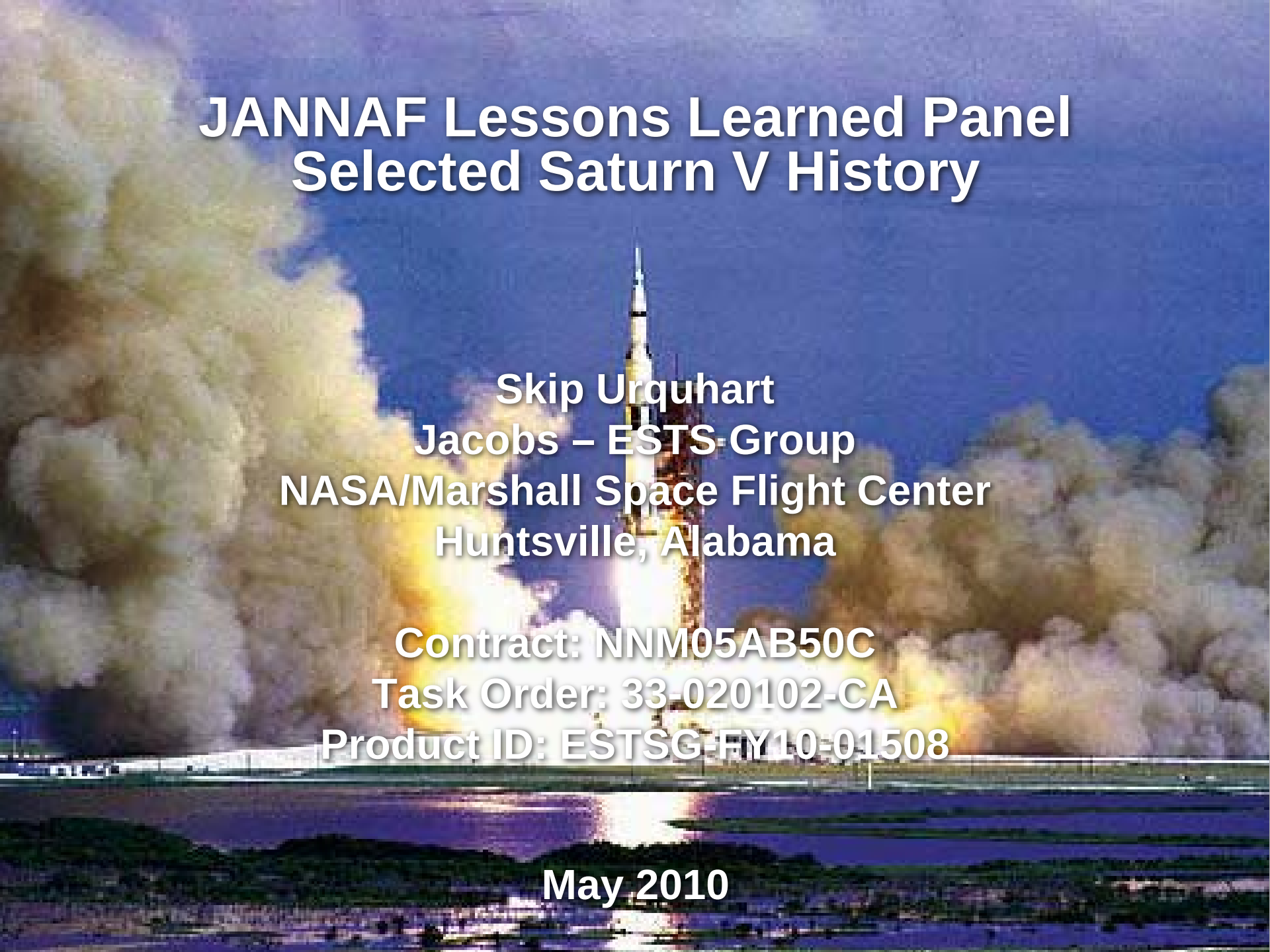

JANNAF Lessons Learned Panel
Selected Saturn V History

Skip Urquhart
Jacobs – ESTS Group
NASA/Marshall Space Flight Center
Huntsville, Alabama

