SAND2010-4571P

Uncertainty-Enabled Design of a Rocket Sled Track Switch

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Albuquerque, NM

Industrial Mathematical & Statistical Modeling Workshop for Graduate Students

Center for Research in Scientific Computation, Raleigh, NC

July 19, 2010

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U.S. DEPARTMENT OF ENERGY

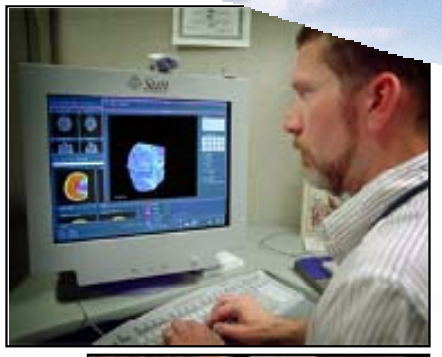
Sandia National Laboratories

Our Business: National Security

- **Core Purpose**
  - **Help our nation secure a peaceful and free world through technology.**
- **Highest Goal**
  - **Become laboratory that the USA turns to 1st for technology solutions to the most challenging problems that threaten our nation and the globe.**

Science and Technology Address Scope and Complexity of National Security

Applying both BREADTH & DEPTH to solving our nation's most challenging national security problems



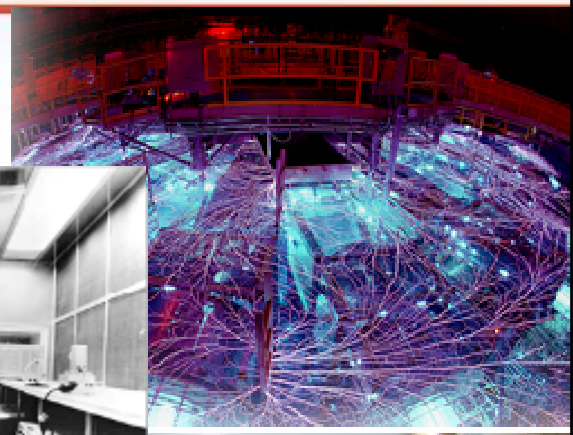
National Security

Sandia National Laboratories

Science & Engineering

Sandia's Unique Set of Resources

- World's largest x-ray source
- Tallest solar tower in the nation
- First clean room
- First MEMS in space
- World's smallest chemical/biological analysis systems
- World's largest center for fundamental and applied study of combustion processes
- World's fastest general-use supercomputers
- World-class team of engineers, chemists, physicists, biologists, mathematicians . . .

