Who was responsible for the Challenger disaster?

Society and its economic, social and political **structures**?

The **Engineering profession** and its values?

Society

Professional Bodies

Macro

Macro Objective	Macro Subjective
social, economic and political structures and public policy	goals and values of the profession
Micro Objective	**Micro Subjective**
organizational culture and processes	consciousness and will power of individual engineers

Objective

Subjective

Workplace

Individual

Micro

Workplace **organisation** and **culture** ..at **Morton Thiokol, NASA**?

..An **individual** or **individual actors**?

Who was responsible for the Challenger disaster?

..dominant societal paradigms?
..lobby groups/elites?
..government/political parties?

Codes of Ethics? Policies?
influenced by ..active membership
..vested sectional/interests

Macro

Society

Professional Bodies

..complex tightly coupled systems?

Macro Objective ocial, economic and olitical structures and ublic policy	**Macro Subjective** goals and values of the profession
Micro Objective organizational culture and processes	**Micro Subjective** consciousness and will power of individual engineers

Objective

Subjective

Workplace

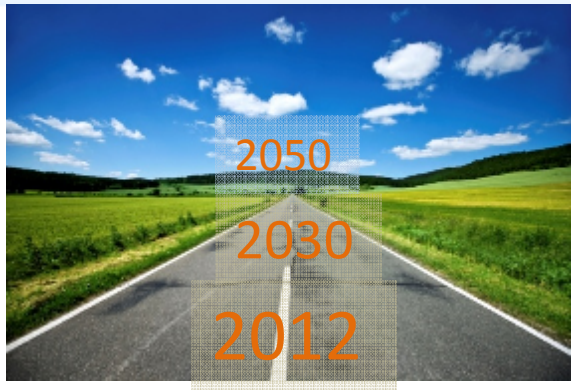
Individual

..'Normalisation of deviance'
..exercise of power?
..near term economic imperatives

Micro

..personal gain/preservation?
whistleblowing?

Engineering ethics



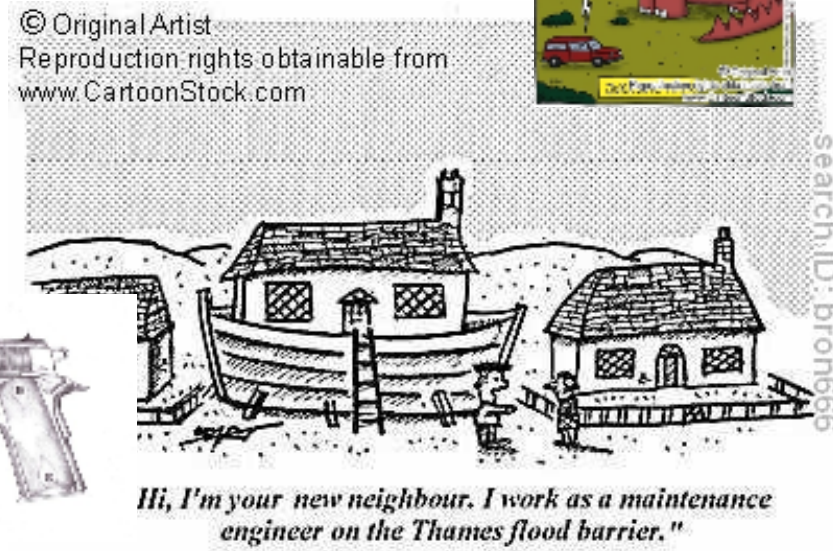
Points to ponder…

*Do engineers bear **moral** and **ethical responsibility** for;*

- working towards and promoting **long term** (trans-generational) **societal** and **environmental flourishing?**
- **'unintended' consequences** that may result from our designs and attempted resolutions of problems?

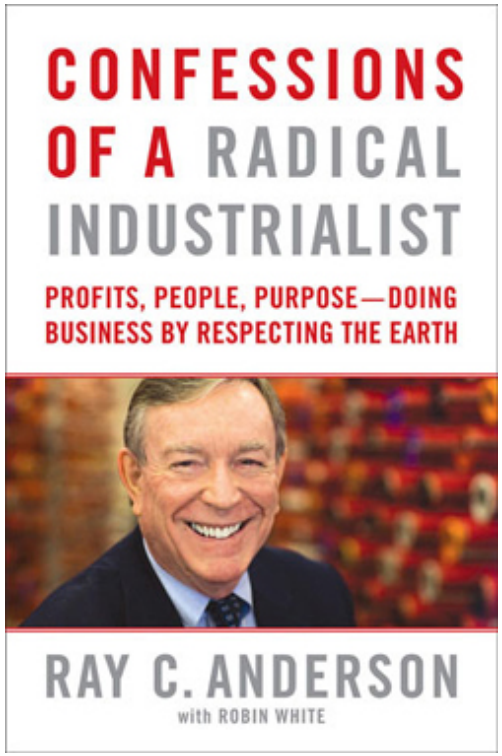
Or is it ok that we just;

- **avoid litigation**, meet **personal ethical** requirements, but..
- disregard **greater than self** (intrinsic) **values** and macroethical issues
- **'take the money and run'** as unconcerned '**paid hands**'?

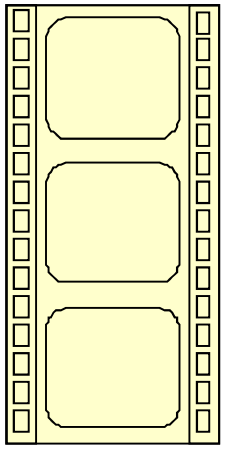


Case study; Ray Anderson (1934-2011)

Ray Anderson, as founder and CEO of **Interface** carpets, the world leading manufacturer of carpet tiles, is an engineer who embraced the broader ethical approach..



