MEEN 10060: Design & Materials

Design Process -

Typical Reasons for Design Failure

Week 1 Lecture 2

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Design material courtesy of David FitzPatrick

Logistics

Timetable for Beam & CAD Laboratories

Blackboard contains two files

1. Offering 1
2. Offering 2

Identify your group and the document contains your lab timetable for this course

MEEN 10060: CAD Labs

CAD (Newstead – F15 (Tutorial); F20 & G80 (Lab))

- Tutorial – Thu: **14:00-14:50** (Split Odd / Even weeks)
- Lab - Thu: **15:00-16:50** (Split Odd / Even weeks)

NOTE: Starts **Thurs 23rd** January for Offering 1 (**Tomorrow**)

Starts **Thurs 30th** January for Offering 2 (**Next week**)

If possible, please download ArchiCAD for your own laptop and test it before coming to the Lab.

MEEN 10060: Design Lab

Design/Materials Lab (Starts in week 3: w/c 3rd Feb)

- Tue: **15:00-16:50** (Split Odd / Even weeks)
- Thu: **15:00-16:50** (Split Odd / Even weeks)

Offering 1 starts in **Week 3** on **Tuesday** Feb 4th

(Newstead - G70; G87 & G88)

Offering 2 starts in **Week 3** on **Thursday** Feb 6th

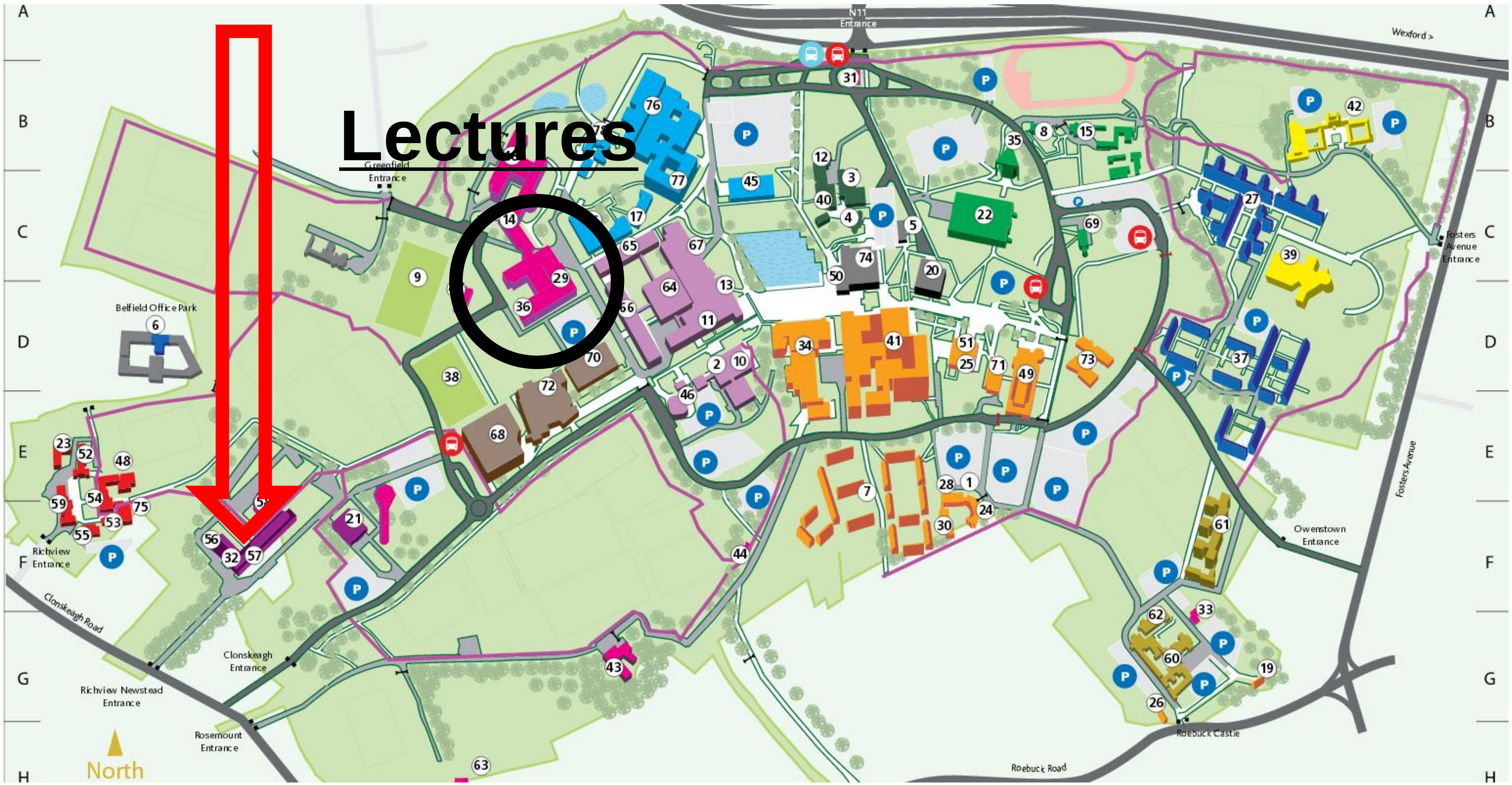
Newstead - G87 & G88

NOTE: Lab Offerings will be redefined due to capacity

Where is Newstead

Newstead for Labs

Lectures



Building 57 on the UCD map

Overview of Lecture Material

- Design: 6 lectures (3 weeks)
- Materials: 7 lectures (4 weeks)

- **Mid-term break (2 weeks)**

- Materials 4/5 lectures (3 weeks)
- Design: Reports 1 lecture
- Materials: MCQ exam (1 week, last lecture before Easter)
- Results of Beam Lab (Last Lecture)

Quick Recap

Recap - Characteristics of ‘good’ design

- You know it when you see it
- Minimalist — meets requirements in an efficient manner
- Wow factor — leaps out at you
- Robust — failure-resistant
- "Anticipatory" — easily modified to overcome unanticipated problems (this is subtle but important)
- Adaptable ; Expandable & Flexible
- Combines functions to increase efficiency — mounting bracket doubles as heat sink, etc.

