# *risk*

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## *risk management*

- about risk
  - risk is the possibility of suffering loss
  - risk itself is not bad, it is essential to progress
  - the challenge is to manage the amount of risk
- two parts:
  - risk assessment
  - risk control
- useful concepts:
  - for each risk: Risk Exposure

    **RE = p(unsatisfactory outcome) × loss(unsatisfactory outcome)**
  - for each mitigation action: Risk Reduction Leverage

    **RRL = $(RE_{before} - RE_{after})$ ÷ cost of mitigating action**

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## *risk management (2)*

- **RRL > 1:** good ROI, do it if you have the money
- **RRL = 1:** the reduction in risk exposure equals the cost of the mitigating action. could pay the cost to fix instead (always?)
- **0 < RRL < 1:** costs more than you save. still improves the situation, but losing $$
- **RRL < 0:** mitigating action actually made things worse! don't do it!

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## *risk assessment*

- quantative:
  - measure risk exposure using standard cost & probability measures (probabilities are rarely independent!)
- qualitative:
  - develop a risk exposure matrix

| | | Likelihood of Occurrence | | |
|---|---|---|---|---|
| | | Very likely | Possible | Unlikely |
| Undesirable outcome | (5) Loss of Life | Catastrophic | Catastrophic | Severe |
| | (4) Loss of Spacecraft | Catastrophic | Severe | Severe |
| | (3) Loss of Mission | Severe | Severe | High |
| | (2) Degraded Mission | High | Moderate | Low |
| | (1) Inconvenience | Moderate | Low | Low |

## *some risks and countermeasures*

- personnel shortfall
  - use top talent
  - team building
  - training
- unrealistic schedule/ budget
  - multisource estimation
  - designing to cost
  - requirements scrubbing
- developing the wrong functions
  - better requirements analysis
- continuing requirements changes
  - high change threshold
  - incremental development
  - agile methods
- developing wrong UI
  - use cases
  - prototypes
- gold plating
  - cost-benefit analysis
  - proper planning

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## *case studies*



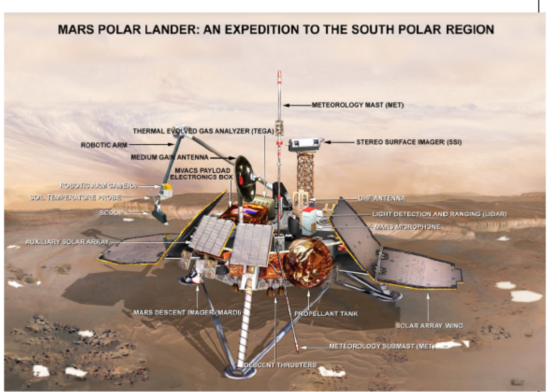
# Case Study: Mars Polar Lander

**Launched**
- 3 Jan 1999

**Mission**
- Land near South Pole
- Dig for water ice with a robotic arm

**Fate:**
- Arrived 3 Dec 1999
- No signal received after initial phase of descent

**Cause:**
- Several candidate causes
- Most likely is premature engine shutdown due to noise on leg sensors







University of Toronto
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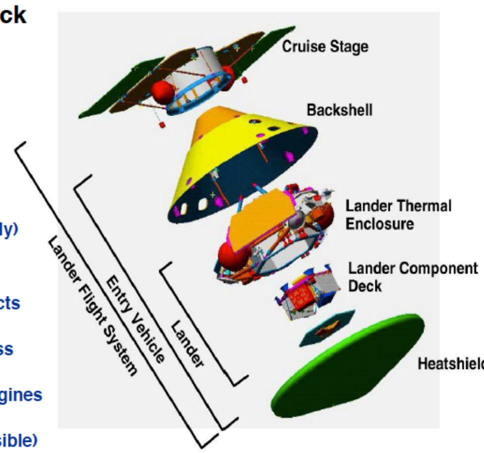
# What happened?

**Investigation hampered by lack of data**
- spacecraft not designed to send telemetry during descent
- This decision severely criticized by review boards

**Possible causes:**
- Lander failed to separate from cruise stage (plausible but unlikely)
- Landing site too steep (plausible)
- Heatshield failed (plausible)
- Loss of control due to dynamic effects (plausible)
- Loss of control due to center-of-mass shift (plausible)
- Premature Shutdown of Descent Engines (most likely!)
- Parachute drapes over lander (plausible)
- Backshell hits lander (plausible but unlikely)



# Premature Shutdown Scenario

## Cause of error

- Magnetic sensor on each leg senses touchdown
- Legs unfold at 1500m above surface
- software accepts transient signals on touchdown sensors during unfolding

## Factors

- System requirement to ignore the transient signals
- But the software requirements did not describe the effect
- Engineers present at code inspection didn't understand the effect
- Not caught in testing because:
- Unit testing didn't include the transients
- Sensors improperly wired during integration tests (no touchdown detected!)

## Result of error

- Engines shut down before spacecraft has landed
- estimated at 40m above surface, travelling at 13 m/s
- estimated impact velocity 22m/s (spacecraft would not survive this)
- nominal touchdown velocity 2.4m/s






**SYSTEM REQUIREMENTS**

1) The touchdown sensors shall be sampled at 100-Hz rate.