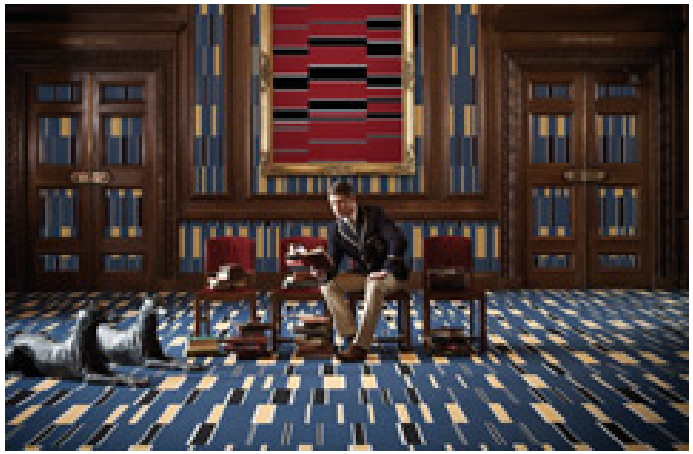
See:



- Ray Anderson, CEO, Interface Carpets
  'Ray Anderson on Sustainability'
  http://www.youtube.com/watch?v=4bAdsJCHGyU (9:35)

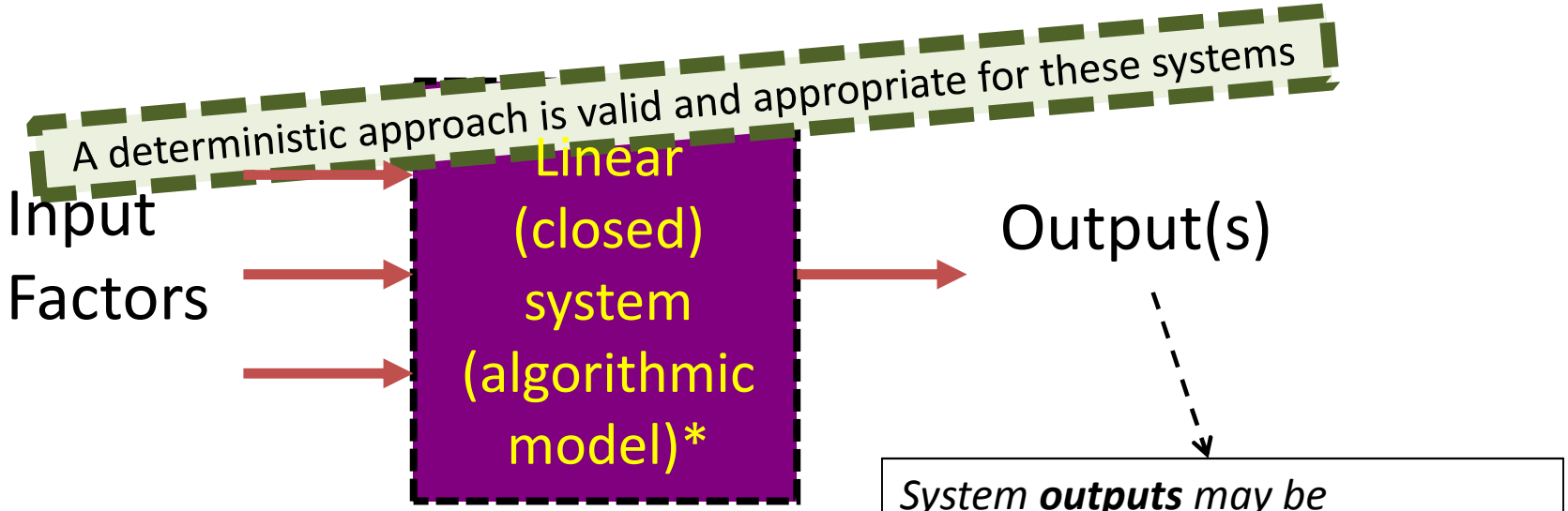
*'Don't just look at it as a **technical problem** to solve.*
*Think about your **people**, the **values**, the **culture** of the organisation.'*