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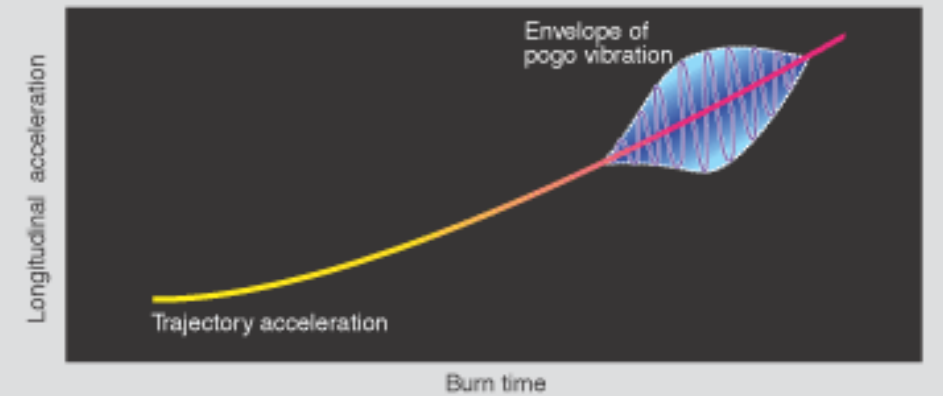
What Is Pogo?

- Pogo occurs when the natural frequency of a propellant feed line comes close to a readily excited rocket longitudinal structural vibration natural frequency.
- Maximum Pogo response corresponds to close tuning of the structural and hydraulic frequencies.
- On Saturn V, accelerations up to 17 g's (Zero To Peak) at the Launch Vehicle/Payload Interface and up to 34 g's at an Engine have been observed.



- Nicknamed “Pogo” because it causes the Rocket to stretch and compress like a Pogo stick.
- First recognized with the Titan II in 1962, Pogo remains a prime consideration in design of launch vehicles today.

Saturn V AS-502 (Apollo 6)

What went wrong?

- Following the near-perfect AS-501 (Apollo 4), launched November 9, 1967.

- AS-502 (Apollo 6), launched April 4, 1968, experienced 3 3-sigma events, one on each stage.

Saturn V AS-502 (Apollo 6)

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S-IC

- AS-502 S-IC experienced Pogo - Vehicle first longitudinal structural mode frequency coupled with the engine response to the oxidizer suction lines resonant frequency from the 110 to 140 seconds.
- Oxidizer suction lines changed to rigid ducts between AS-501 and AS-502 because of manufacturing difficulties with flexible ducts.
- AS-501 did not experience Pogo, in part, because of more compliant oxidizer suction lines.

Note: S-IC propulsion systems performed satisfactorily on both flights. Concerns of Pogo compromising structural integrity.

Lesson Learned: There are NO small changes!

S-IC Pogo Mitigation

After Pogo was experienced on AS-502, the following changes were implemented:

- Outboard prevalves redesigned to include helium cavities to provide compliance to the systems.
- POGO suppression system supplied helium gas obtained from the onboard fuel pressurization system. Four resistance thermometers in each prevalve determine the presence of gas or liquid in the prevalve cavity (see schematic).
- The POGO suppression system performed satisfactorily on AS-503 and subsequent flights.

Saturn V AS-502 (Apollo 6)