Last Class – Examples of 'Good' Design

Some examples:

- Smart phones/Tablets
- Mercedez C180
- Your paper plane?
- …

Attributes:

- Efficient
- Easy to Use
- Reliable
- Convenient
- Affordable / cost effective
- …

Today's lecture:
What can we learn from bad design – especially design failures?

Big Idea for Today's Lecture

What lessons can be learned from high profile design failures?

Classic Design Failures

1. Charnley hip replacement (Circa 1960)
2. DeHavilland Comet aircraft (1949-1954)
3. Sinclair C5 Electric Vehicle (mid 1980's)
4. Warship 'VASA' (1628)

Classic Design Failures 1

Charnley hip (Circa 1960)

- Wrong choice of materials led to very high wear rates
- Used PTFE (very low friction) as the polymer element
  - Low friction because it 'sheds' it surface layer - very weak interlayer bonding

Solution

- Change the bearing material to High Molecular Wt. Polyethylene

Image -courtesy of Dr. A. Carr

Read: ' Charnley – The Man & the Hip' by W. Waugh (1990)

Classic Design Failures 2

De Havilland Comet aircraft (1949-1954)

- First commercial jet airliner (1952)
- 3 in-flight failures – fuselage structural failure
- Poor understanding of technology and suitable manufacturing methods/processes
- Small radii in corners of windows & differential expansion of outer and inner skins led to crack propagation through the skin of the aircraft.

Solution

- Redesign stress regions to reduce crack initiation
- Re-engineer the manufacturing process

Read: 'No Highway' by Nevil Shute

Classic Design Failures 3

Sinclair C5 (~1985)

- Low market appeal
- Poor performance even over short distance
- Danger from other traffic because so low to the ground
- Poor value for money

Solution

- Stop manufacture
- Market withdrawal

Additional information: http://en.wikipedia.org/wiki/Sinclair_C5

Classic Design Failures 4

1628 A.D. - Swedish Warship '*VASA*'

Background

- King Gustavus Adolphus on the throne - ambitious and aggressive.
- Sweden at war with Poland and Empire building around the Baltic Sea.
- Increase in naval power required.
- 1625 - GA orders the design and manufacture of several new naval ships, including the biggest and most heavily armed ship of its time - the VASA.

Warship 'VASA'

Key technology factors:

- Naval warfare technology changing
  - pre 1620's - light guns and soldiers (capture)
  - post 1620' - heavy guns - 'Ships of the Line'
- VASA to be heavily armed
  - 64 x 20lb cannons (heavy artillery at the time)
  - two gun decks with heavy cannons
- Shipbuilding
  - Skill & know-how based design and manufacture
  - Use of 'reckonings' to determine 'safe' designs

Warship ‘VASA’ - Key Players

- King Gustavus Adolphus
  - wanted as many heavily armed ships as possible. Had ‘approved’ the VASA’s dimensions and wanted her built rapidly.
- Admiral Klas Fleming
  - One of the most influential men in the Navy. Responsible for overseeing the project and commissioning.
- Henrik Hybertsson (Shipbuilder)
  - Very experienced, brought in from the Netherlands for the project. Died the year before completion of the ship.
- Captain Sofring Hansson
  - In command on maiden voyage.

Warship ‘VASA’ - Chronology

- Order placed in 1625
  - To be ready as soon as possible.
- Design & Build 1625 - 1628
  - Completed by the son of Henrik Hybertsson, following his death in1627. ‘Reckonings’ used were those for previous, smaller, ships with one gun deck.
- Launched Stockholm 1628
  - Validation carried out - Stability tests with ship moored to quay.
- Maiden voyage August 10th 1628
  - Used as a publicity coup with a huge crowd, including invited foreign diplomats.
  - **Set sail and fired a salute; Sailed on, briefly, heeled over and sank!**

VASA - Lack of Scientific Knowledge

<u>Incomplete Validation:</u>

'Thirty men had run back and forth across the Vasa's deck when she was moored at the quay. The men had to stop after three runs, well before the test could be completed - otherwise, the ship would have capsized.'

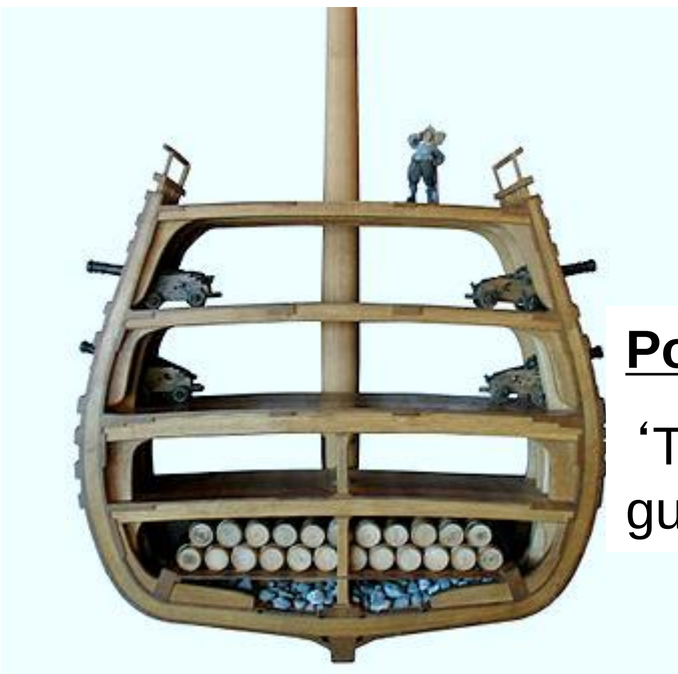


Image from Wikipedia

<u>Poor Design:</u>

'The ballast was not enough as counterweight to the guns, the upper hull, masts and sails of the ship.'

<u>UK equivalent?</u>

Vasa - Conclusions

‘... the inquiries showed that no one could really be blamed for the disaster. The main reason being the insufficient theoretical know-how of the period.’

‘The Vasa was something new - a military experiment. After the Vasa, many successful ships were built with two, three and even four gundecks. The shipbuilders learned from their mistakes with the Vasa and improved later designs.’