Jim Hartzfeld, MD, InterFaceRaise



Complex Problems; Risks and Uncertainty

Characterising LINEAR *(often complicated)* systems

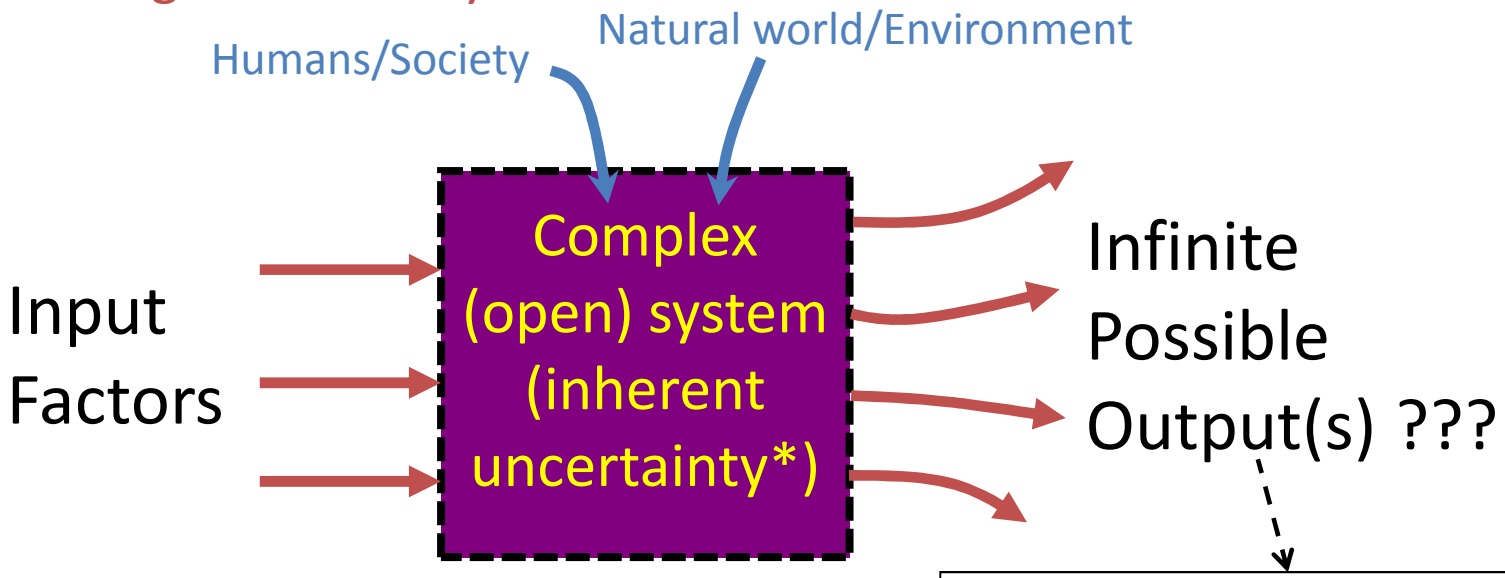


May incorporate degree of uncertainty as a result of **incompleteness of theories or **model** or due to **unknown values** for **input factors** or for their inherently uncertain or **random** nature*

*System **outputs** may be **deterministically** predicted. All possible outcomes known and system uncertainty is expressed in terms of output **probabilities***

Complex Problems; Risks and Uncertainty

Characterising COMPLEX systems



**Deterministic models are often applied to describe and/or predict complex systems ('by repressing disorder, by pushing aside the uncertain'[1]). While these may provide useful insights, they need to be treated with appropriate caution as they are incapable of pre-stating all possible outcomes or associated probabilities.*

*System **outputs** cannot be **deterministically** predicted.*
*All possible outcomes cannot be pre-determined, never mind their associated **probabilities***

[1] Edgar Morin, *On Complexity,* (2008, p.5)

LINEAR (COMPLICATED) SYSTEMS

Toyota RAV EV; Withdrawn 2003

EV's launched from 2011/2012

Electric Cars

COMPLEX SYSTEMS

+  * = Sold 300 units p.a.

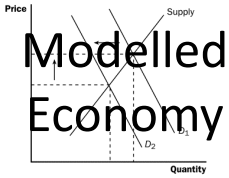
* Human effects; legislation, context, infrastructure, technological services, cost, marketing, culture, perception, unk unk's..

+  * = Success or Failure?

May be **TIME** and **SPACE** dependent; **CONTEXT, HISTORY** and **CULTURE** important

BE

LINEAR (COMPLICATED) SYSTEMS



Modelled Economy + 'Homo Economicus' =

% failure

% failure

Economic Growth

% failure

Characterised by **PROBABILITY**

COMPLEX SYSTEMS

Real Economy

+  = Annual Road Deaths

+  = Nuclear Accident

+  = Economic Growth/ Collapse

+  = Water Supply/ Demand

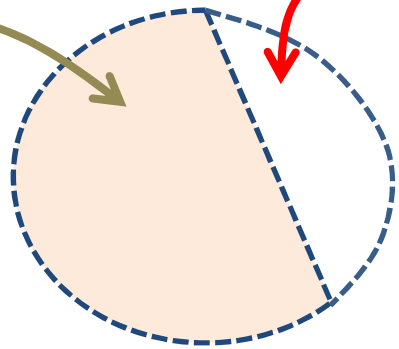
Characterised by **UNKNOWABLE POSSIBILITIES** (outputs)

In summary,

Human and natural inputs bestow complexity..

Linear realm:
Closed quantifiable systems, all possible outcomes known which can be **identified** and **predicted** or assigned probabilities.
e.g. **machine** operations

