29th Annual **INCOSE**
international symposium

Orlando, FL, USA
July 20 - 25, 2019

Famous Failures Revisited:
A Focus on Integration

www.incose.org/symp2019

Original Paper on Failures

- *Requirements Development, Verification, and Validation Exhibited in Famous Failures*
  - Bahill, A. T. and Henderson, S. J.,
  - 2005, Systems Engineering, Vol. 8, No. 1, Wiley Periodicals, Inc.
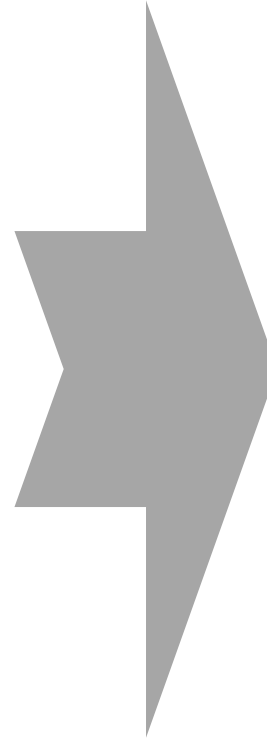
Systems/Events Addressed

- Titanic
- Tacoma Narrows Bridge
- Edsel automobile
- War in Vietnam
- Apollo-13
- Concorde SST
- IBM PCjr
- GE rotary compressor refrigerator
- Space Shuttle Challenger
- Chernoble Nuclear Power Plant
- New Coke
- A-12 airplane

- Hubble Space Telescope
- SuperConducting SuperCollider
- Ariane 5 missile
- UNPROFOR Bosnia Mission
- Lewis Spacecraft
- Motorola Iridium System
- Mars Climate Orbiter
- Mars Polar Lander
- September 11 attack on WTT
- Space Shuttle Columbia
- Northeast power outage

Original Analysis

Table II Did they do these tasks right?				
Name	Year	RD	VER	VAL
Titanic	1912	No	No	Yes
Tacoma Narrows Bridge	1940	Yes	Yes	No
Edsel automobile	1958	Yes	Yes	No
War in Vietnam	1967-72	Yes	Yes	No
Apollo-13	1970	Yes	No	Yes
Concorde SST	1976-2003	Yes	Yes	No
IBM PCjr	1983	No	Yes	Yes
GE rotary compressor refrigerator	1986	Yes	No	Yes
Space Shuttle Challenger	1986	Yes	No	No
Chernobyl Nuclear Power Plant	1986	Yes	Yes	No
New Coke	1988	Yes	Yes	No
A-12 airplane	1980s	No	No	No
Hubble Space Telescope	1990	Yes	No	Yes
SuperConducting SuperCollider	1995	Yes	Yes	No
Ariane 5 missile	1996	Yes	No	No
UNPROFOR Bosnia Mission	1992-95	No	No	No
Lewis Spacecraft	1997	Yes	Yes	No
Motorola Iridium System	1999	Yes	Yes	No
Mars Climate Orbiter	1999	No	No	No
Mars Polar Lander	2000	Yes	No	Yes
September 11 attack on WTT	2001	No	Yes	Yes
Space Shuttle Columbia	2002	Yes	No	No
Northeast power outage	2003	No	Yes	Yes

Assessment of whether Requirements Development, Verification, or Validation was done well

Use in Class on Integration, Verification, and Validation

Table II Did they do these tasks right?					INT
Name	Year	RD	VER	VAL	
Titanic	1912	No	No	Yes	
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- Discussion of conclusions
- Discussion of relevance to course
- Addition of column for integration

In This Paper

- Review of integration issues in original paper
- Addition of other systems with similar issues
- Synthesis of several key concerns that should be addressed in integration
- Not an exhaustive review of all integration issues
  - No instances of system of interest parts not fitting together

Hardware to Hardware – Indirect

- ## Columbia
  - – Tank to Shuttle

- ## Concorde
  - – Tire to FOD to fuel tank
  - – Also, 747 maintenance?

