Engineering as social experimentation

Unit-II

ENGINEERING AS EXPERIMENTATION

- Experimentation (Preliminary tests or Simulations) plays a vital role in the design of a product or process.
- In all stages of converting a new engineering concept into a design like,
  - first rough cut design,
  - usage of different types of materials and processes,
  - detailed design,
  - further stages of work design and
  - the finished product,

ENGINEERING AS EXPERIMENTATION (Continued)

- Experiments and tests are conducted to evaluate the product. Modifications are made based on the outcome of these experiments.
  - The normal design process is thus iterative (modifications being made on the basis of feedback information acquired from the tests).
- Even though various tests and experiments are conducted at various stages, the engineering project as a whole in its *totality* can be viewed as an *experiment.*

SIMILARITIES TO STANDARD EXPERIMENTS

- Any project is carried out in partial ignorance due to
  - The uncertainties in the abstract model used for the design calculations,
  - The uncertainties in the precise characteristics of the materials purchased,
  - The uncertainties caused by variations in processing and fabrication of materials and
  - The uncertainties about the nature of stresses the finished product will encounter.
- Indeed, Engineer's success lies in the *ability to accomplish tasks* with only a *partial knowledge* of scientific laws about nature and society.

SIMILARITIES TO STANDARD EXPERIMENTS (Continued)

- The final outcome of engineering projects, like those of experiments, is generally uncertain. Very often, possible outcomes are not even known and great risks may be presented which could never be thought of.

- Effective Engineering relies upon knowledge gained about products both before and after they leave the factory- knowledge needed for improving current products and creating better ones. That is, ongoing success in engineering depends upon gaining new knowledge.

LEARNING FROM THE PAST

- Engineers should learn not only from their own earlier design and operating results, but also from other engineers.

- Engineers repeat the past mistakes of others due to the following reasons.

  - Lack of established channels of communication.
  - Misplaced pride in not asking for information
  - Embarrassment at failure or fear of litigation (legal problems).
  - Negligence.

LEARNING FROM THE PAST (Continued)

***Examples**:*

- The *Titanic* lacked sufficient number of life boats resulting in the death of 1522 out of 2227 (life boat capacity available was only 825), a few decades later *Arctic* perished due to the same problem.

- In June 1966, a section of the Milford Haven Bridge in Wales collapsed during construction. A bridge of similar design, erected by the same bridge- builder in Melbourne, Australia, also partially collapsed in the month of October, same year. During this incident 33 people were killed and many were injured.

- Malfunctions occurred at nuclear reactors at various locations and the information reports were with Babcock and Wilcox, the reactor manufacturer. In spite of these, no attention was paid leading to a pressure relief valve giving rise to the Three Mile Island nuclear accident on March 28, 1979.

CONTRASTS WITH STANDARD EXPERIMENTS

EXPERIMENTAL CONTROL:

- In standard experiments, members are in two different groups. Members of *one group receive special* experimental treatment. The other group members, called '*control group' do not receive* special treatment, though they are from the same environment in all other respects.
- But this is not true in engineering, since most of the experiments are not conducted in laboratories. The subjects of experiments are human beings who are outside the experimenter's control.

CONTRASTS WITH STANDARD EXPERIMENTS (Continued)

- It is not possible to study the effects of changes in variable on different groups. Hence only historical and retrospective data available about various target groups has to be used for evaluation. Hence engineering as a social experimentation seems to be an extended usage of the concept of experimentation.

CONTRASTS WITH STANDARD EXPERIMENTS (Continued)

INFORMED CONSENT:

- It has two elements, *knowledge* and *voluntariness*.
- The subjects (human beings) should be given all the information needed to make a reasonable decision. Next, they must get into the experiment without being subjected to *force, fraud or deception*.
- Supplying complete information is neither necessary nor in most cases possible. But *all relevant information* needed for making a reasonable decision on whether to participate should be conveyed. Generally, we all prefer to be the subject of our own experiments rather than those of somebody else.

CONTRASTS WITH STANDARD EXPERIMENTS (Continued)

Conditions defining *Informed or Valid Consent*

- The consent is given voluntarily
- The consent is based on information a rational person would want, together with any other information requested and presented to them in understandable form.
- The consenter was competent to process the information and make rational decisions.
- Information has been widely disseminated.
- The subject's consent is offered by proxy by a group that collectively represents many subjects like interests, concerns and exposure to risk.