Traditional engineer adept at solving

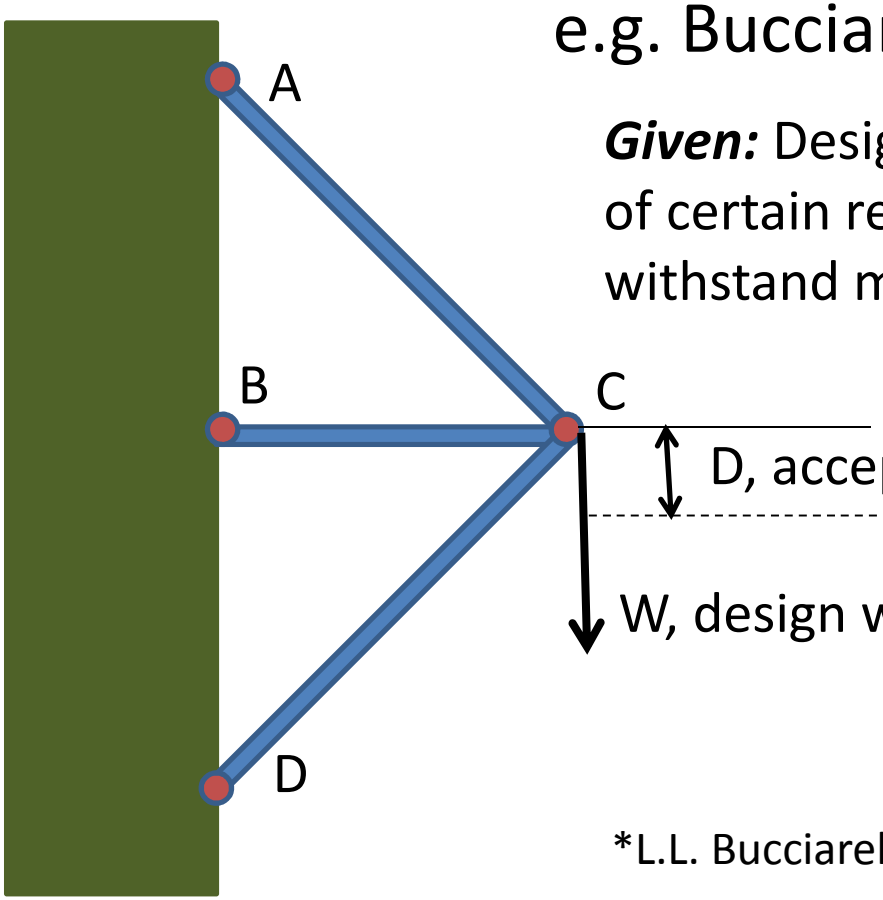


Complex realm:
Open systems with **infinite unknown possibilities** to which probabilities cannot be assigned ('unknown unknowns'), enables **creativity, evolution, inherent uncertainty** and **risk, context, agency**, **values, emergence, self organisation,**
e.g. **human** activity and agency, wicked problems
Requires 'new engineer'

Human input introducing complexity

Human and natural inputs bestow complexity on linear systems..

e.g. Bucciarelli's Truss Structure*



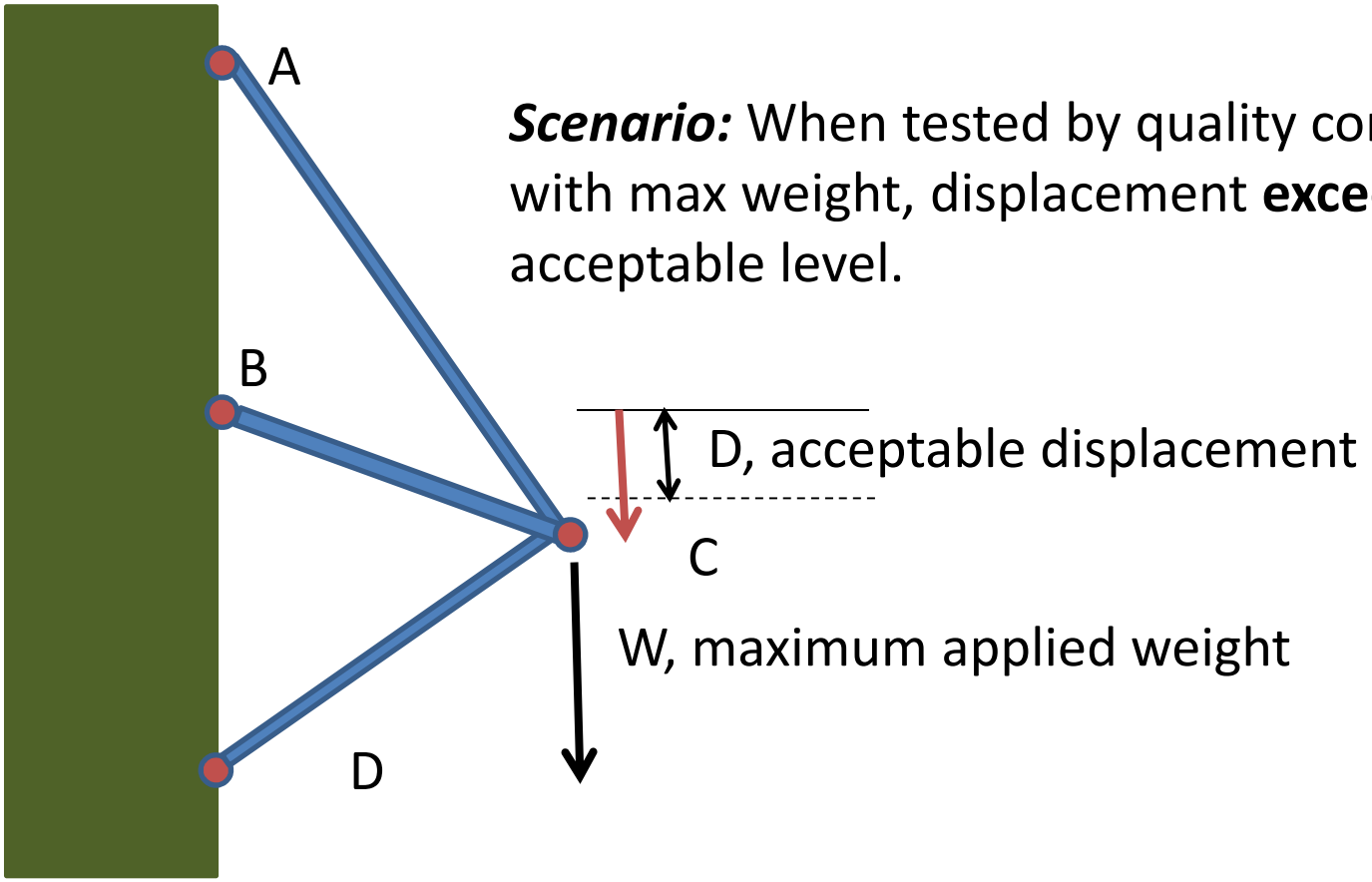
Given: Design a **simple truss structure** of certain required stiffness to withstand maximum load, W