Hardware to Hardware – Under Stress

- ## Challenger O-rings
  - Cold temperatures

- ## Kinzua Bridge
  - Tornado
  - Vertical forces

Software Inputs

- Ariane 5
  - Larger number
  - Equivalence Partitioning tests?
- Mars Polar Lander
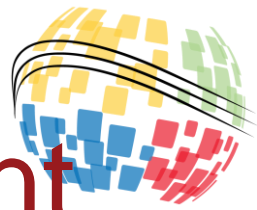 - Spurious touchdown signals
  - Valid input but at wrong time

Surrounding Environment

- ## Tacoma Narrows Bridge
  - High winds
  - Oscillations

- ## Hyatt Walkway
  - Larger loading
  - Dynamic loading
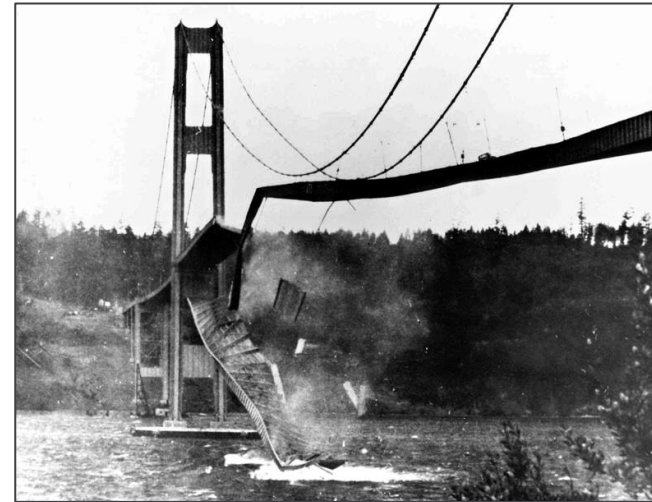
Integration of Technology into Environment

- Tacoma Narrows Bridge
  - New design approaches
- Solid State ILS
  - Early SS use outdoors
  - Lightning problems
- Vigont Dam
  - Concrete
  - Deep valley

ILS Localizer

Human Systems Integration

- Chernobyl
- Air France
- Vincennes
- Footbridges

Enabling Systems

- ## Challenger
  - Transportation
- ## Satellite
  - 1/2g horizontal force
  - Transportation mode?
- ## Tactical Telephone Switch AN/TTC-42
  - 85% single unit replacement
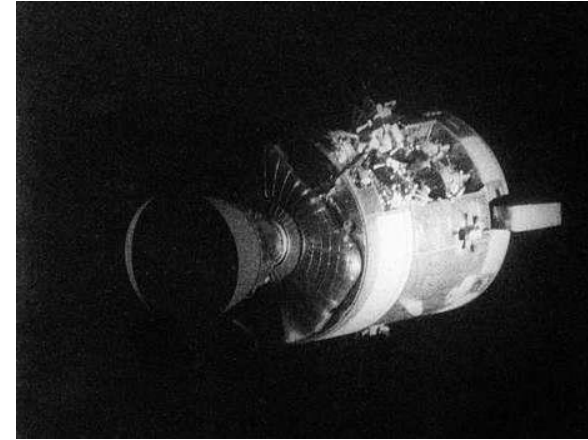 - Maintenance policies