(Source: VASA Museum Archives)

Class exercise 3

Other High-Profile Design Failures

- Team Philips ‘Super-Cat’ (2000)
- Space Shuttle
  - Challenger (1986)
  - Columbia (2003)
- Toyota Accelerator Recall (2010)

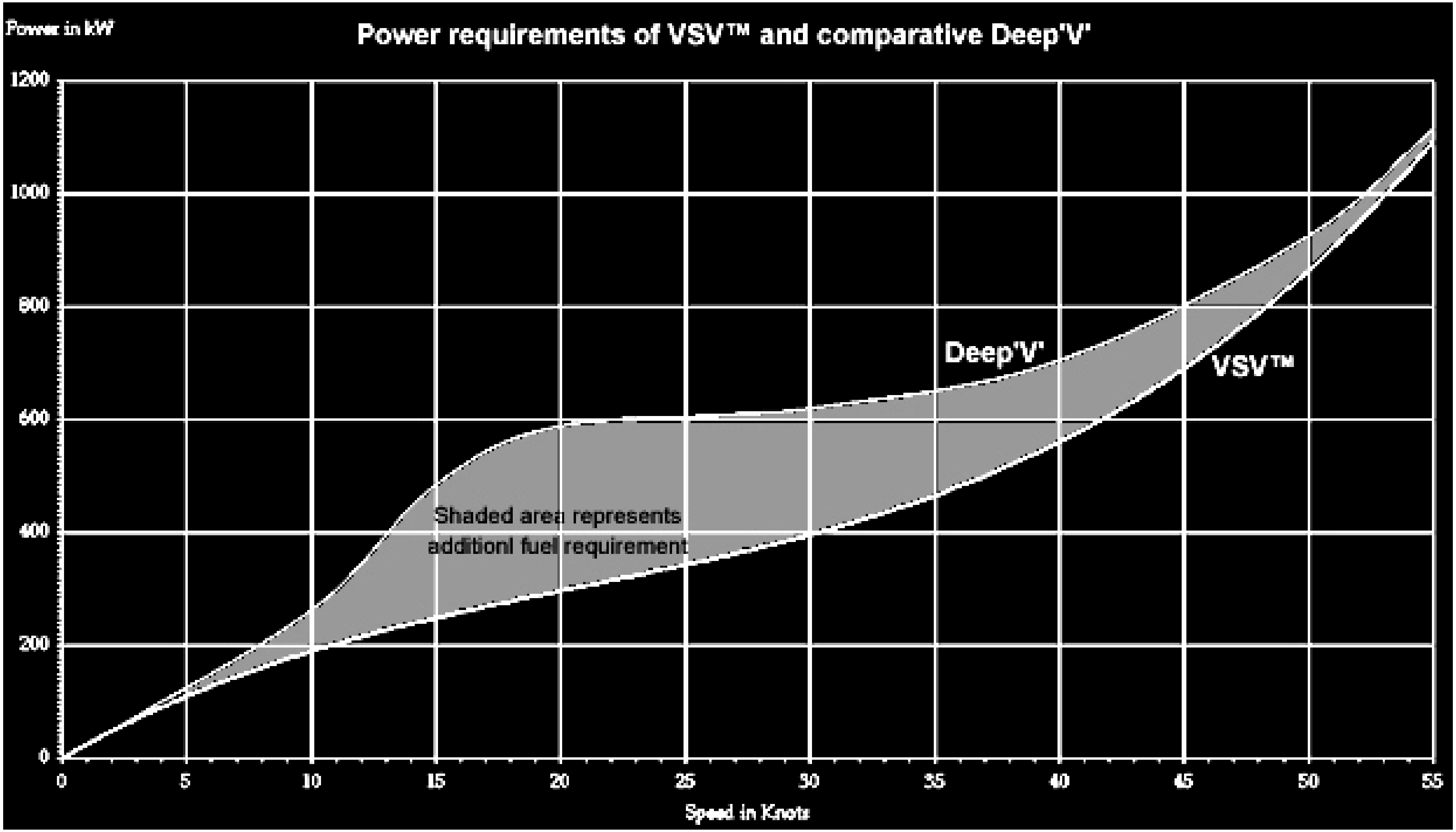
Team Philips - ‘Supercat’

- ‘VSV™ Design
- Revolutionary design - based on ‘wave piercing’ concept.
- VSV™ concept - slender elliptical sectioned body, beam to length ratio > 6:1

VSV™ Design

- VSV™ - 'Very Slender Vessel'
  - Low power requirement – efficient hull form
  - Wave piercing design – reduced 'g' loads
- Patented & registered design
- First boat designed in 1990 by Adrian Thompson for 6 people, to operate in the Irish Sea in all weathers
- Mk III used by SBS since 1999

VSV ™ - Power Requirements



Source: http://www.vsvboats.com/

Team Philips - Core Facts

- Novel design - commissioned in 1998
  - Adrian Thompson commissioned for design
- Objective to participate in 'The Race' - round the world yacht race, starting Dec 31 2000.

- Key principles:
  - Wave piercing catamaran hull form
  - Free standing masts
  - Composite material construction
    - The world's largest carbon composite structure

'Team Philips' - Design Features

- Configuration
  - Catamaran, with centre accommodation 'pod'
  - Total weight ~ '3 small elephants'
- Hull Form
  - Designed to cut through waves rather than ride them
  - 37m (120 ft) long; 2.7m (9ft) high; 1.4m (4' 6'') width
- Mast & Sails
  - Mast shaped like an aerofoil, freely rotating in hull
  - Sails designed with CAD, manuf. from composites
- Cross Beams
  - Most complex area of design - provide structural integrity to whole boat.
  - Hold accommodation pod high off the water