D, acceptable displacement

W, design weight; maximum weight to be applied

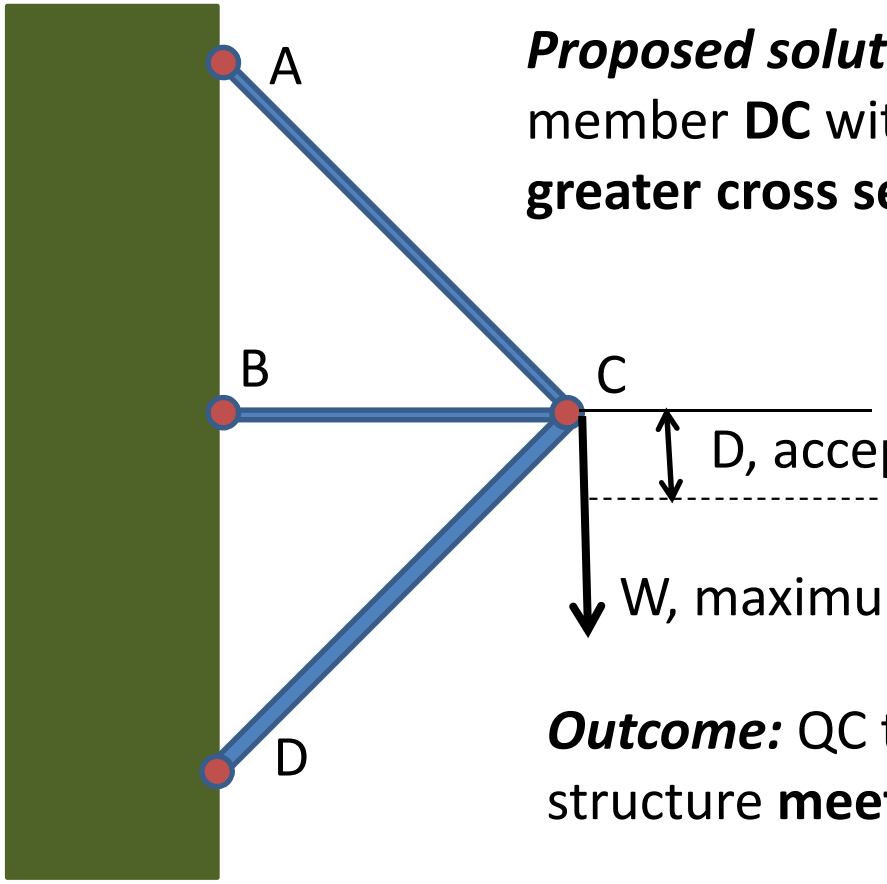
*L.L. Bucciarelli, 'Engineering Philosophy' (2003)

Human input introducing complexity



Scenario: When tested by quality control with max weight, displacement **exceeded** acceptable level.