The sampling process shall be initiated prior to lander entry to keep processor demand constant.

However, the use of the touchdown sensor data shall not begin until 12 meters above the surface.

2) Each of the 3 touchdown sensors shall be tested automatically and independently prior to use of the touchdown sensor data in the onboard logic.

The test shall consist of two (2) sequential sensor readings showing the expected sensor status.

If a sensor appears failed, it shall not be considered in the descent engine termination decision.

3) Touchdown determination shall be based on two sequential reads of a single sensor indicating touchdown.

**FLIGHT SOFTWARE REQUIREMENTS**

3.7.2.2.4.2 Processing

a. The lander flight software shall cyclically check the state of each of the three touchdown sensors (one at 100 Hz during EDL.

b. The lander flight software shall be able to cyclically check the touchdown event state with or without touchdown event generation enabled.

c. Upon enabling touchdown event generation, the lan flight software shall attempt to detect failed sens marking the sensor as bad when the sensor indicat "touchdown state" on two consecutive reads.

d. The lander flight software shall generate the landin event based on two consecutive reads indicating touchdown from any one of the "good" touchdown sensors.

Adapted from the "Report of the Loss of the Mars Polar Lander and Deep Space 2 Missions -- JPL Special Review Board (Casani Report) - March 2000".
See http://www.nasa.gov/newsinfo/marsreports.html






# Lessons?

**Documentation is no substitute for real communication**

**Software bugs hide behind other bugs**
(full regression testing essential!)

**Fixed cost + fixed schedule = increased risk**






# Case Study: Mars Climate Orbiter

## Launched

- 11 Dec 1998

## Mission

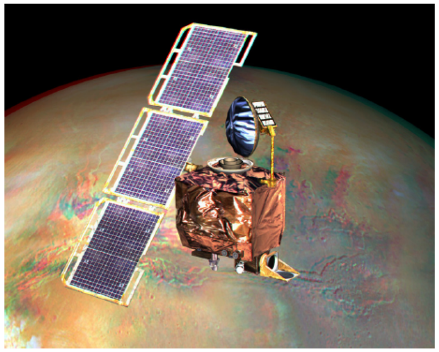
- interplanetary weather satellite
- communications relay for Mars Polar Lander

## Fate:

- Arrived 23 Sept 1999
- No signal received after initial orbit insertion

## Cause:

- Faulty navigation data caused by failure to convert imperial to metric units



# MCO Events

## Locus of error
- Ground software file called “Small Forces” gives thruster performance data
  - data used to process telemetry from the spacecraft
- Angular Momentum Desaturation (AMD) maneuver effects underestimated
  - (by factor of 4.45)

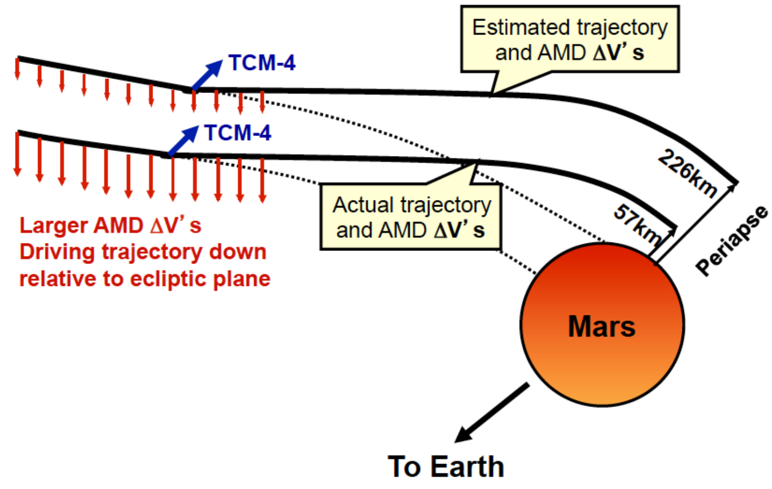
## Cause of error
- Small Forces Data given in Pounds-seconds (lbf-s)
- The specification called for Newton-seconds (N-s)

## Result of error
- As spacecraft approaches orbit insertion, trajectory is corrected
  - Aimed for periapse of 226km on first orbit
- Estimates were adjusted as the spacecraft approached orbit insertion:
  - 1 week prior: first periapse estimated at 150-170km
  - 1 hour prior: this was down to 110km
  - Minimum periapse considered survivable is 85km
- MCO entered Mars occultation 49 seconds earlier than predicted
  - Signal was never regained after the predicted 21 minute occultation
  - Subsequent analysis estimates first periapse of 57km






# MCO Navigation Error









# Contributing Factors

## For 4 months, AMD data not used (file format errors)
- Navigators calculated data by hand
- File format fixed by April 1999
- Anomalies in the computed trajectory became apparent almost immediately

## Limited ability to investigate:
- Thrust effects measured along line of sight using doppler shift
- AMD thrusts are mainly perpendicular to line of sight