CONTRASTS WITH STANDARD EXPERIMENTS (Continued)

'Engineering experiments are not conducted to gain new knowledge unlike scientific experiments'. Is this distinction necessary?

- This distinction is not vital because we are concerned *about the manner* in which the experiment is conducted, such as *valid consent* of human subjects being sought, *safety measures* taken and means exist for *terminating* the experiment *at any time* and providing all participants a *safe exit*.

Engineers as Responsible Experimenters

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Features of morally responsible engineers in social experimentation

- ***Conscientiousness*: A primary obligation to protect the safety of human subjects and respect their right of consent.
- ***Relevant information*: A constant awareness of the experimental nature of any project, imaginative forecasting of its possible side effects and a reasonable effort to monitor them.
- ***Moral autonomy*: Autonomous, personal involvement in all steps of the project.
- ***Accountability*: Accepting accountability for the results of the project.

CONSCIENTIOUSNESS

- Conscientious moral commitment means sensitivity to the full range of relevant moral values.
- Sensitivity to responsibilities that is relevant.
- Willingness to develop the skill and expend the effort needed to reach the best balance possible among these considerations.
- Conscientiousness means consciousness because mere intent is not sufficient.

Conceiving engineering as social experimentation restores the vision of engineers as guardians of the public interest in that they are duty bound to guard the welfare and safety of those affected by engineering projects.

RELEVANT INFORMATION

- Conscientiousness is blind without relevant factual information. Moral concern involves a commitment to obtain and assess all available pertinent information.
- Another dimension to factual information is the consequences of what one does. While regarding engineering as social experimentation points out the importance of context, it also urges the engineer to view his or her specialized activities in a project as part of a larger whole having a social impact that may involve a variety of unintended effects.
- It may be better to practice ‘defensive engineering’ (Chauncy Starr) or ‘preventive Technology’ (Ruth Davis).

MORAL AUTONOMY

- People are morally autonomous when their moral conduct and principles of action are their own.
- Moral beliefs and attitudes must be a critical reflection and not a passive adoption of the particular conventions of one’s society, religion or profession.
- Moral beliefs and attitudes cannot be agreed to formally and adhered to merely verbally.
- They must be integrated into the core of one’s personality and should lead to committed action.

MORAL AUTONOMY (Continued)

- It is wrong to think that as an employee when one performs '*acts*' serving company's interests, one is no longer morally and personally identified with one's actions.
- Viewing engineering as a social experimentation helps to overcome this flawed thought and restores a sense of autonomous participation in one's work.
  - As an experimenter, an engineer is exercising the specialized training that forms the core of one's identity as a professional.
  - A social experiment that can result in unknown consequences should help inspire a critical and questioning attitude about the adequacy of current economic and safety standards.
  - In turn, this leads to better personal involvement with work.

ACCOUNTABILITY

- Responsible people accept moral responsibility for their actions.
- Accountability is the willingness to submit one's actions to moral scrutiny and be open and responsive to the assessment of others.
- It should be understood as being culpable and blameworthy for misdeeds

ACCOUNTABILITY (Continued)

Submission to an employer's authority creates in many people a narrow sense of accountability for the consequences of their action. This is because of

- Only a small contribution is made by one individual, when large scale engineering work is fragmented. The final product which is far away from one's immediate workplace, does not give a proper understanding of the consequences of one's action.
- Due to the fragmentation of work, a vast diffusion of accountability takes place. The area of personal accountability is delimited to the portion of work being carried out by one.
- The pressure to move on to another new project does not allow one to complete the observations long enough. This makes people accountable only for meeting schedules and not for the consequences of action.
- To avoid getting into legal issues, engineers tend to concentrate more on legal liabilities than the containment of the potential risks involved in their area of work.

Research Ethics

Research Ethics is a kind of applied or practical ethics, meaning that it attempts to resolve not merely general issues but also specific problems that arise in the conduct of research. Its goal is to determine the moral acceptability and appropriateness of specific conduct and to establish the actions that moral agents ought to take in particular situation. Research ethics therefore not merely theoretical. It aims to establish practical moral norms and standards for the conduct of research.”