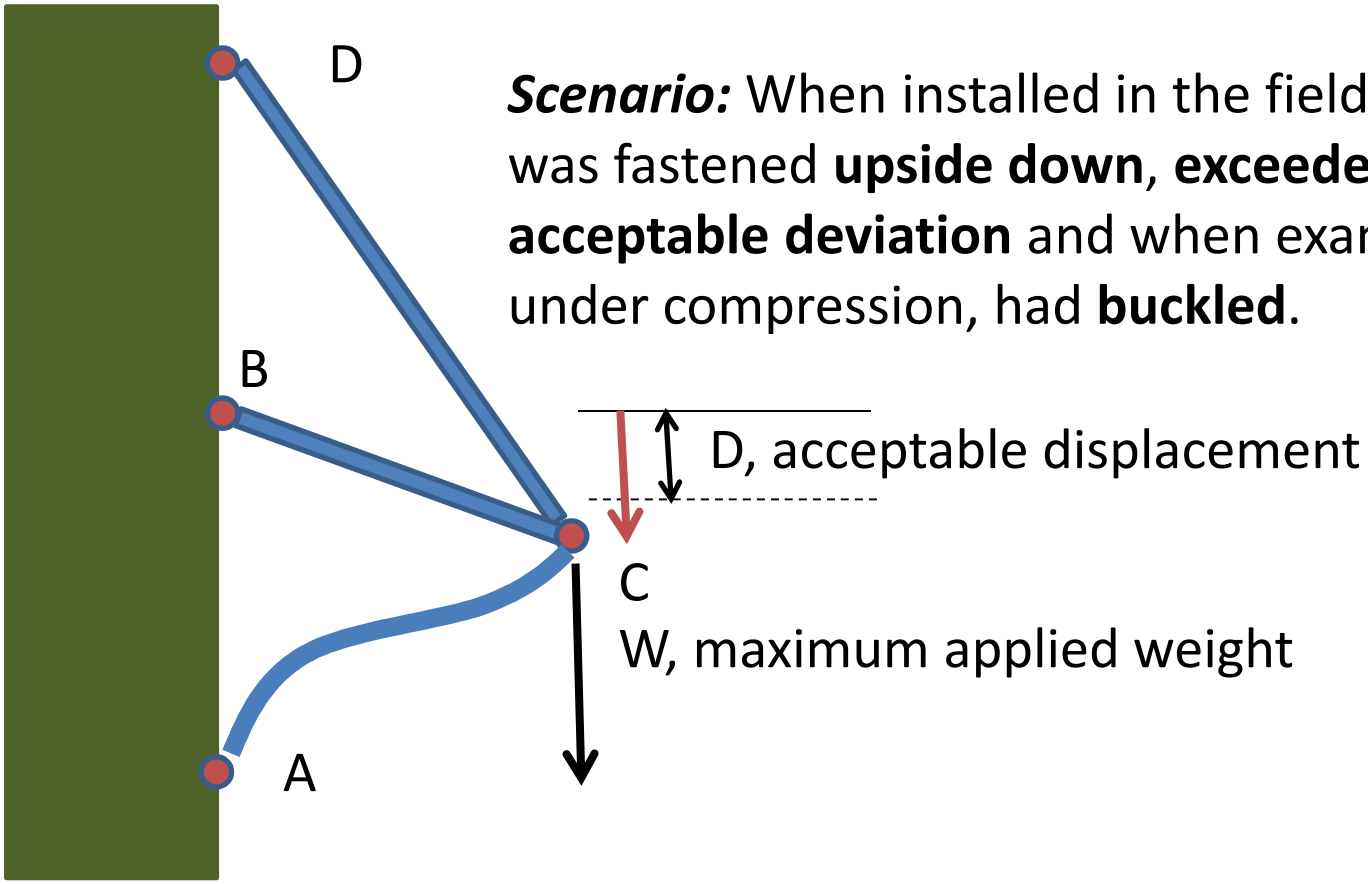
Human input introducing complexity



Proposed solution: Replace bottom member **DC** with a stiffer member of **20% greater cross sectional area**

Outcome: QC tests show improved structure **meets specifications**.

Human input introducing complexity



Scenario: When installed in the field, bracket was fastened **upside down**, **exceeded acceptable deviation** and when examined, **AC** under compression, had **buckled**.

Human input introducing complexity

Q. **Why** did the **failure** occur?

A. Because the backet was installed **incorrectly**.
Had it been installed correctly it would not have failed.

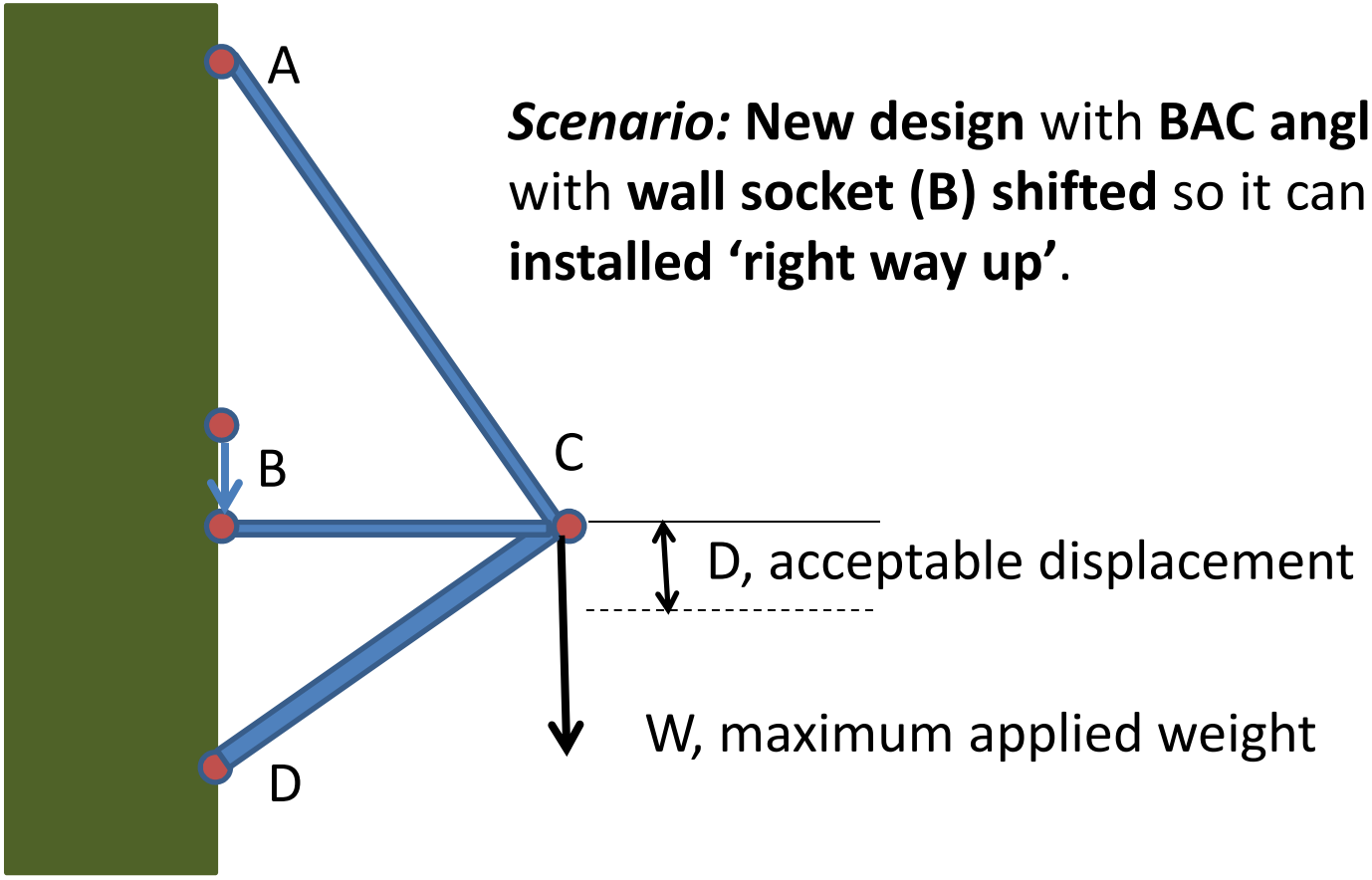
But this was not the case here: the **context changed**; no one considered the possibility that it would be installed upside down. This was '**unthought-of**', an **'unknown' possibility** and '**unimagined**'.
<u>Such possibilities will always exist!</u>