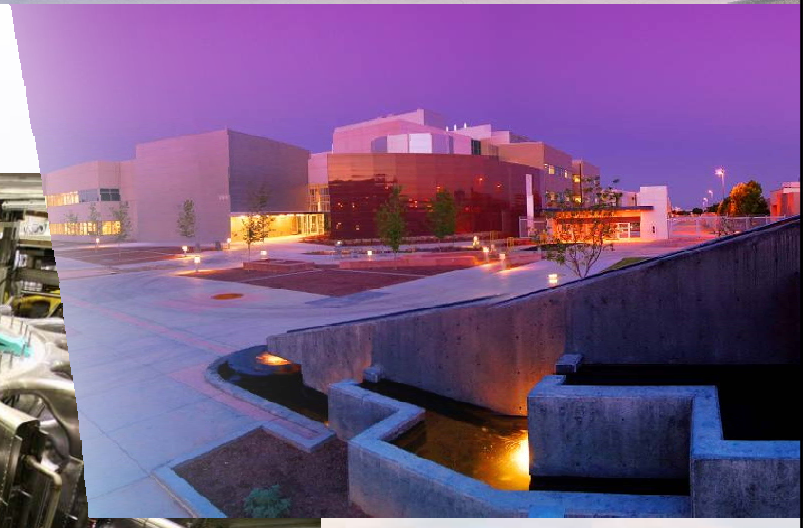


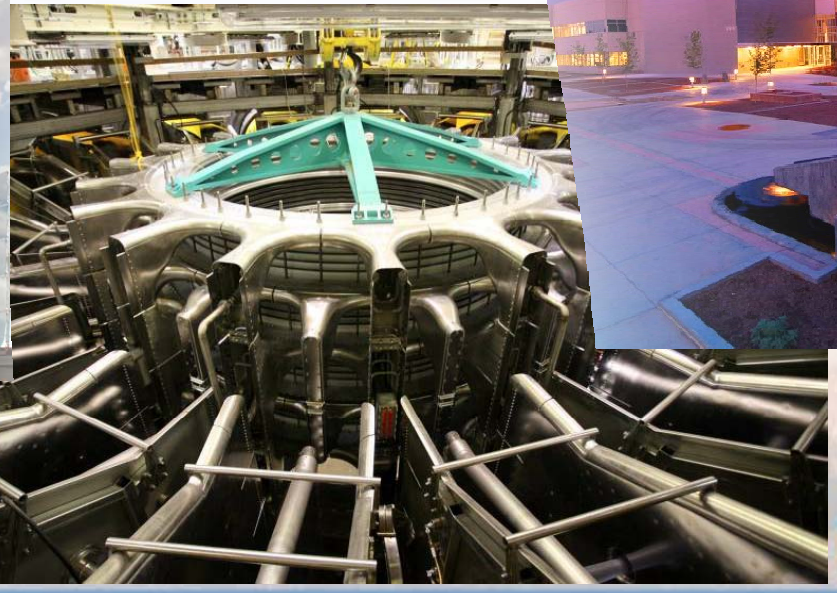
- ***World class Facilities & Testing capabilities.***

Sandia National Laboratories

Unparalleled Facilities and Test Capabilities

- User facilities
- Designated national capabilities
- Z-Machine and radiation effects
- Real-life physical test ranges