Why do you need ethics in research?

- “Research is a process, using defensible methodology that is done on behalf of society, in search of knowledge that can be shared and used. Research is usually supported through public or private funds. Research matters because it is judged to be important by knowledgeable peers.
- Just as researchers have responsibilities to their colleagues and to the institution in which they work, researchers have responsibilities to potential and actual funders, to the audiences and publishers to whom they submit their work, and to peers.”

Codes and Guidelines

- 1974 – US Congress formed the National Commission for the Protection of Human Subjects in Biomedical and Behavioral Research
- 1979 – Belmont Report was published as a result of the commissions deliberations
- International codes also exist, for example the Code of Nuremberg (1949) and Declaration of Helsinki (1974)
- Virtually every journal has a policy statement regarding obtaining informed consent, etc.

Codes and Guidelines, cont’d

- Codes and guidelines evolved because of human subjects’ rights abuses
  - Nazi experiments using war chemicals, environmental extremes, food and sleep deprivation, etc
  - Alaskan Eskimos fed radioactive iodine pellets
  - Tuskegee Alabama study where men with syphilis were “treated” with a placebo instead of a drug

Ethical Issues

- Justification for the research
- Access to participants/Privacy
- Informed consent
- Potential harm

Cost-Benefit Analysis

- With research involving human subjects the risks and costs must be balanced against the potential benefits
- Trivial or repetitive research is may be unethical where the subjects are at risk

Areas of Scientific Dishonesty

1. Plagiarism
2. Fabrication and falsification
3. Non-publication of data
4. Faulty data-gathering procedures
5. Poor data storage and retention
6. Misleading authorship
7. Sneaky publication practices

Plagiarism

- Plagiarism—using the ideas, writings, and drawings of others as your own

Fabrication and Falsification

Fabrication and falsification—making up or altering data

Non-publication of Data

- Sometimes called “cooking data”
- Data not included in results because they don’t support the desired outcome
- Some data are “bad” data
- Bad data should be recognized while it is being collected or analyzed
- Outlier – unrepresentative score; a score that lies outside of the normal scores
- How should outliers be handled?

Faulty Data Gathering

- Collecting data from participants who are not complying with requirements of the study
- Using faulty equipment
- Treating participants inappropriately
- Recording data incorrectly

Data Gathering

- Most important and most aggravating.
- Always drop non-compliers.
- Fix broken equipment.
- Treat subjects with respect and dignity.
- Record data accurately.
- Store data in a safe and private place for **3** years.

Poor Data Storage and Retention

- Data should be stored in its original collected form for at least 3 years after publication
- Data should be available for examination
- Confidentiality of participants should be maintained

Misleading Authorship

Misleading authorship—who should be an author?

- Technicians do not necessarily become joint authors.
- Authorship should involve only those who contribute directly.
- Discuss authorship before the project!

Sneaky Publication Practices

- Publication of the thesis or dissertation
  - Should be regarded as the student's work
  - Committee chair and members may be listed as secondary authors
- Dual publication – a manuscript should only be published in a single journal
  - What about studies which include a huge amount of data?

CODES OF ETHICS

Our engineering ethics codes are derived from a Western cultural tradition

- Ancient Greeks
- Judeo-Christian religions
- Philosophers and thinkers (e.g. Locke, Kant, Mills)

CODES OF ETHICS (Continued)

The Hammurabi Code

If a builder has built a house for a man and has not made his work sound, and the house he has built has fallen down and so caused the death of the householder, that builder shall be put to death. If it causes the death of the householder’s son, they shall put the builder’s son to death….

(Hammurabi, King of Babylon, 1758 B.C.)