Human input introducing complexity

Q. But surely any engineer worth their salt would have displayed **better design practice**; tested the truss in **both configurations**, then perhaps replaced both members with **stiffer configurations** to meet specs?
..and/or put a **'this end up'** label on the truss,
..or design it so it could only be **installed one way up**, say so that top member is at smaller angle.

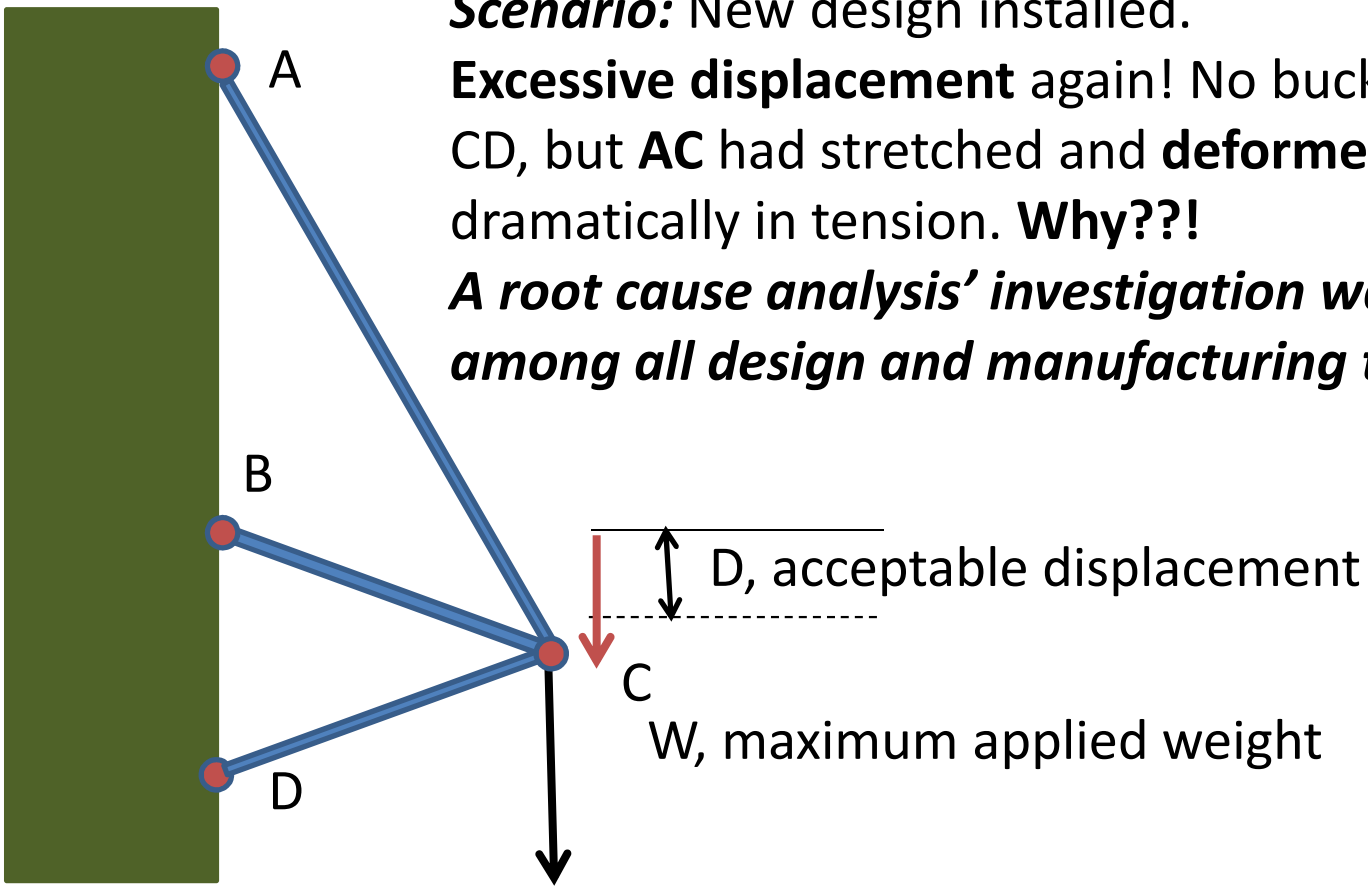
A. OK! Let's design it so it can be **installed one way up**…