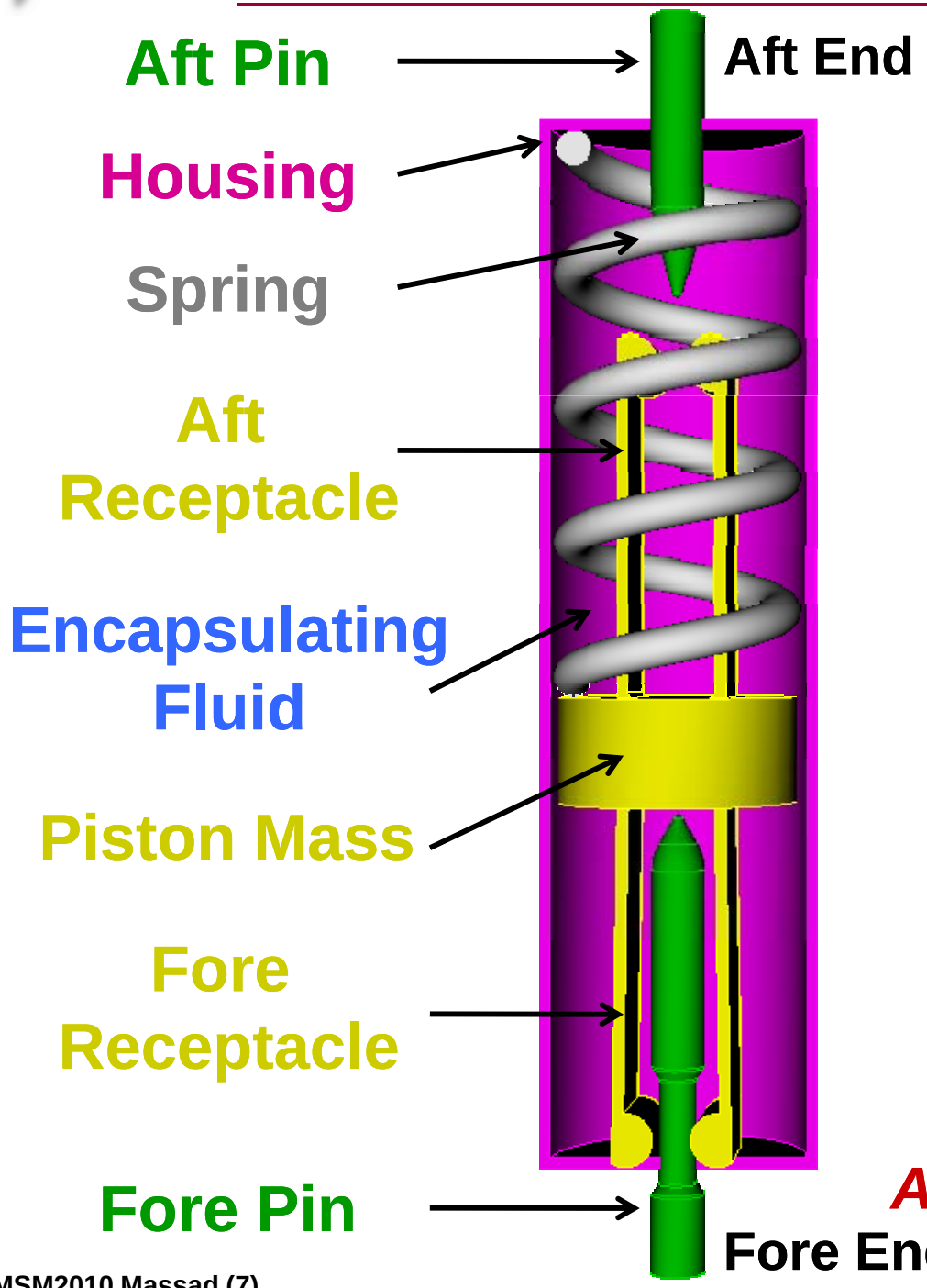




Rocket Sled Track

- Provides controlled environment for high-velocity impact, aerodynamic, acceleration of small and large items.
- 10,000-foot and 2,000-foot tracks.
- Some tests have a destructive end!
- Exceptional Instrumentation Capabilities:
  - Photometrics, laser trackers, telemetry;
  - Information sampled at high rates;
  - High-speed video, flash x-ray, and film cameras.
- Typical Data Acquired
  - Temperature;
  - position;
  - velocity;
  - *acceleration*.

Instrumentation: An Acceleration Switch



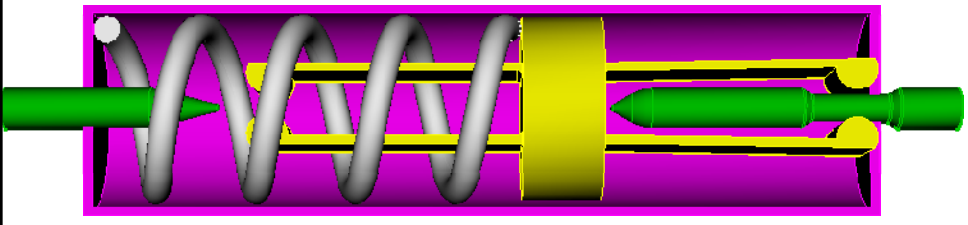
- Some instrumentation is activated along the track and during the test.
- An acceleration switch is designed to close during axial acceleration.
- Receptacles contact pins to close and activate instrumentation.
- Housing is filled with encapsulating fluid.
- Preloaded spring holds switch open; works against axial acceleration.

A sled may use multiple switches.

How the Switch Closes

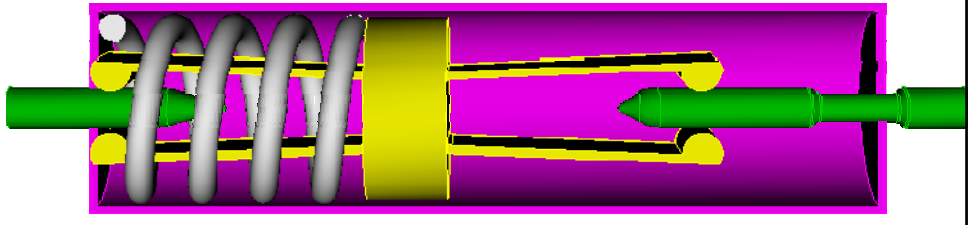
- **Axial Acceleration**: piston mass moves from *fore* to *aft* due to forward acceleration of the rocket sled.
- **Spring Force**: linear spring keeps switch open at rest, resists actuation.