‘Natural Design’ – Risk/Reward

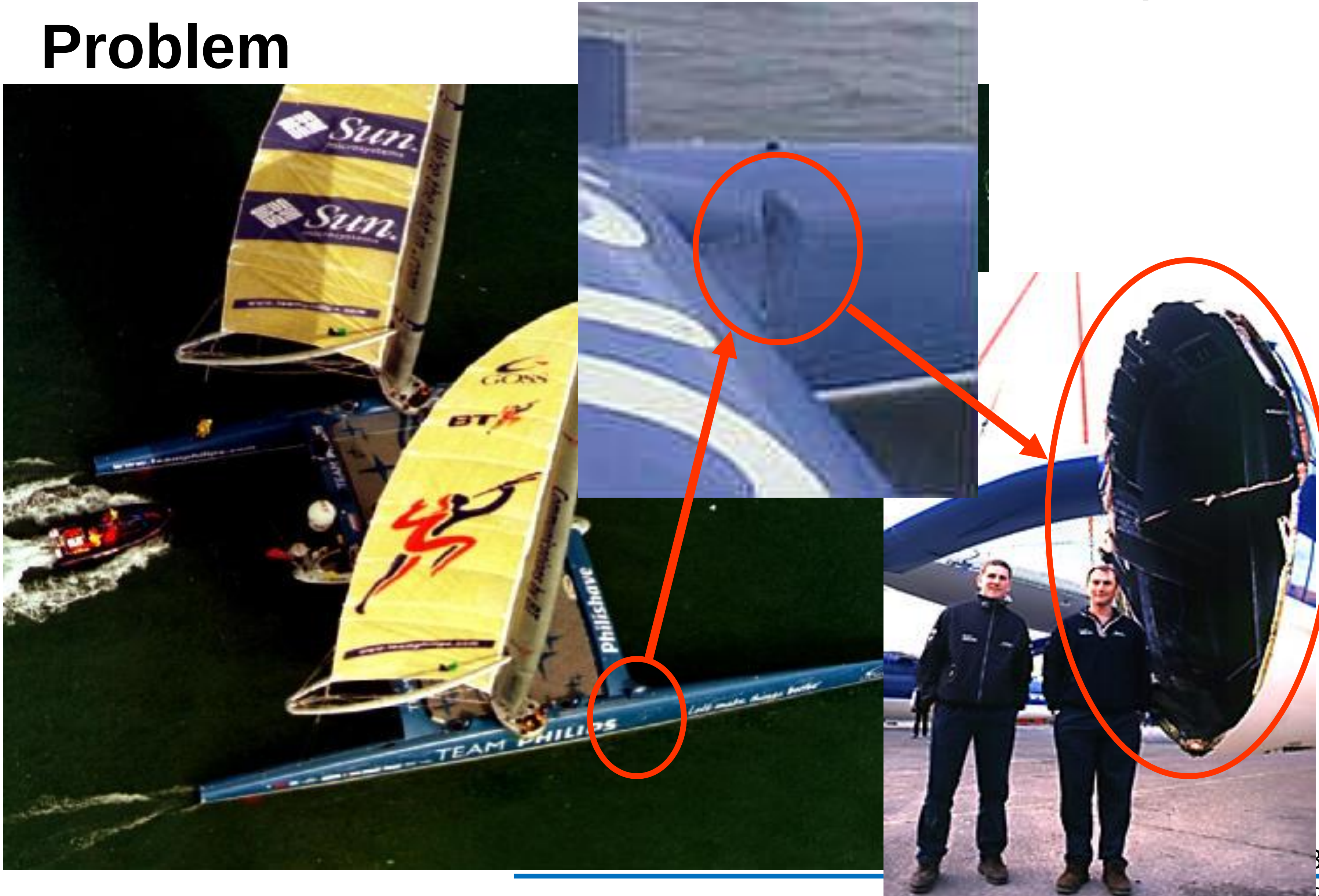
‘Our challenge, in engineering terms, has been to develop something slender, but strong enough to the do the job.’

‘It's a big responsibility, which involves finely honed decisions based on degrees of risk. Simply, a boat that is impossible to break will never win.’

Adrian Thompson (Designer)

First Sea Trial – Process Development

Problem

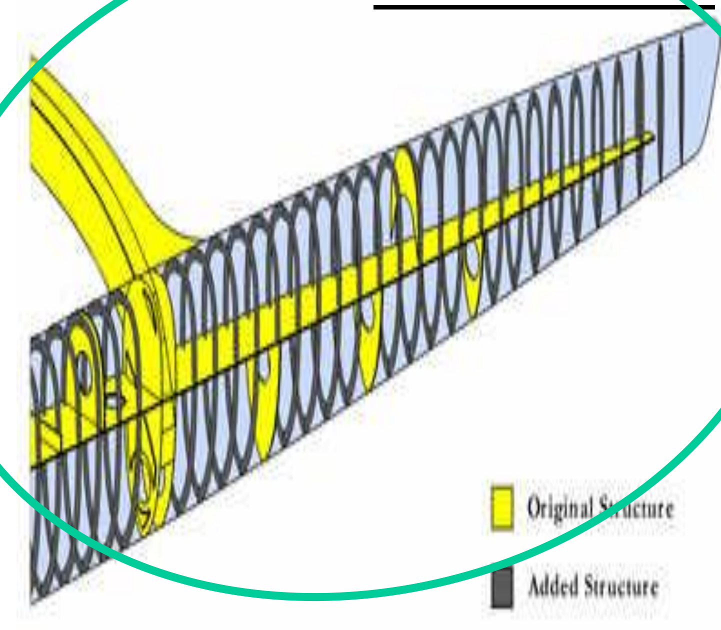


Team Philips - Process Development

"The 45 ft port bow section of Team Philips failed due to a production problem.

Solution

…



The solution will add a series of stringers and ring frames to each hull making them strong enough to withstand the loads that will be applied to them in the Southern Ocean."

(Source - Team Philips Archives)