CODES OF ETHICS (Continued)

Code of Ethics for Engineers

Accreditation Board for Engineering and Technology (ABET)

The Fundamental Principles:

- *Engineers shall uphold and advance the integrity, honor, and dignity of the engineering profession by:*
  - *using their knowledge and skill for the enhancement of the human race;*
  - *being honest and impartial and serving with fidelity the public, their employers, and clients;*
  - *striving to increase the competence and prestige of the engineering profession.*
  - *supporting the professional and technical societies of their discipline.*

<u>CODES OF ETHICS (Continued)</u>

<u>**The Fundamental Cannons**</u>

Engineers shall

- *hold paramount the safety, health, and welfare of the public in the performance of their professional duties;*
- *perform service only in areas of their competence;*
- *issue public statements only in an objective and truthful manner;*
- *act in professional matters for each employer or client as faithful agents or trustees, and shall avoid conflicts of interest;*
- *build their professional reputations on the merits of their services and shall not compete unfairly with others*
- *act in such manner as to uphold and enhance the honor, integrity and dignity of the profession;*
- *continue their professional development throughout their careers, and shall provide opportunities for the professional development of those engineers under their supervision.*

CODES OF ETHICS (Continued)

Roles of Codes

1. Inspiration and Guidance:

- Codes provide positive stimulus for ethical conduct and helpful guidance by using positive language.
- Codes should be brief to be effective and hence such codes offer only general guidance.
- Supplementary statements or guidelines to give specific directions are added by a number of societies or professional bodies.

CODES OF ETHICS (Continued)

2. Support:

- Codes give positive support to those seeking to act ethically.
- An engineer under pressure to act unethically can use one of the publicly proclaimed codes to get support for his stand on specific moral issues.
- Codes also serve as legal support for engineers.

CODES OF ETHICS (Continued)

3. Deterrence and discipline:

- Codes can be used as a basis for conducting investigations on unethical conduct.
- They also provide a deterrent for engineers to act immorally.
- Engineers who are punished by professional societies for proven unethical behavior by revoking the rights to practice as engineers are also subjected to public ridicule and loss of respect from colleagues and local community.
- This helps to produce ethical conduct even though this can be viewed as a negative way of motivation.

CODES OF ETHICS (Continued)

4. Education and mutual understanding:

The codes can be used for discussion and reflection on moral issues and thereby improve the understanding of moral responsibilities among all engineers, clients, public and good organizations.

5. Contributing to the profession's public image:

Codes present the engineering profession as an ethically committed society in the eyes of the public thus enhancing their image.

CODES OF ETHICS (Continued)

6. Protecting status quo:

Codes establish ethical conventions, which can help promote an agreed upon minimum level of ethical conduct.

7. Promoting business interests:

Codes can place unwarranted restraints of commerce on business dealings.

CODES OF ETHICS (Continued)

Relative importance of the various functions of codes of ethics

- The perspective of engineering as social experimentation clearly emphasizes the primary role 'supportive function' of the codes of ethics. This is so because, only this support enables engineers, speak out clearly and openly their views, to those affected by engineering projects.
- The, 'inspiration and guidance' and 'educative' functions are also important in promoting mutual understanding and in motivating engineers to act with higher moral standards.

CODES OF ETHICS (Continued)

- The ‘disciplinary’ function in engineering codes is of secondary importance. Those with unethical conduct when exposed are subject to law. Developing elaborate paralegal procedures within professional societies duplicates a function which can be done better by legal system. At best, codes should try to discipline engineers in areas which are not covered by law.
- The worst abuse of codes has been to restrict honest moral effort in the name of ‘preserving profession’s public image’ and ‘protecting status quo’. The best way to increase trust is by encouraging and aiding engineers to speak freely and responsibly about public safety.

CODES OF ETHICS (Continued)

***Limitations* of Codes of Ethics**

1. Codes are restricted to general and vague wording. They cannot be straightaway applied to all situations. It is impossible to foresee the full range of moral problems that can arise in a complex profession like engineering.

2. It is easy for different clauses of codes to come into conflict with each other. Usually codes provide no guidance as to which clause should have priority in those cases, creating moral dilemmas.

CODES OF ETHICS (Continued)

3. They cannot serve as the final moral authority for professional conduct. If the code of a professional society is taken as the last word, it means that we are getting into a particular set of conventions i.e. ethical conventionalism.

4. Andrew Oldenquist and Edward Slowter pointed out how the existence of separate codes for different professional societies can give members the feeling that ethical conduct is more relative than it is and that it can convey to the public the view that none is 'really right'. The current codes are by no means perfect but are definitely steps in the right direction.

Industrial Standards

- Standard facilitate the interchange of components.
- They serve as ready-made substitute for lengthy design specifications.
- They decrease production costs.