Open



Aft End **Fore End**

Closed

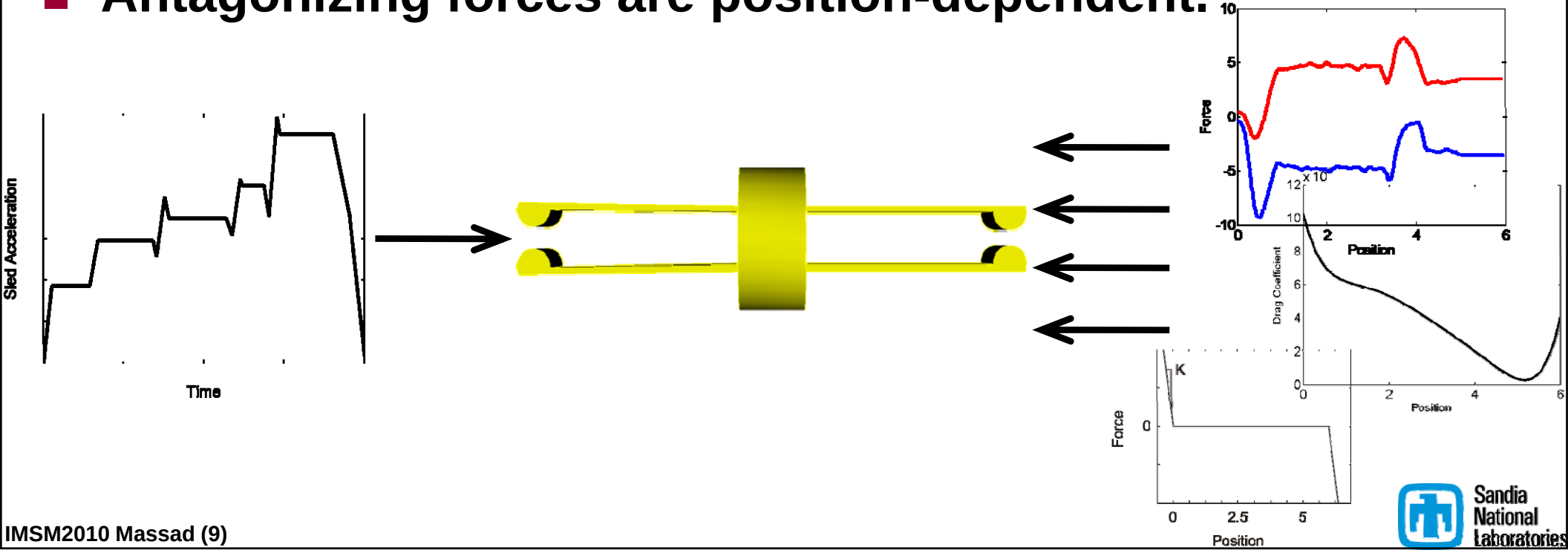


- **The switch is designed to close within a range of times during sled acceleration.**

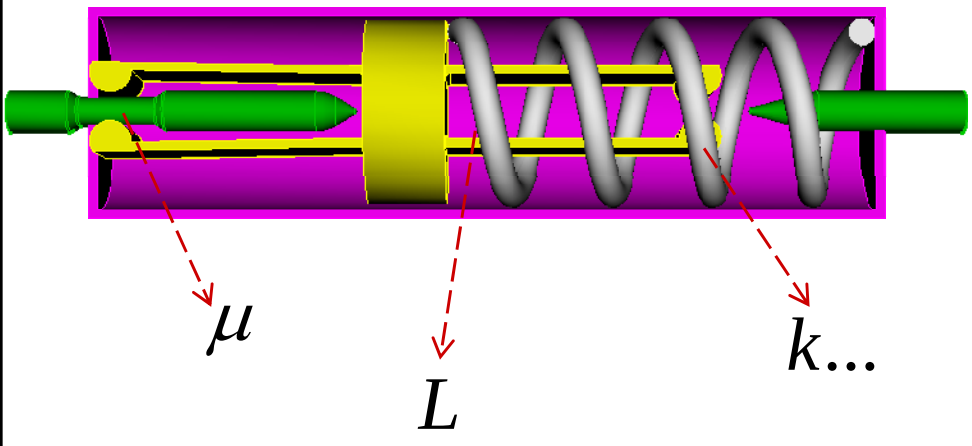
Complicated Switch Behavior

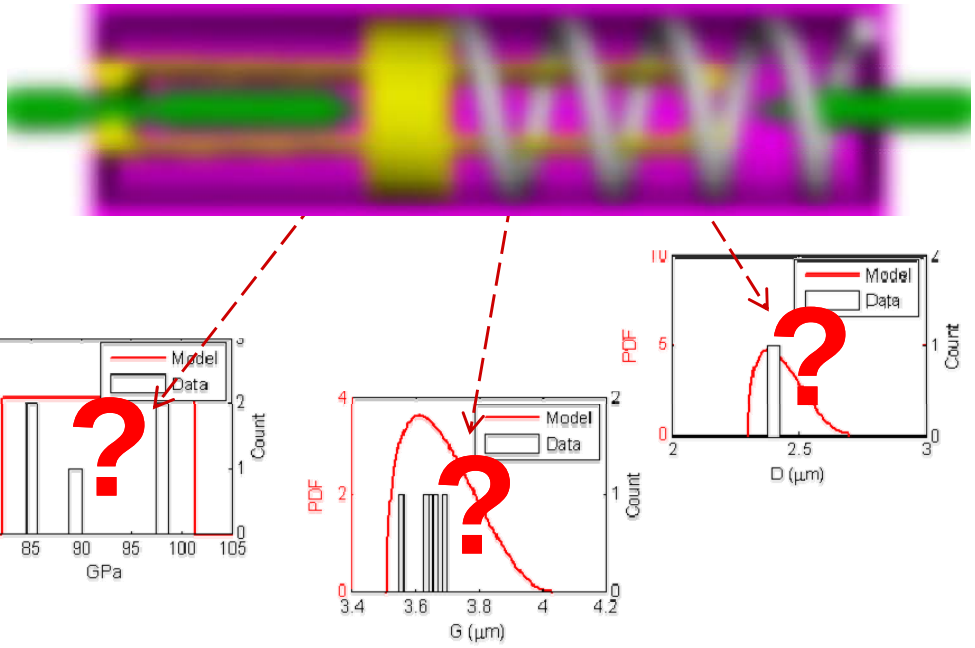
Nonlinear forces act on piston mass during actuation.