## Poor communication
- Navigation team not involved in key design decisions
- Navigation team did not report the anomalies in the issue tracking system

## Inadequate staffing
- Operations team monitoring 3 missions simultaneously (MGS, MCO and MPL)

## Operations Navigation team unfamiliar with spacecraft
- Different team from development & test
- Did not fully understand significance of the anomalies
- Surprised that AMD was performed 10-14 times more than expected

## Inadequate Testing
- Software Interface Spec not used during unit test of small forces software
- End-to-end test of ground software was never completed
- Ground software considered less critical

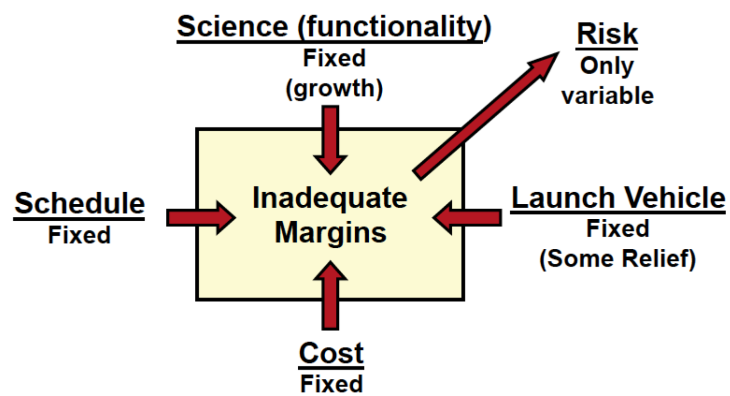
## Inadequate Reviews
- Key personnel missing from critical design reviews

## Inadquate margins…






# Failure to manage risk




Adapted from MPIAT - Mars Program Independent Assessment Team Summary Report, NASA JPL, March 14, 2000.
See http://www.nasa.gov/newsinfo/marsreports.html

## *down-to-earth examples*

**THE RISKS DIGEST**

forum on risks to the public in computers & related systems

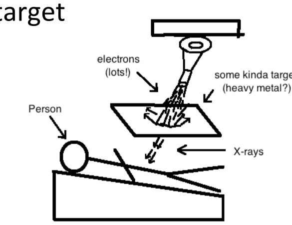
been around since 1985

http://catless.ncl.ac.uk/Risks/



## *down-to-earth examples (2)*

- therac-25 from AECL, 1985-87
  - http://catless.ncl.ac.uk/Risks/3.11.html#subj1
  - http://en.wikipedia.org/wiki/Therac-25
- radiation therapy machine
  - two modes:
    - low dose, short period, electron-beam
    - megavolt x-ray therapy, collides high-dose, high-energy electron beam with target
- problem: could be made to operate w/o target in place!






## *down-to-earth examples (3)*

- a less tragic example...
- in 1995 an "*abandoned oil tank phone harasses ma woman for 6 months*"
  - http://catless.ncl.ac.uk/Risks/17.34.html#subj3.1
- old oil tank (???) rigged to call the oil company every 90 minutes when low
- configured with wrong number of poor unsuspecting woman
- pick up phone, say "*hello?*", no answer
- why did it take phone co. six months to trace? c'mon, really?



## *lessons?*

- if it doesn't behave how you expect it's not safe
- if your teams don't coordinate neither will their software (is this Conway again?)
- with software, everything is connected to everything else – every subsystem is critical

## lessons? (2)

- full communication is only possible among peers; subordinates are too reoutinely rewarded for telling pleasant lies rather than the truth
  - do you agree?
- Not a good idea to have the IV&V team and R&D team reporting to the same person
  - why not?



## Principles of Risk Management

*Source: Adapted from SEI Continuous Risk Management Guidebook*

**Global Perspective**
- View software in context of a larger system
- For any opportunity, identify both:
  - Potential value
  - Potential impact of adverse results

**Forward Looking View**
- Anticipate possible outcomes
- Identify uncertainty
- Manage resources accordingly

**Open Communications**
- Free-flowing information at all project levels
- Value the individual voice
  - Unique knowledge and insights

**Integrated Management**
- Project management is risk management!

**Continuous Process**
- Continually identify and manage risks
- Maintain constant vigilance

**Shared Product Vision**
- Everybody understands the mission
  - Common purpose
  - Collective responsibility
  - Shared ownership
- Focus on results

**Teamwork**
- Work cooperatively to achieve the common goal
- Pool talent, skills and knowledge






## Continuous Risk Management

*Source: Adapted from SEI Continuous Risk Management Guidebook*

**Identify:**
- Search for and locate risks before they become problems
  - Systematic techniques to discover risks

**Analyse:**
- Transform risk data into decision-making information
- For each risk, evaluate:
  - Impact
  - Probability
  - Timeframe
- Classify and Prioritise Risks

**Plan**
- Choose risk mitigation actions

**Track**
- Monitor risk indicators
- Reassess risks

**Control**
- Correct for deviations from the risk mitigation plans

**Communicate**
- Share information on current and emerging risks







## Identifying Risks: Fault Tree Analysis

*Source: Adapted from Leveson, "Safeware", p321*