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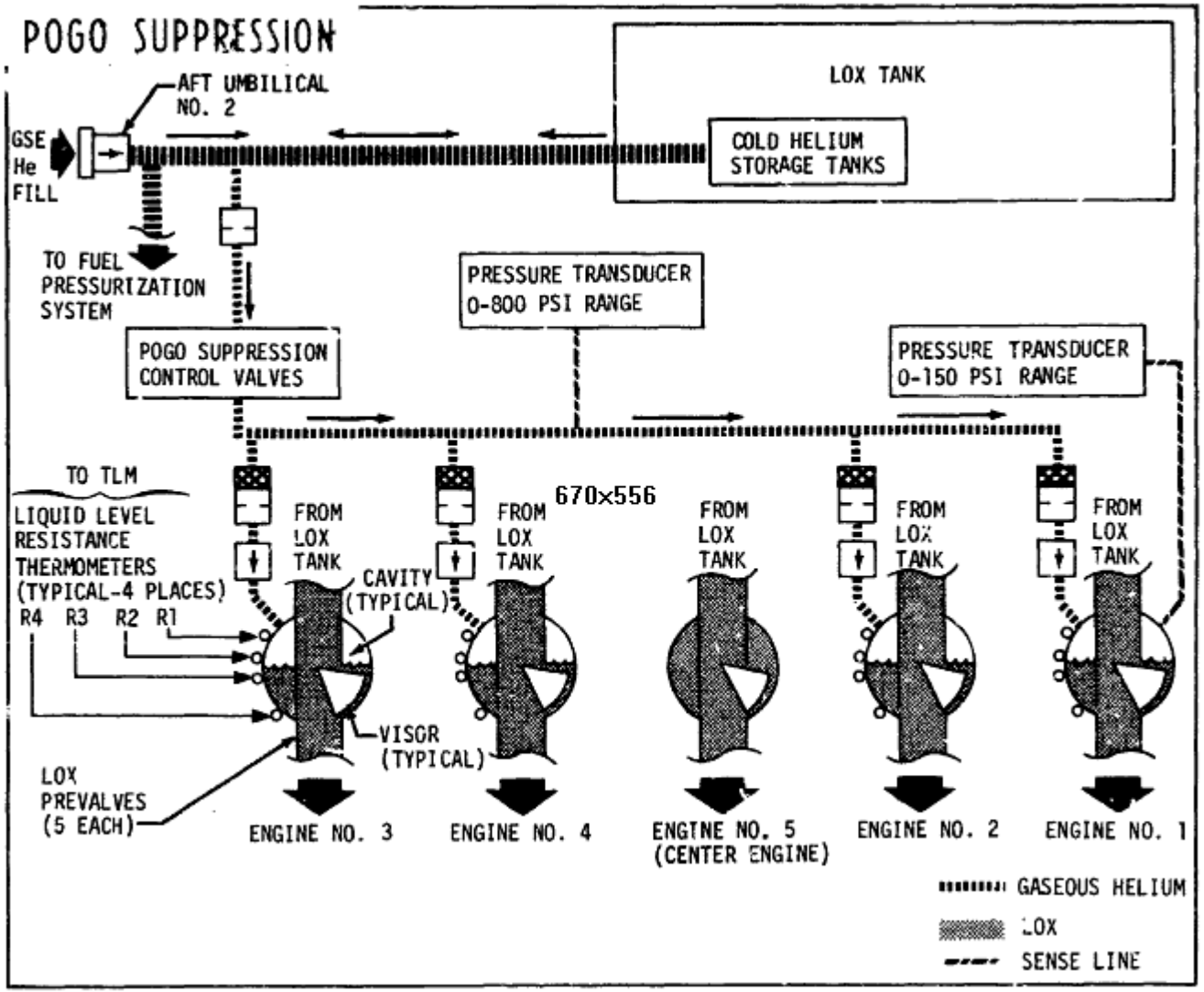
S-IC Pogo Suppression System (AS-503 & Subsequent)



Saturn V AS-502 (Apollo 6)

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S-II

- On AS-502 S-II two J-2 engines shutdown prematurely.
- Augmented Spark Igniter (ASI) fuel line leak on Engine No. 2 led to degraded performance and command to shutdown engine No. 2 at approximately 413 seconds.
- Engine No. 3 cutoff resulted from cross-wiring the control wiring harnesses for engines No. 2 and 3 Liquid Oxygen (LOX) Prevalve Solenoids.
- S-II engine outs caused performance short falls.

Lesson Learned: Perfect designs do NOT work if not properly installed!

S-II Engine Out Resolution

- Cross-wiring solved by paying attention to details, checking, and following procedures during all assembly operations.
- ASI fuel line leakage resolved by redesign of the ASI propellant lines.