Manufacturing

- ## Hyatt Regency Bridge
  - Installation problems
  - Field Mod

2P

P

P on nut

(a) Original design

Cross-beam section

2P

P

2P on nut

P

(b) Actual construction
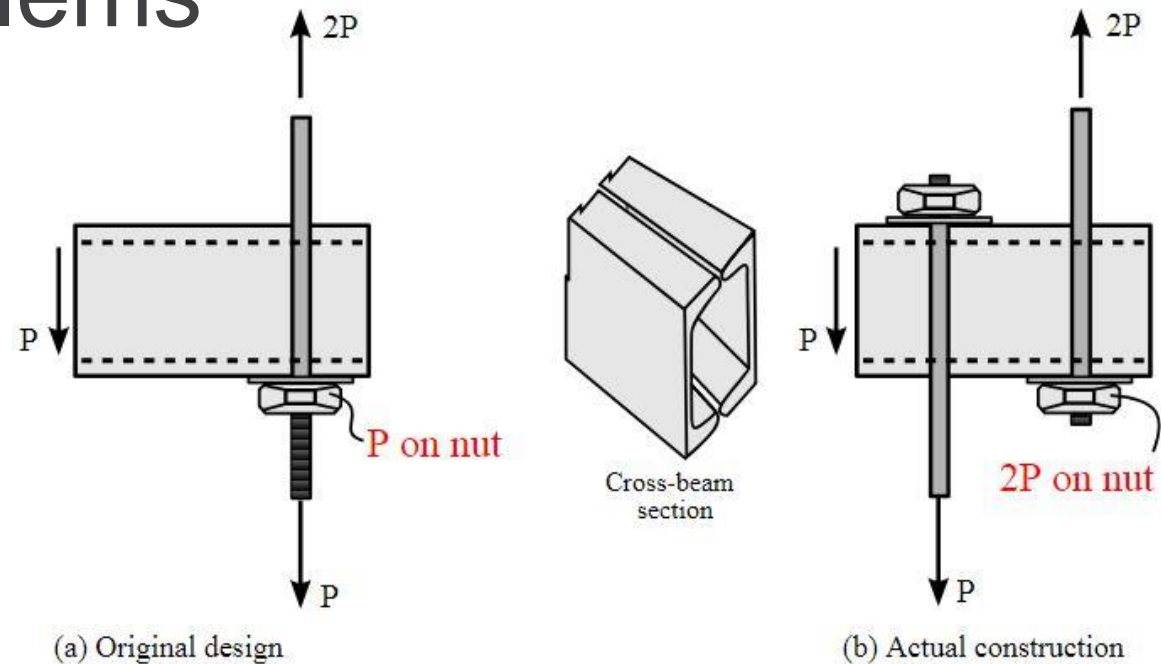
Modifications

- Apollo 13
  - Configuration Issue
- AT&T Switch
  - Mod cause system outage
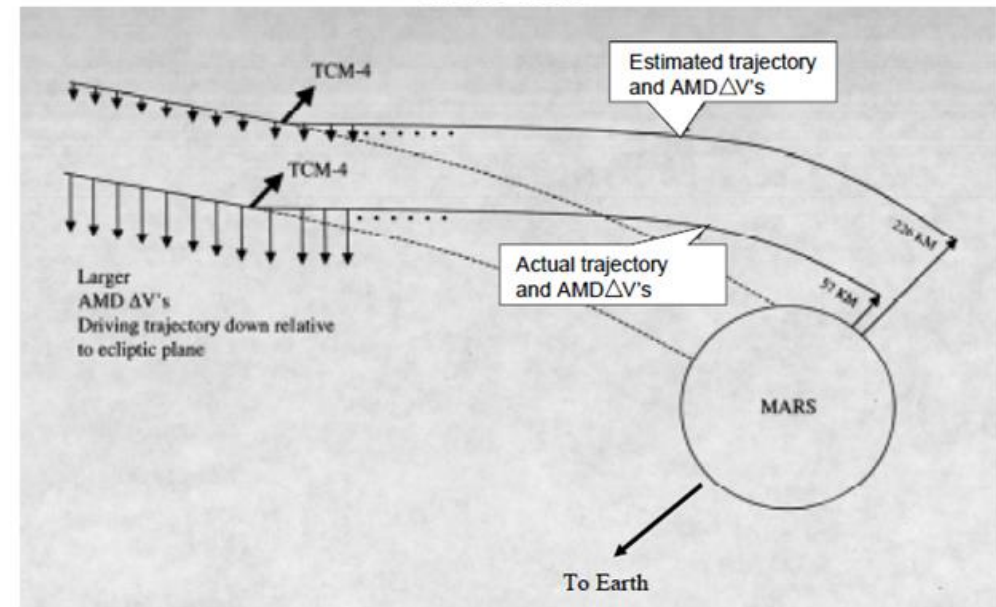- American Airlines ipad
  - New charts