Industrial Standards (Continued)

Types of standards

Criterion	Purpose	Example
Uniformity of physical properties and functions	Accuracy in measurement, interchangeability, ease of handling	Standards of weights, screw thread dimensions, standard time, film size
Safety and reliability	Prevention of injury, death, and loss of income or property	National Electric Code, boiler code, methods of handling toxic wastes
Quality of product	Fair value for price	Plywood grades, lamp life
Quality of personnel and service	Competence in carrying out tasks	Accreditation of schools, professional licenses
Use of accepted procedures	Sound design, ease of communications	Drawing symbols, test procedures
Separability	Freedom from interference	High way lane markings, radio frequency bands

Industrial Standards (Continued)

- Standards can also hindrance at times. They were mostly descriptive.
- We often assume that stricter regulation exists than may actually be the case.
- Standards are thought to apply when in actuality there is no standard at all.

The problems of law in engineering

1. The greatest problem of law in engineering is of ‘minimal compliance’. Engineers and employers can search for loop holes in the law to barely keep to its letter while violating its spirit. Engineers will tend to refer to standard readymade specifications rather than come up with innovative ideas. Minimal compliance led to the tragedy of the ‘Titanic’.
2. Continually updating laws and regulations may be counter-productive and will make law always lag behind technology. This also overburdens the rules and regulators.

The problems of law in engineering (Continued)

3. Many laws are 'non-laws' i.e. laws without enforceable sanctions. These merely serve as window dressing, frequently gives a false sense of security to the public.
4. The opponents of the law may burden it intentionally with many unreasonable provisions that a repeal will not be far off.
5. Highly powerful organizations, like the government can violate the laws when they think they can get away with it by inviting would be challengers, to face them in lengthy and costly court proceedings. This also creates frustration with the law.

Role of law in engineering

- It is wrong to write off rule-making and rule following as futile. Good laws, effectively enforced, clearly produce benefits.
- Reasonable minimum standards are ensured of professional conduct.
- It also provides a self-interested motive for most people and corporations to comply.
- They also serve as powerful support and defense for those who wish to act ethically in situations where ethical conduct might not be welcome.

Role of law in engineering (Continued)

- Viewing engineering as social experimentation provides engineers with a better perspective on laws and regulations.
- Precise rules and enforceable sanctions are appropriate in cases of ethical misconduct that involve violations of well established and regularly reexamined procedures that have as their purpose the safety of public.
- In areas of experimentation, rules must not attempt to cover all possible outcomes of an experiment, nor must they force the engineer to adopt a rigidly specified course of action. Here the regulations should be broad based guidelines but should hold the engineer accountable for his or her decisions.

The Challenger Disaster
-A Case study

Introduction

- Following the 1960's and 1970's, the united states had established themselves superior in space exploration. The United States invested limitless money and resources into the program.

Successes of the Apollo Program

- Apollo missions 8 – 10 successfully delivered astronauts into lunar orbit
- Mission 11 marked the first successful lunar landing
- Missions 12, 14, 15, 16, and 17 also marked successful lunar landings
- Apollo 13 ended in a lunar flyby as equipment malfunctions prohibited a landing

International Cooperation

- At the conclusion of the Apollo space program, astronauts from the Soviet Union and the United States rendezvoused and docked in orbit
- This marked unprecedented indication of cooperation in space

A Decrease in Interest

- After the conclusion of the Apollo program and the death of president Kennedy, the country began to lose interest in space exploration.
- Goals had been achieved but future benefits were viewed as somewhat unnecessary
- Cutting funding and support of traditional space exploration was put into consideration.