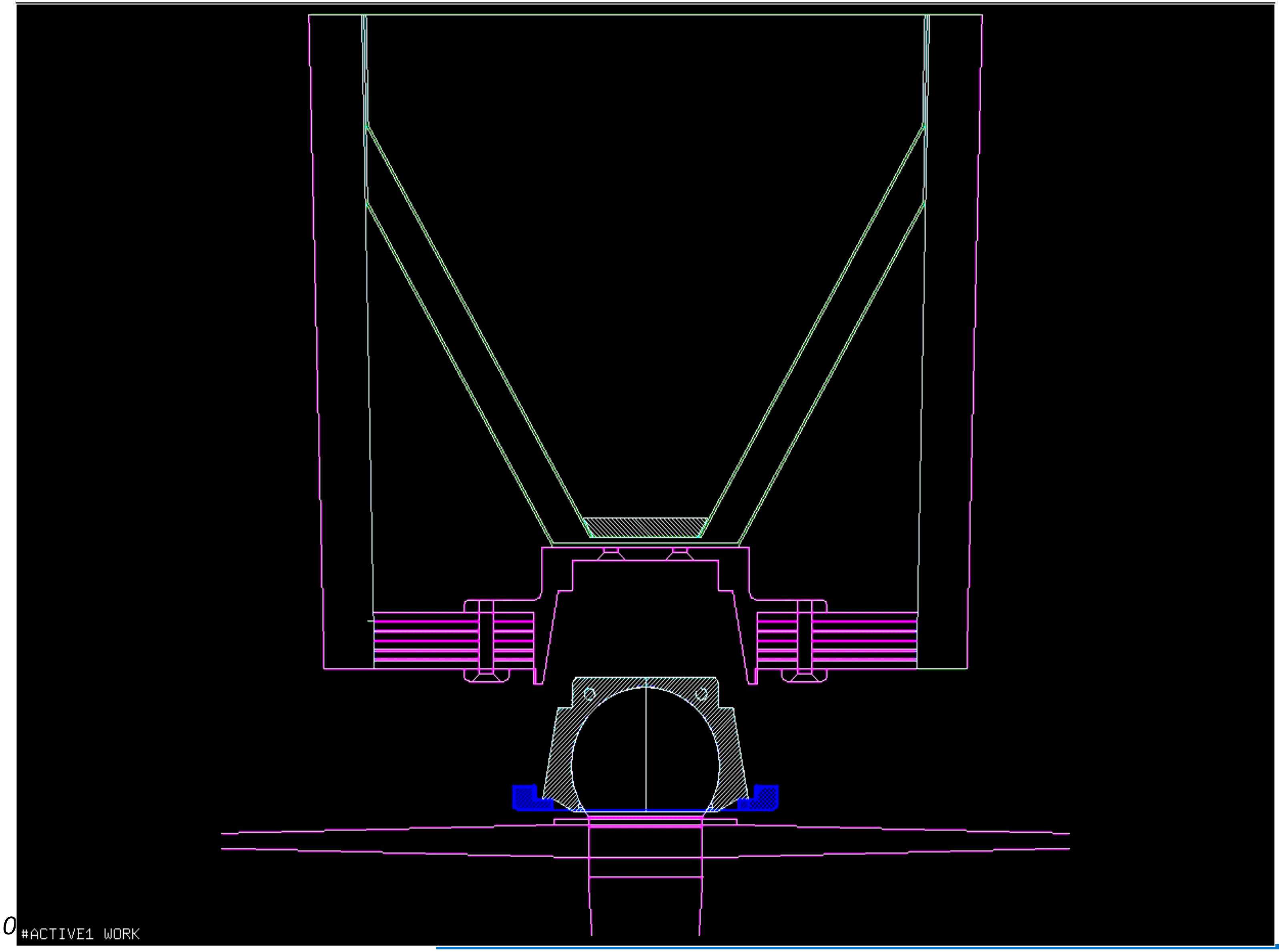
Second Trial - Mast Design Failure

'When she was good, she was very very good... But when she was bad, she was horrid'

Sailing at 25 Knots (October 2000)

Mast base - Cone Failure

Team Philips - Mast Redesign



Team Philips-Second Failure: Mechanical Design

- Ball & Socket bearing at base of mast failed
  - Designed to carry the full vertical load of the mast and to allow 360° axial rotation
  - Lubrication failure and bearing collapse!
- Mast design had been validated
  - BUT not in conjunction with the mast bearing geometry
  - all testing had been under static loads
- Poor implementation of existing, understood, technology.

Performance Problems - Summary

First sea trial (March 2000)

- Concept proven, high speeds attained
- Bow failure - one complete, one partial

Second sea trial (October 2000)

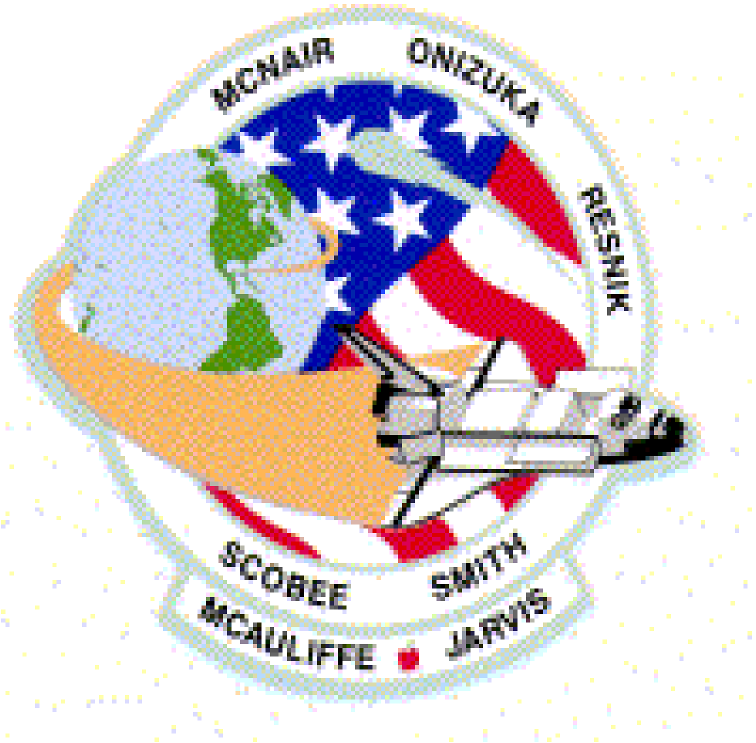
- Strengthened bows performed well
- Mast bearing failure

Race Qualifying trial (December 2000)

