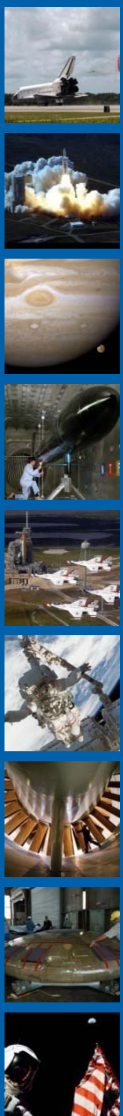
National Aeronautics and Space Administration



Head-On Collision:

Large Hadron Collider

Leadership ViTS Meeting

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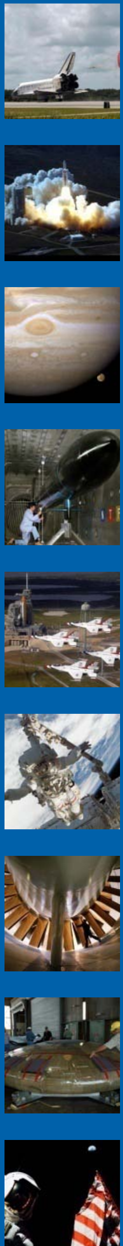
This and previous presentations are archived at:
http://pbma.nasa.gov/



THE MISHAP

The Large Hadron Collider (LHC) located in Geneva, Switzerland is a particle accelerator made up of a 17-mile ring of electromagnets. After sixteen years and billions of dollars of development, the LHC suffered a serious failure stemming from a simple engineering error during final testing. On March 27, 2007, structural supports in one of the magnets burst during a crucial pressure test. Repairs to the support structures required over six months of additional work, delaying the original project start date and incurring millions of dollars in additional cost.

What is the LHC?

•The Large Hadron Collider (LHC) is the world's most powerful particle accelerator.

•Consists of 9,300 superconducting electromagnets laid end to end in a 17-mile ring.

•Superconductivity has allowed particle acceleration to 99.9999991% of the speed of light to date with manageable power requirements.

How does the LHC work?

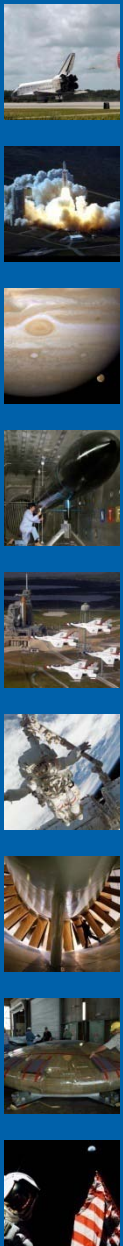
•Fires two beams of high-energy particles (hadrons) in opposite directions.

•Hadrons travel near light speed, gain energy with each lap around the ring, and are guided into collision with one another.

•Collisions occur up to 30 million times per second and are believed to mimic the conditions immediately following the Big Bang.

•Data is collected, stored, and processed by four massive electromagnetic detectors at different points around the ring.

The LHC ring cost over $10 billion in design and construction.



WHAT HAPPENED?

Structure Collapse

•Final stages of pressure testing occurred on March 27, 2007.

•During one of the stress tests, as the magnet moved longitudinally within its cryostat vessel, a support structure holding the cold mass inside the outer jacket tore loose.

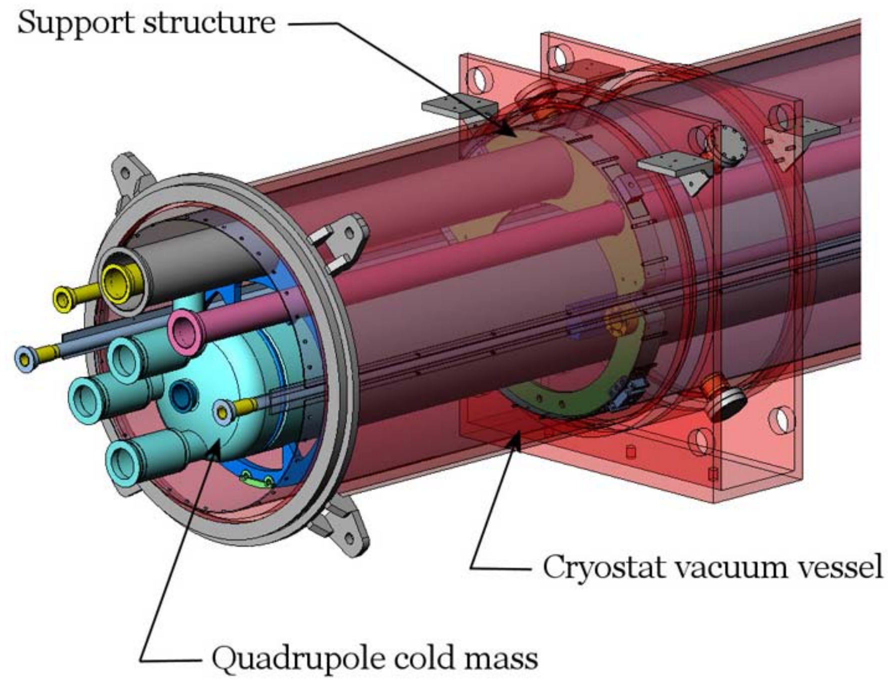
•The structural collapse ruptured the cold mass vessel and caused large amounts of helium gas to leak into the tunnel, severely damaging LHC components.