- **Nonlinear forces imparted due to sled track acceleration.**
- **Nonlinear forces work against switch due to**
  - **fluid drag;**
  - **friction of receptacles along pin geometry;**
  - **final contact.**
- **Antagonizing forces are position-dependent.**



Switch Properties Vary and are Uncertain





Deterministic Analysis

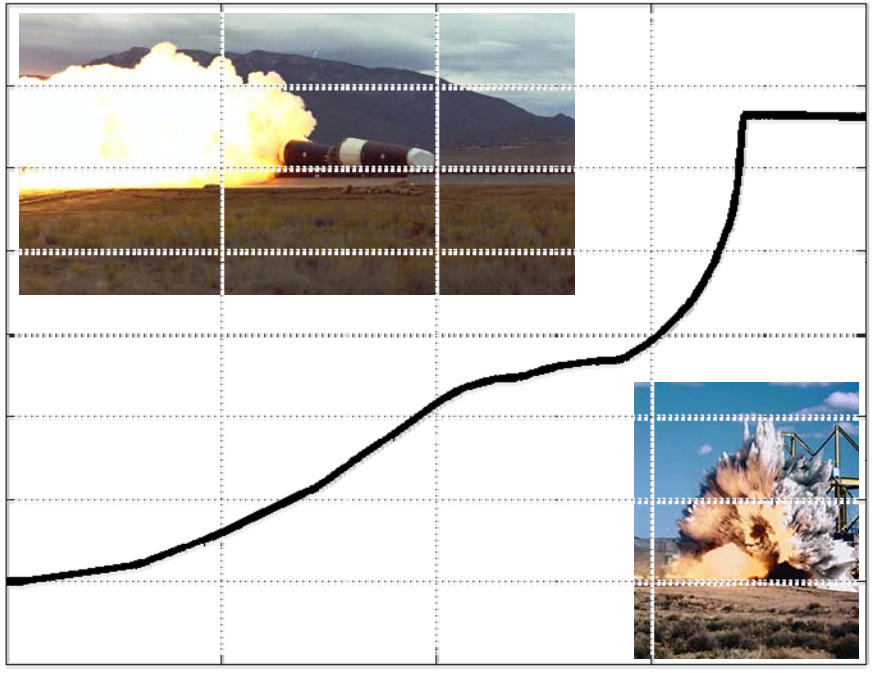
- Ignores variation in switch parameters.
- Succeeds only if:
  - switch parameters vary little,
  - switch response is ***insensitive*** to variation.
- Enables design of a ***single*** switch for a ***single*** sled acceleration.

Statistical Analysis

- Accommodates ***sensitivity*** of switch behavior to parameter variations.
- Describes random variation in parameters by probability density functions.
- Enables design of an ***ensemble*** or ***sample*** of switches for a possible ***uncertain*** sled acceleration.

Will the switch close under uncertainty?

- **Switch timing is determined by switch design and the interaction of nonlinear, position-dependent forces.**
- **Possibility: a combination of uncertain variations and nonlinear dynamics can result in a non-functional switch.**



If the switch does not close before a critical time is reached, then the test may fail.

What Sandia Wants to Know

Given a switch under a given sled acceleration: How do variations in switch parameters influence switch operation?

- **Questions include:**
  - **What is the probability of successful operation given variation and uncertainty?**
  - **What design can maximize that probability?**

Addressing this problem can help us quantify the feasibility of using this switch design.

- ***Whipped Cream: what if the given sled acceleration is uncertain or varies?***
- ***Cherry: what if the system includes multiple switches connected in parallel?***