Conway's Law

- Mars Climate Orbiter
  - Metrics vs. English
  - LMCO/JPL/NASA
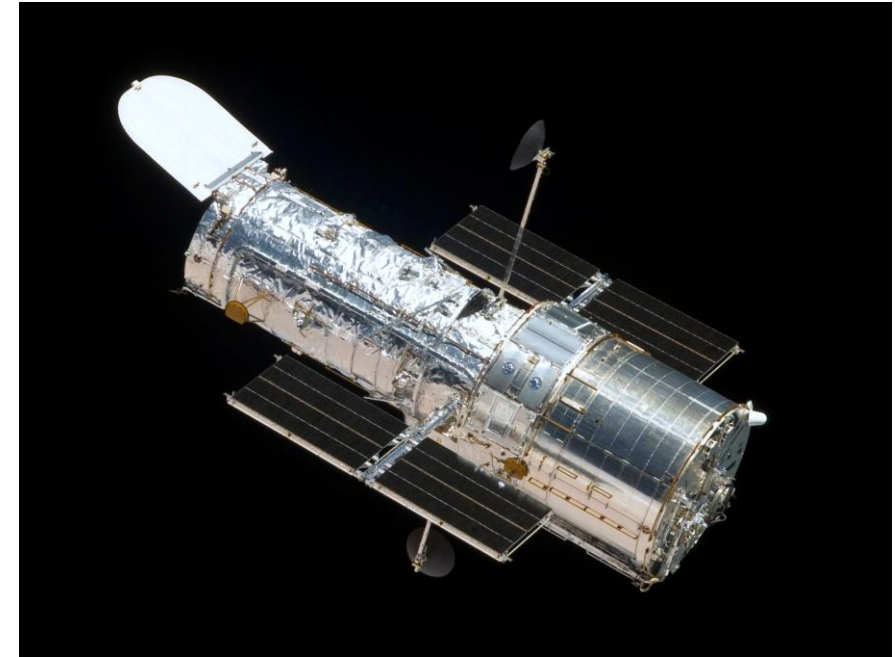 - Root cause, not only factor in failure

Schematic MCO Encounter Diagram
Not to scale

Integration Related Verification

- Hubble
  - Lens testing

- Mars Climate Orbiter
  - ICD units verification

- Mars Polar Lander
  - Retest of full sequence

Summary of Things to Think About

- Indirect interaction
- Abnormal conditions
- Invalid software inputs
- External environment
- Technology Integration

- Human Systems
- Enabling Systems
- Manufacturing
- Modifications
- Conway's Law

Bonus: Integration Related Verification

Concluding Note

- Not all issues
  - Hundreds of bridge incidents alone
- Many from long ago, but
  - Fire trucks not fitting stations, etc.
  - Trains not fitting stations, etc.
  - Albuquerque Rapid Transit