Minimizing Costs

- The innovative idea of building a reusable vehicle rose as a favorable solution
- Cheaper, lighter materials were considered in order to minimize weight
- Maximization of payload was the ultimate goal of achieving the ‘most with the least’

The Birth of the Space Shuttle

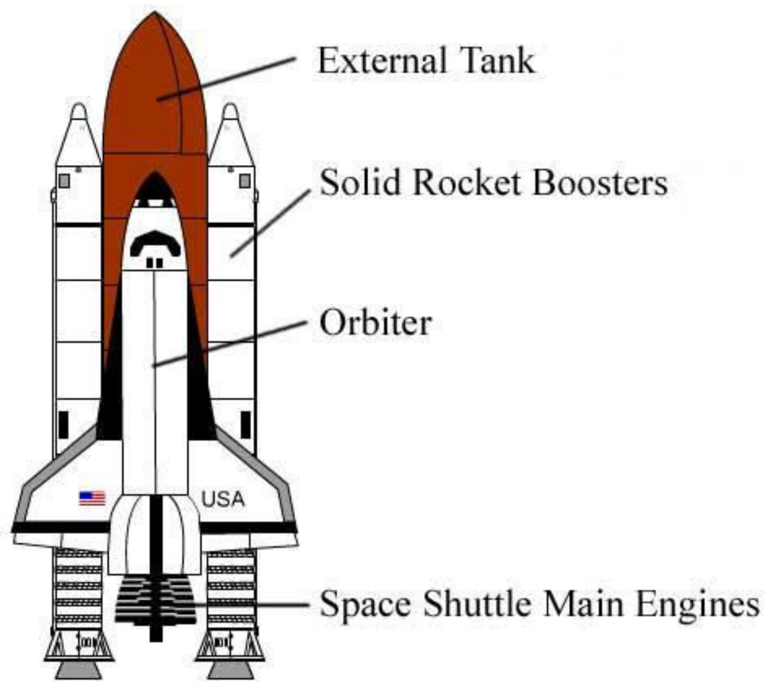
The space shuttle was the culmination of the country's a need for a reusable vehicle with orbital capabilities and reusability. It was designed to have a large payload and a lightweight body.

The Shuttle Stack Design

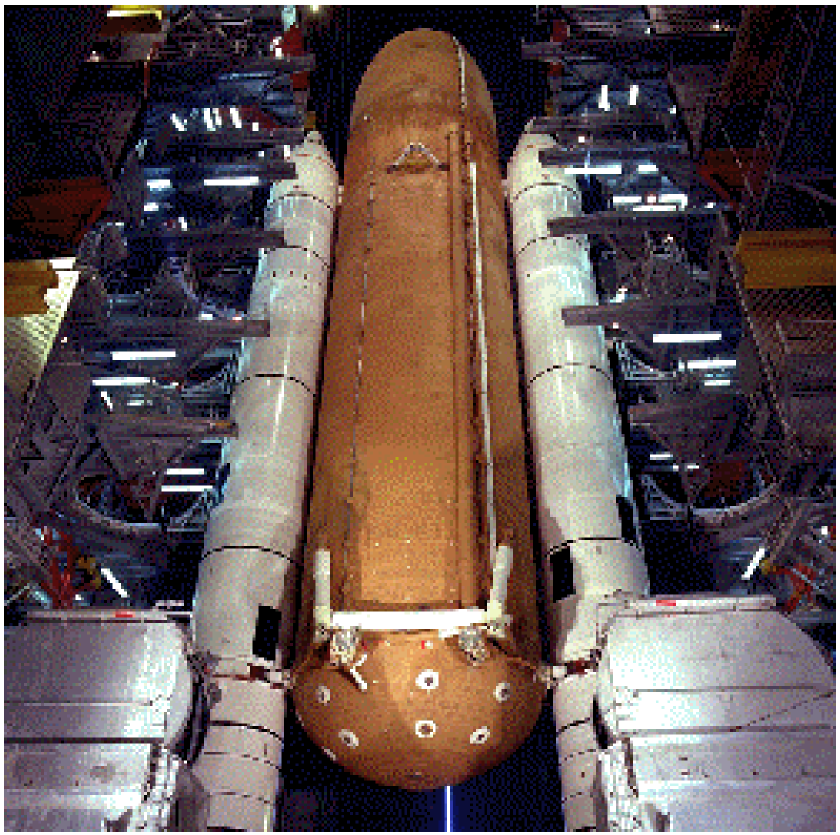
- The shuttle stack is the combination of all the separate components that operate together in the launch of a crew into orbit

The shuttle stack is composed of…

- the external tank
- the Orbiter
- two solid rocket boosters



The External Tank



- Mounted on the underside of the orbiter between the two solid rocket boosters
- Houses the liquid fuel (liquid hydrogen and liquid oxygen) that react to fuel the main engines located on the rear of the orbiter
- At launch, it is the heaviest component of the shuttle. It is jettisoned after the main engines shut down into the earth's atmosphere and splashes down into the ocean.