Engineering Miscalculation

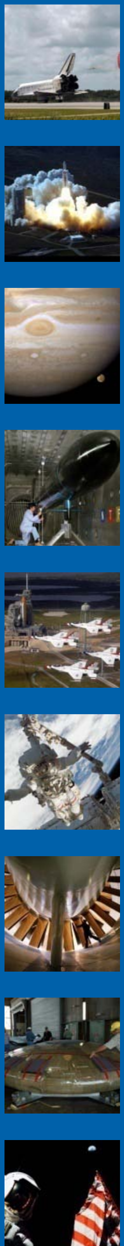
•Longitudinal movement is to be expected under normal operations due to the intense forces magnets withstand from accelerating particles.

•The longitudinal movement was not taken into account during planning and construction, and the manufacturer created an insufficient support structure that could not withstand the pressure.

•Magnets were only tested individually; Fermilab engineers did not account for real operating conditions in which the magnets would function when laid end-to-end.



The components of a magnet include the inner quadrupole cold mass holding the liquid helium, the outer cryostat jacket, and the support structure in green.



PROXIMATE CAUSE

The support structure holding the magnet cold mass in place within the cryostat vacuum vessel collapsed as the magnets moved longitudinally. This collapse ruptured the cold mass vessel and caused large amounts of helium gas to escape into the LHC tunnel.

ROOT CAUSE / UNDERLYING ISSUES

Failure to Follow Processes:

•Fermilab, the magnet's designer and manufacturer, lacked a standard design and documentation process, resulting in different engineers using differing approaches during development.

•The Quality Assurance manual was ignored due to assumptions that it applied only to fabrication, not design. The cross-checking information it contained, if followed, may have prevented the failure.

Failure to Follow Best Practices:

•Fermilab's training programs did not provide information on proper design procedures, standards, or techniques such as team-based reviews or project controls within the design process.

•Project managers received inadequate training for their roles, did not come from project management backgrounds, and did not oversee day-to-day operations.

Flaws in General Procedures:

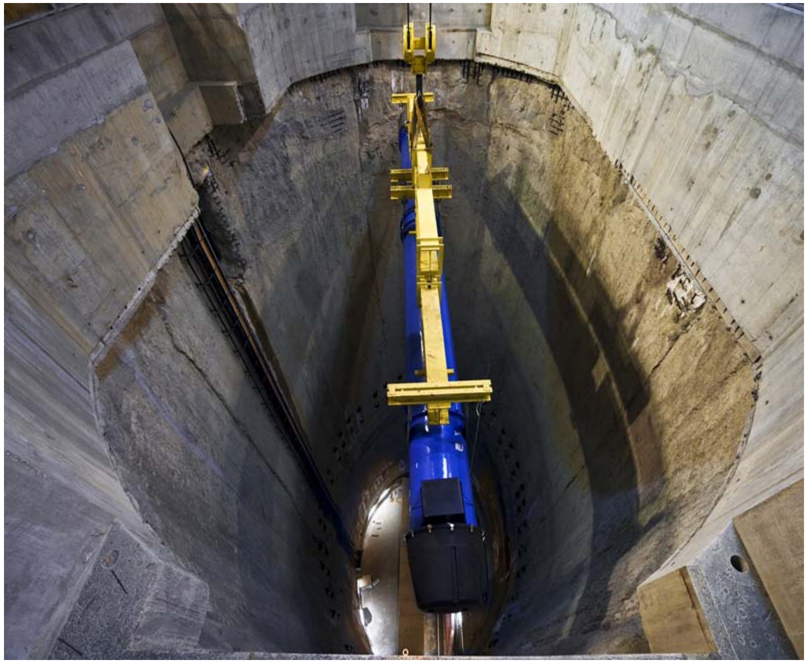
•Operational and performance specifications were not defined until late in the project life cycle, and therefore were not prepared in time for independent reviews.

•Independent reviews were not well documented, were restricted to vague topics, and were conducted based on the judgment of individual scientists and engineers instead of a system-wide set of qualifications.

FOR FUTURE NASA MISSIONS

For NASA:

- The simple miscalculation and resulting failure highlights the importance of thorough processes and procedures not only at Fermilab, but also at knowledge-crucial industries such as NASA.
- Public trust and funding of large, high-energy projects demands true systems engineering and attention to quality from the design stage forward.
- Simulation and testing must account for the whole system operating across and even beyond its design envelope.
- The importance of sharing engineering knowledge across groups is crucial, as the vitality of organizations such as NASA lies largely in the knowledge of its people and their ability to pass that knowledge forward.



A replacement magnet is lowered into the LHC tunnel during a repair process