Final Thought

"It's not that we shoot ourselves in the foot that surprises me…
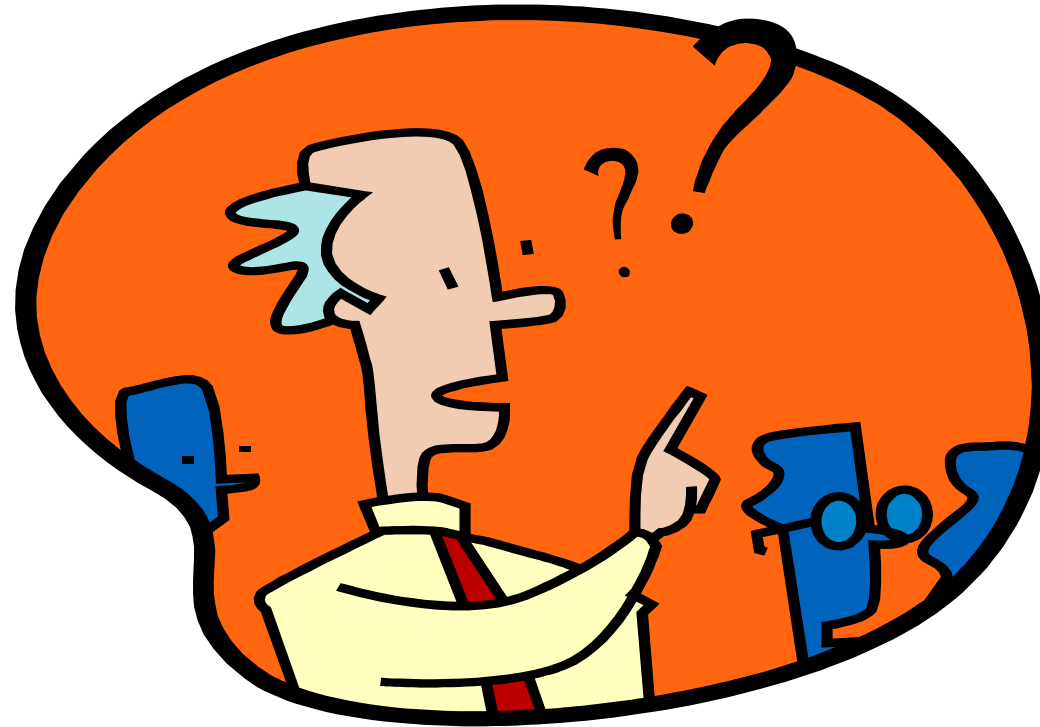

…it's how fast we reload!"

- Anonymous

Bonus Extra: Things I Emphasize in Class

- External Interfaces
  - Portland water treatment plant
  - Original budget $500m
  - Connecting pipes not included - $350m
- Understanding other side functionality
  - "NULL" Calif. personal license plate
  - Intent – avoid parking tickets
  - Result – Over $12k in ticket charges
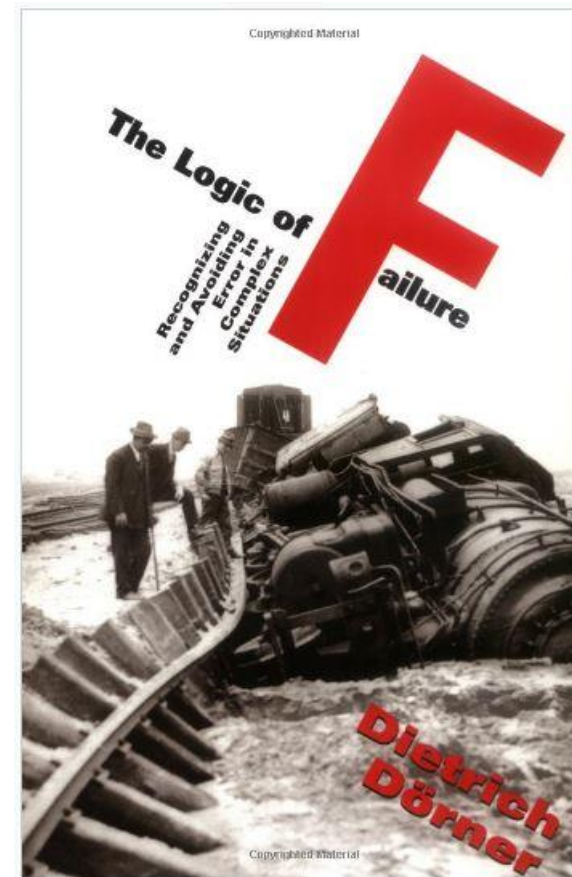
- AARP Bulletin, Nov 2019

Questions?

Drawing

- The Logic of Failure: Recognizing and Avoiding Error in Complex Situations - Dietrich Dorner

- Two Main Issues
  - Non-linear behavior
  - Time delays

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