Saturn V AS-502 (Apollo 6)

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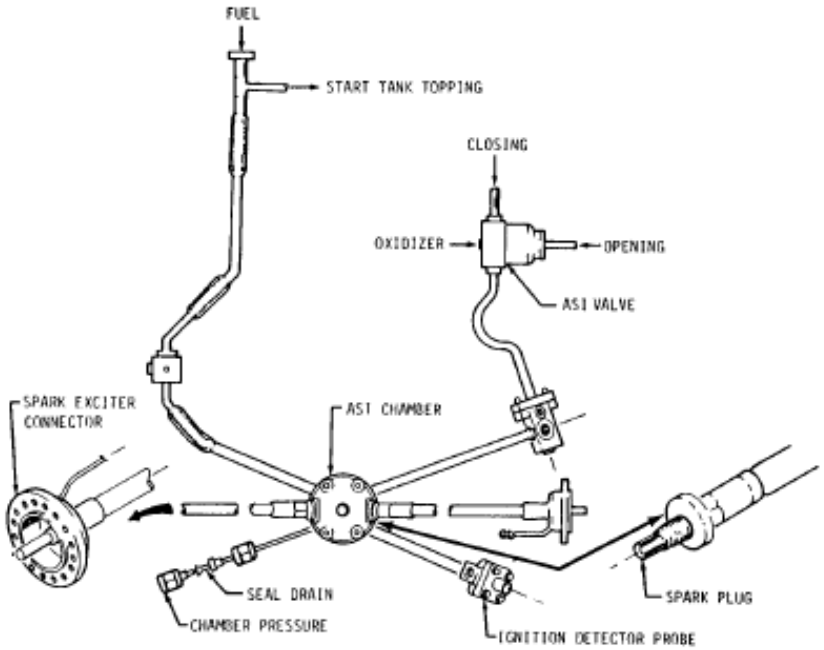
S-IVB

- The AS-502 S-IVB failed planned restart on orbit.
- All engine chilldown and preparations for restart were accomplished satisfactorily. However, the J-2 engine did not ignite due to leakage of ASI fuel line.
- Propulsion system met all operational requirements during first burn, cutoff transient, and orbital coast.

Lesson Learned: Pay attention to possible common cause failures (ASI propellant line failures on S-II and S-IVB)!

S-II and S-IVB ASI Failure Resolution

- ASI fuel line leakage resolved by redesign of the ASI propellant lines.



ASI is a small chamber which is center-mounted in the thrust chamber injector. Its purpose is to create and maintain a small ignition flame for thrust chamber ignition.

Saturn V S-II Pogo History

- AS-501 & AS-502 – no S-II Pogo was observed.
  (limited instrumentation)
- AS-503 - 17 Hz oscillation near 480 seconds.
  Self limiting – local oscillation on center engine.
- AS-504 - 17 Hz oscillation near 500-540 seconds.
  12g's at center engine - self limiting – local oscillation .
- AS-505 & AS-506 - No S-II Pogo was observed
  (limited instrumentation) Center engine cutoff approximately 60 seconds early as planned.
- AS-507 - 16 Hz near 120-180 & 240-300 seconds.
  Self limiting – local oscillation. Center engine cutoff approximately 60 seconds early as planned.
- AS-508 - 16 Hz near 120-160 seconds (24 g's amplitude)
  Pump cavitation caused early center engine cutoff
- AS-509 & subsequent flights – no Pogo at 16 Hz.
  Center engine LOX line accumulator implemented.