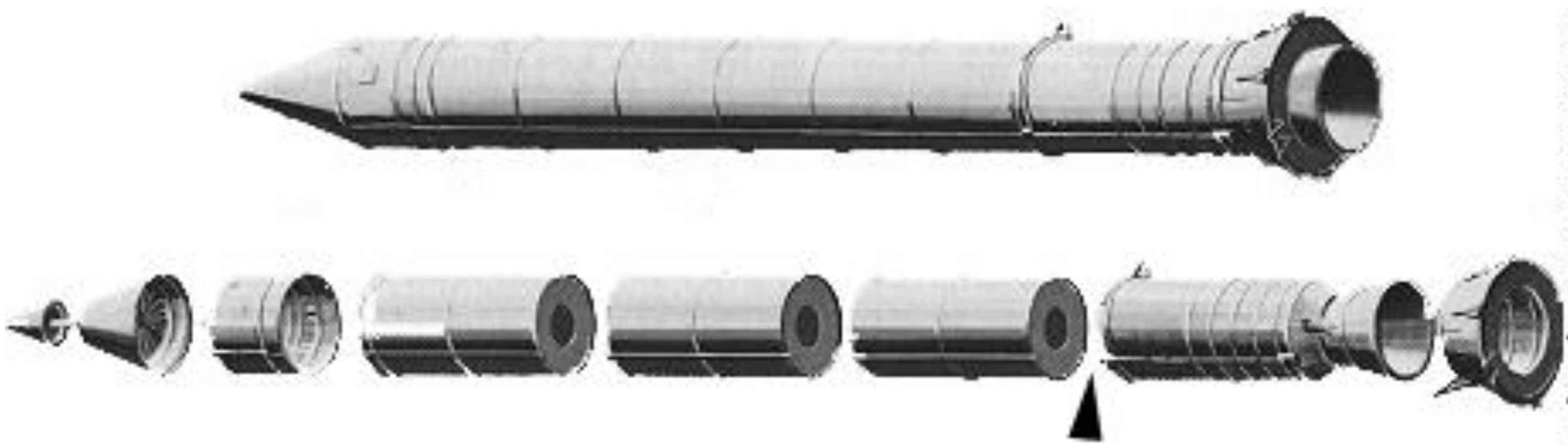
- Heavy seas in Atlantic
- Central pod hit by successive 'big' waves
- **Failure of pod & hull integrity - SANK!**

NASA - Space Shuttle ‘Challenger’

January 28th 1986



Challenger SRB ‘Field Joints’



- SRB’s built by Morton Thiokol Inc. (Utah)
- Shipped by rail to NASA (Florida)
- Necessitated final assembly at NASA and the need to provide a means of modular assembly and sealing

Space Shuttle - Background

– **Shuttle Design**
  - Developed without a firm application.
  - Sold to politicians as giving a ‘quick payoff’; to military as a means of incr. National security and to industry as a new commercial opportunity.
  - Development decisions made to meet the needs of organisational, political and economic factors rather than specific mission goals.

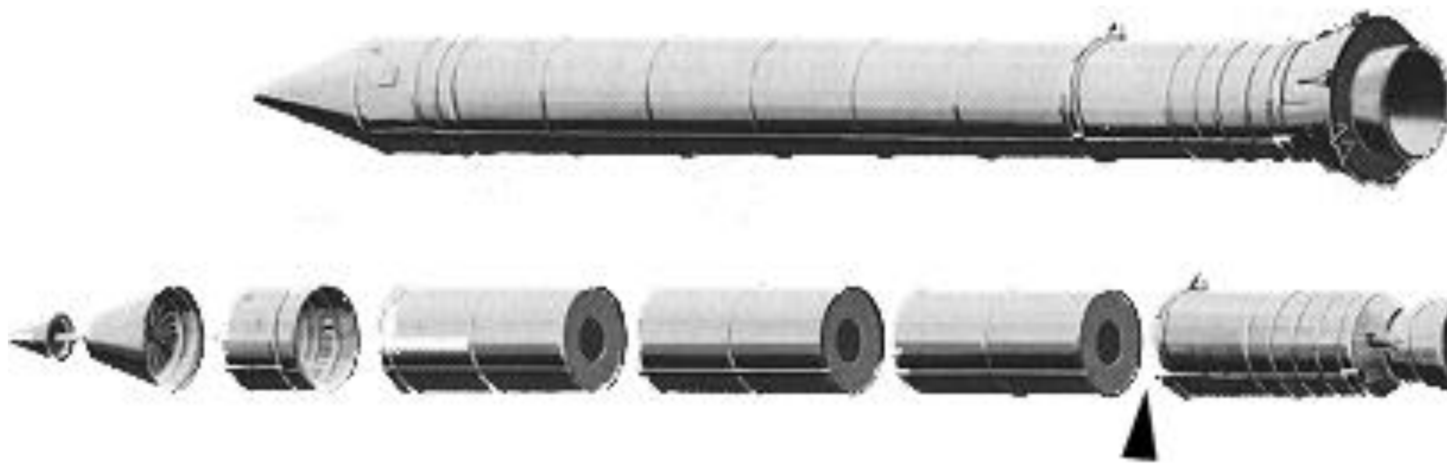
– **Space programme**
  - Space programme had become boring in public eye.
  - Accelerated launch rate put in place -2 flights/month
  - Civilians (teachers) to be included in crews.

– **Manufacturing**
  - Single manufacturer (Morton Thiokol) - responsible for design, manufacture and refurbishment

NASA - Background

- Organisation
  - operating in a pseudo commercial business manner
  - morale low - Shuttle forced (Reagan) to be declared operational before development complete.
- Development
  - internal strife and territorial battles rampant
  - managers operating in an environment of ‘overload and turbulence’
  - decision making ‘semi-uncontrolled’, consisting of short-cuts, compromise and over-ruling by political power.

Challenger SRB ‘Field Joints’