Human input introducing complexity



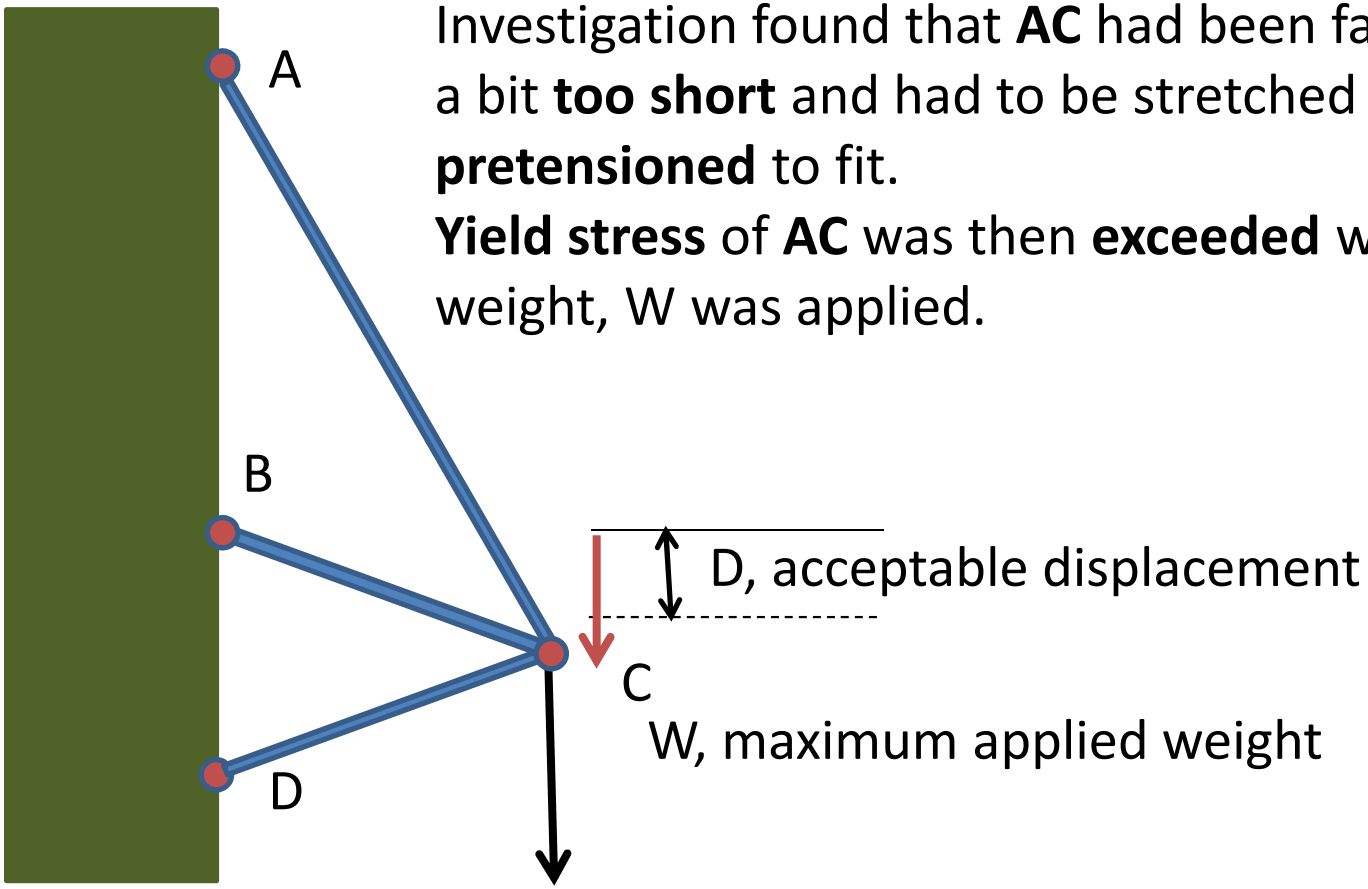
Scenario: **New design** with **BAC angle smaller** with **wall socket (B) shifted** so it can only be **installed 'right way up'**.

Human input introducing complexity



Scenario: New design installed.
Excessive displacement again! No buckling of CD, but **AC** had stretched and **deformed** dramatically in tension. **Why??!**
A root cause analysis' investigation was held among all design and manufacturing team..

Human input introducing complexity



Investigation found that **AC** had been fabricated a bit **too short** and had to be stretched and **pretensioned** to fit.

Yield stress of **AC** was then **exceeded** when weight, W was applied.

Human input introducing complexity

And so it can go on…

Whatever **'fix'** or improvement that is made which eliminates one possibility (e.g. improve **quality control** to eliminate sub standard fabrication) there can **always** be **another possibility not considered** (e.g. in designing, manufacturing, assembly, packaging, installation, use, maintenance, etc.) (i.e. an **'unknown unknown'**) and which could engender **failure**.

<u>The set of possibilities is NEVER complete.</u>

Complexity implies inherent risk

If this can happen to the most **simple structural design** with **limited** human interaction, then the occurrence of **unknown possibilities**, the **opportunities for failure** and for **unintended consequences** associated with **complex** and **wicked** problems are even **more significant** and **constant companions!**

<u>Risk is inherent</u> and

<u>Murphy's Law applies!</u>

Complexity implies inherent risk

Adding **increased complexity**, even as a means of achieving **additional precautions**, can help **<u>create new risks</u>** as **<u>unintended consequences</u>**.

e.g. A NASA Aviation Safety Reporting System report[1] found *'decreased flight crew altitude awareness because of the presence of the altitude alert system. The system was originally conceived as a backup, not a primary means of altitude control'*. It suggested the removal of the aural alert on short distance flights *'would assist in enhancing flight crew altitude awareness, if accompanied by appropriate retraining'* (6th Quarterly Rept. TM-78511, 1978)