Saturn V S-II Pogo History

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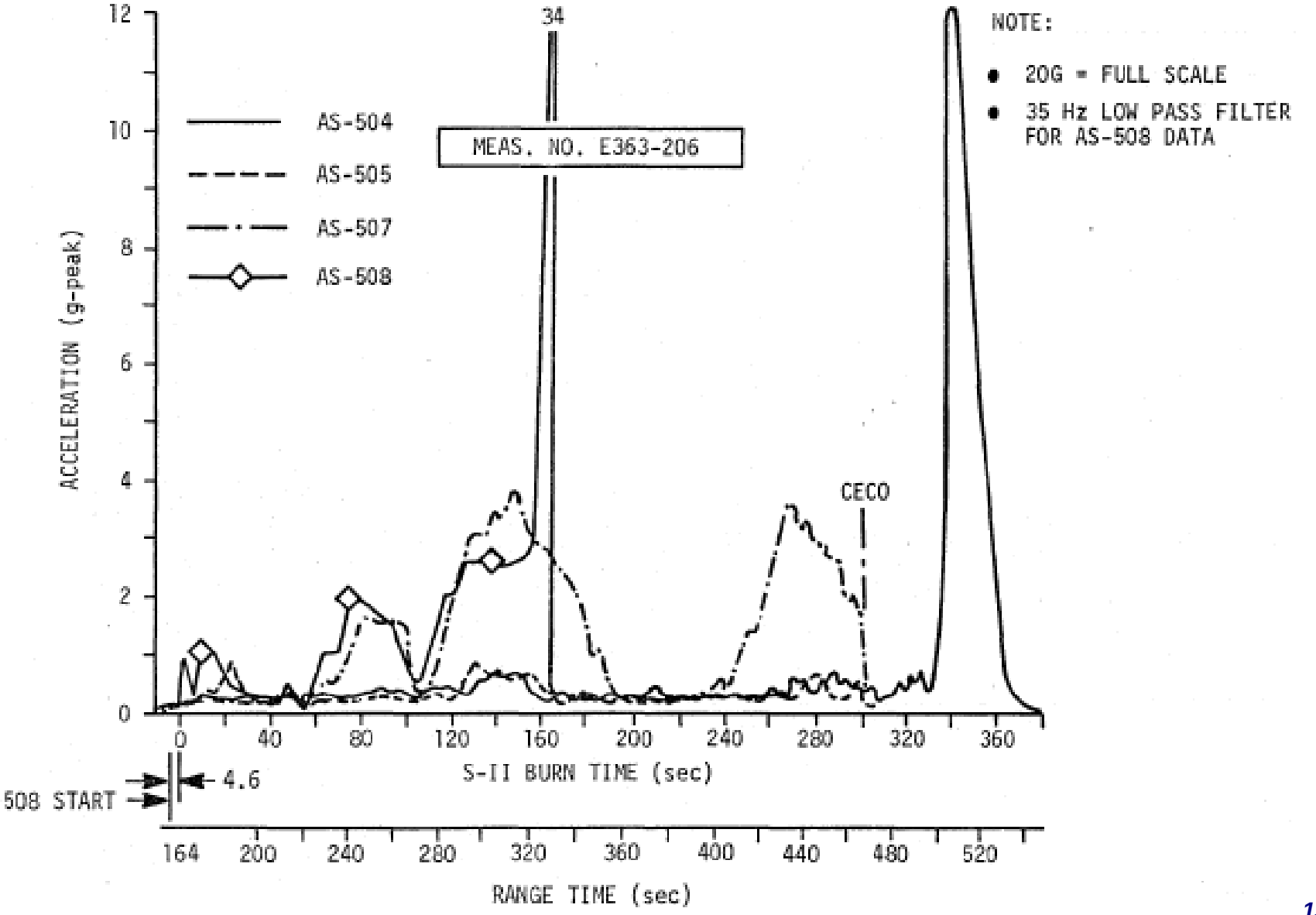