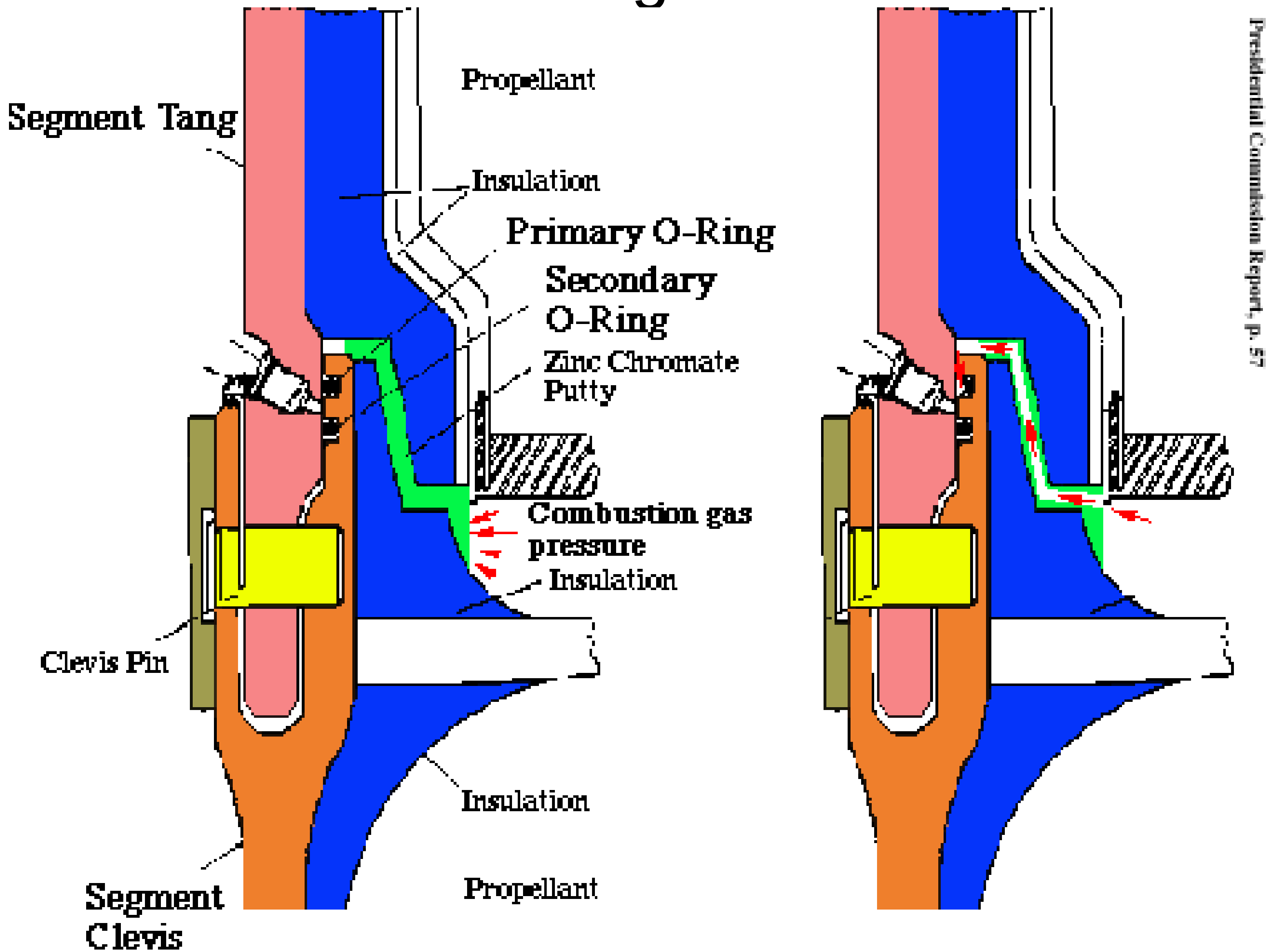
Presidential Commission Report, p. 52

‘It is my honest and very real fear that if we do not take immediate action to dedicate a team to solve the problem with the field joint having the number one priority, then we stand in jeopardy of losing a flight along with all the launch pad facilities.’

R. M. Boisioly (31 July 1985)

Letter to VP Engineering, Morton Thiokol

Challenger SRB 'Field Joints'

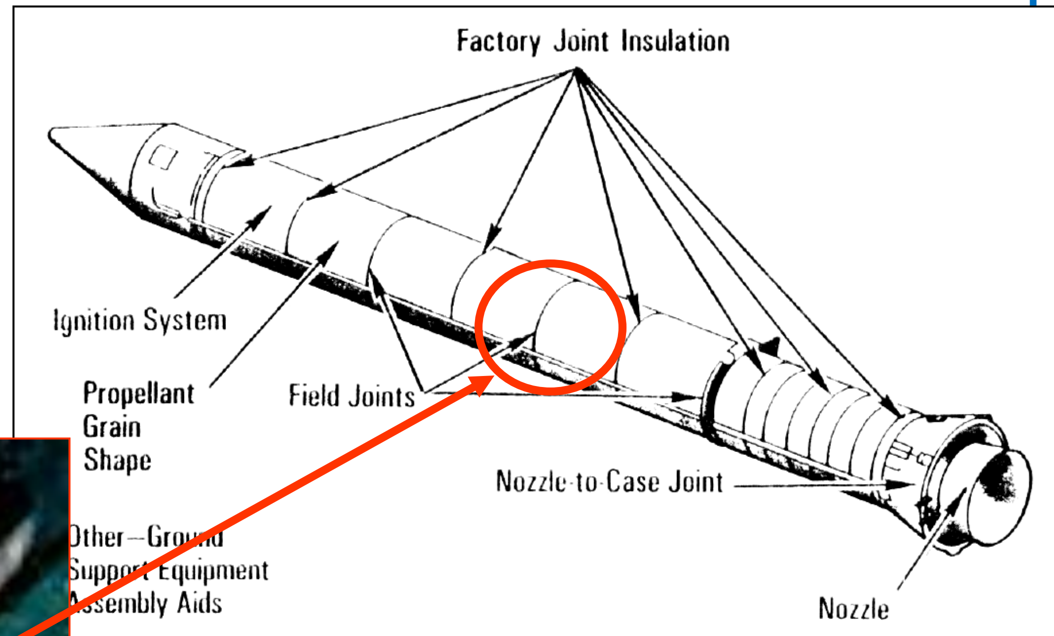


Normal Operation **O-Ring Erosion**

NASA/Morton Teleconference

- NASA requested teleconference (Jan 27 1986)
  - Presentation made by engineers with hastily prepared material. Poor presentation meant that data not believed
  - ***Engineers recommended no launch at T < 53° F (11.6° C)*** (Tufte)
- Off-line Morton discussion
  - Engineers excluded from decision. Driven by Gen. Mgr. of Morton. Management not technical discussion.
  - **Morton fear loss of exclusive NASA contract if they 'hold back' the shuttle flight.**
- Mason (GM) to Bob Lund (VP engineering)
  - told him to 'take off his engineering hat and put on his management hat'.
- ***Morton revise decision & allow launch at T < 11° C***

Space Shuttle - 'An Accident Waiting to Happen!'