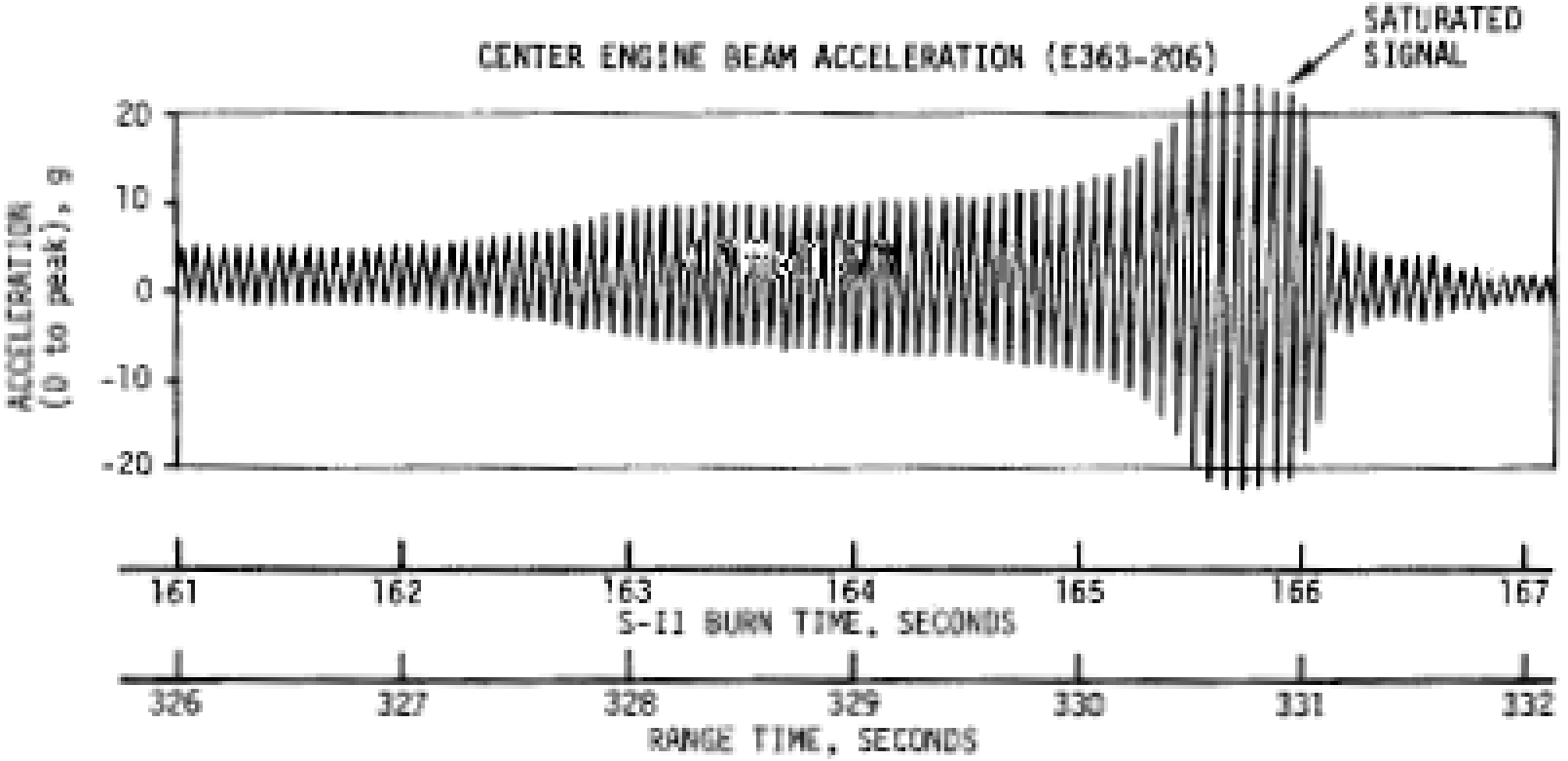
Comparison of Center Engine Acceleration



Saturn V AS-508 (Apollo 13)

Pogo Data



Saturn V AS-509 (Apollo 14)

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Suppression System Design

- Before AS-508 (Apollo 13), S-II Pogo events were considered to be self limiting and local.
- Ironically, AS-508 (Apollo 13) was planned to incorporate a Pogo Suppression System. Stage contractor indicated that the change was to be made on S-II-8 and subsequent vehicles (see label on following schematic).
- Implementation was delayed.
- Pogo event on AS-508 (Apollo 13) forced an immediate change to incorporate a Pogo Suppression System.

Saturn V AS-509 (Apollo 14) Pogo

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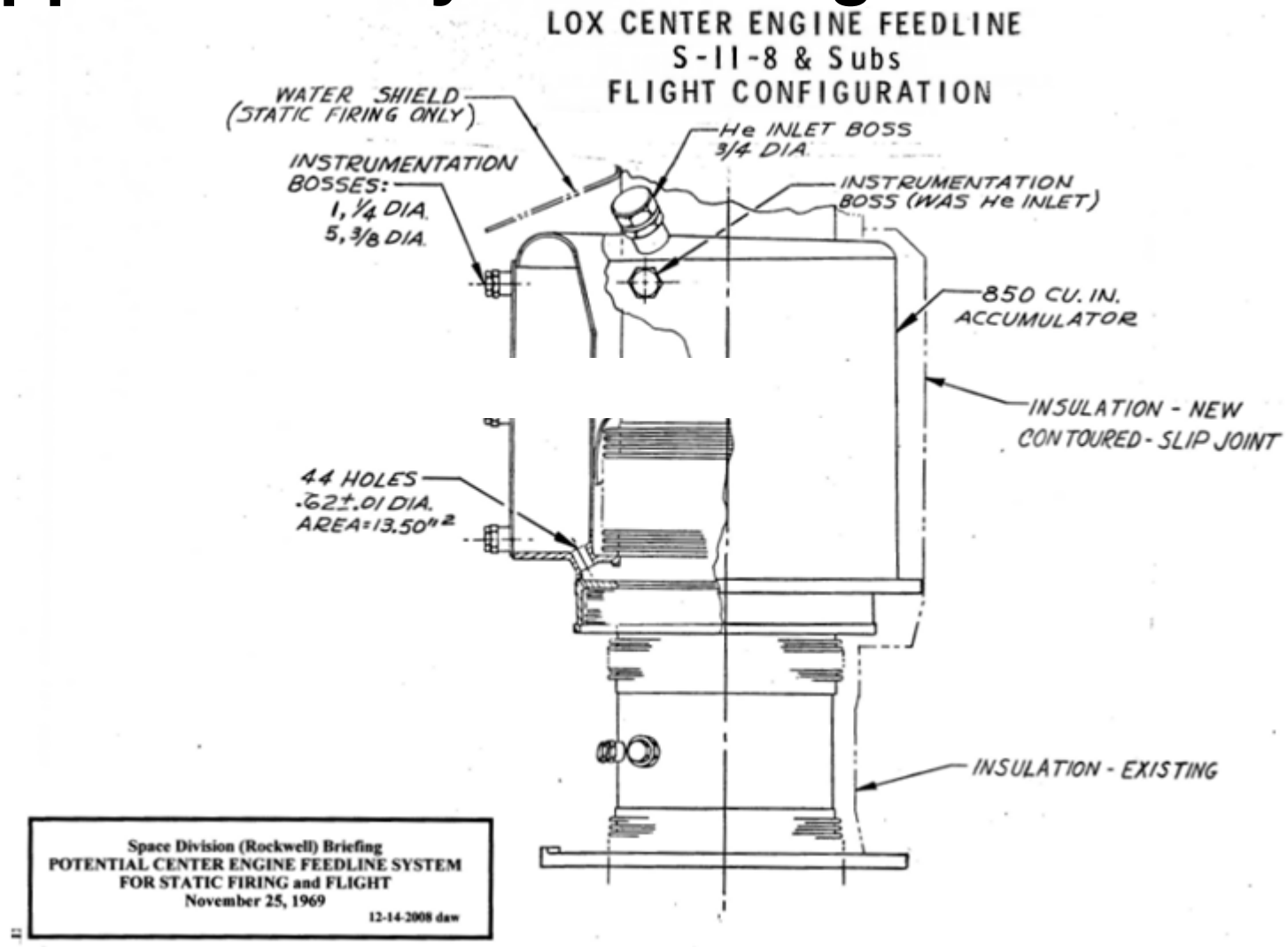
Suppression System Design



Saturn V S-IVB Pogo

- S-IVB experienced Pogo events but all were considered to be self limiting and local. Signal was not felt at the Command Module.

- No Pogo suppressor system was implemented on S-IVB.

Lesson Learned: Don't fix something that isn't broken!

Lessons Learned Summary

Lesson Learned: There are NO small changes!

Lesson Learned: Perfect designs do NOT work if not properly installed!

Lesson Learned: Pay attention to possible common cause failures!

Lesson Learned: Design with analysis / verification in mind!

Lesson Learned: Pay attention to the lessons learned!!!

Lesson Learned: Don't fix something that isn't broken!