SRB Assembly - O Ring joints

<u>Poor Design ?:</u>
Incomplete understanding of failure modes and critical operating parameters.

Challenger - Cause of the Accident

The decision to launch the Challenger was flawed.

Those who made that decision were unaware of the recent history of problems concerning the O-rings and the joint and were unaware of the initial written recommendation of the contractor advising against the launch at temperatures below 53° F (11.6° C) and the continuing opposition of the engineers at Thiokol after the management reversed its position.'

(Source: The Presidential Commission
on the Space Shuttle Challenger Accident Report, June 6, 1986)

Challenger: Investigation Outcomes

- '... the cause of the Challenger accident was the failure of the pressure seal... The failure was due to a faulty design unacceptably sensitive to a number of factors.'

- 'These factors were the effects of temperature, physical dimensions, the character of materials, the effects of reusability, processing and the reaction of the joint to dynamic loading.'

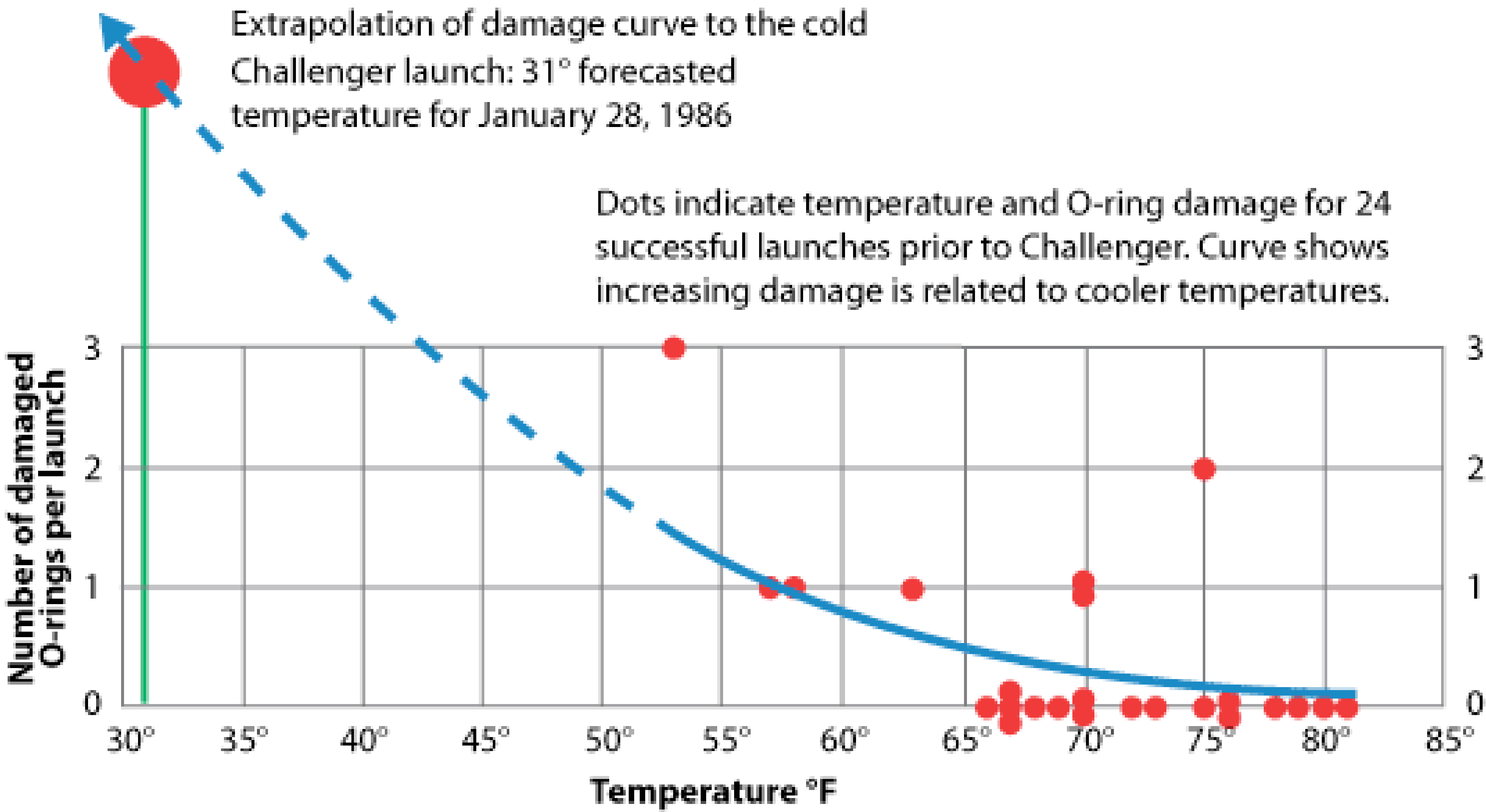
(Source: The Presidential Commission on the Space Shuttle Challenger Accident Report, June 6, 1986 p.40, p.70-81)

Challenger: Critical Issues

- Decision to launch
  - remote teleconferencing & communication
  - technical understanding & ‘hard data’
  - only selected ‘senior’ officials voted on launch
  - no internal reporting within NASA to indicate concerns
- Development programme
  - lack of QA procedures & management support
  - lack of validation & testing of the SRB design

- Differences of opinion of probability of failure:
  - Engineers 1 in 100
  - Management 1 in 100,000

Suggested communication for NASA Engineers



Engineering Design - Examples

- Warship VASA (1628)
  - Lack of understanding of scientific principles
  - The customer is King - time pressures and cost of failure.
- Team Philips (2000)
  - Incomplete integration of design & process development
  - Pushing boundaries of known performance and technology
  - Single delivery date - no second chance for ‘market’
- NASA Challenger (1986)
  - Management and engineering communication
  - Incomplete understanding of design requirements

Design Failure - Common Threads

- ‘Customer’ Demands and/or Requirements not defined or poorly understood
- New technology requirements
  - Materials and/or Processes
- New applications of existing technologies
  - Poor understanding of operating parameters and failure modes
  - Inappropriate design parameters
- Insufficient or Inappropriate validation
- Time Pressures
- **Communication level & understanding within design process**

Current/Future Design Failures?

- Segway PT ?
- Dublin Public transport system ?
- Boeing 787 Dreamliner ?