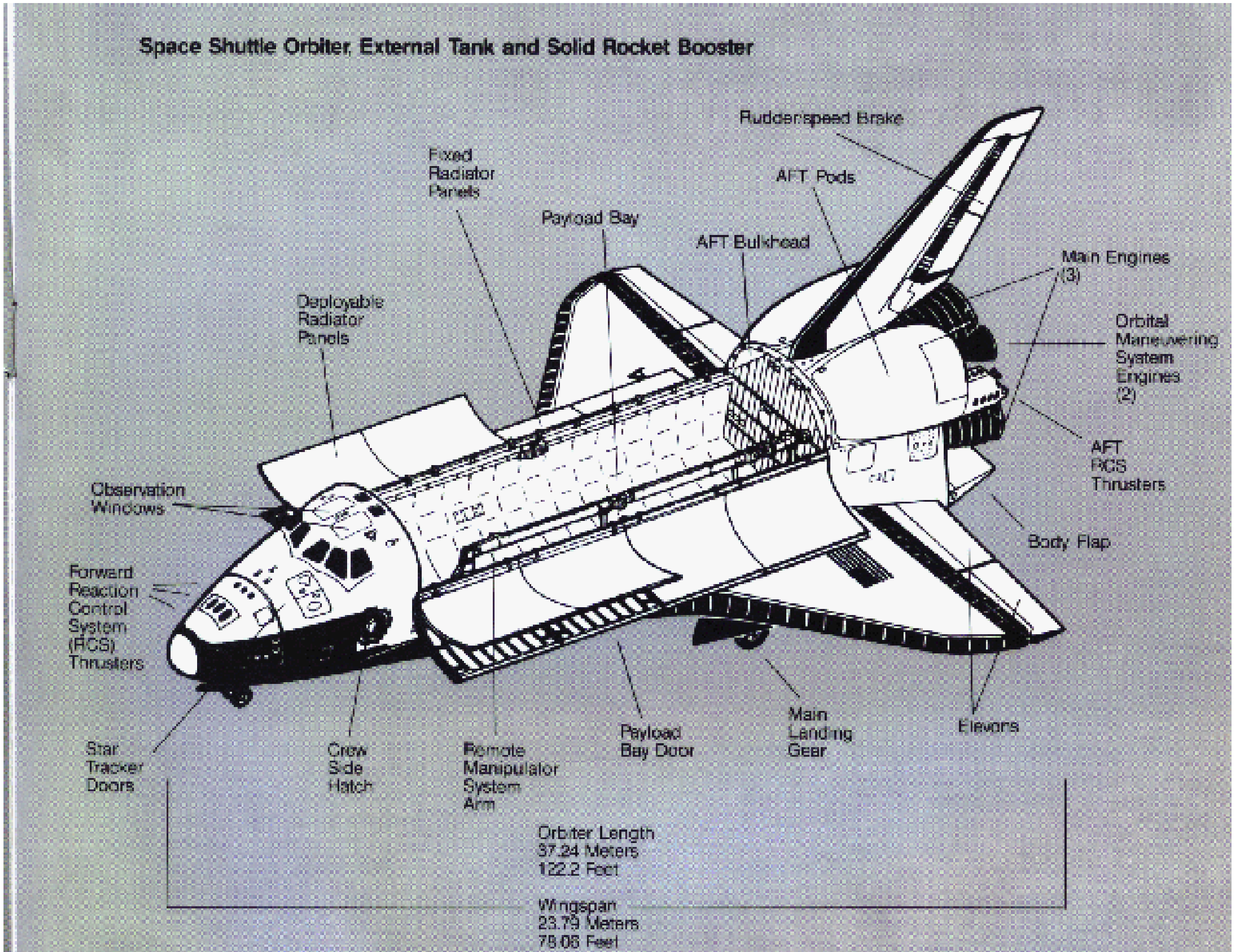
The Solid Rocket Boosters (SRBs)

- Provide a majority of the thrust required to put the shuttle stack into orbit (3,300,000 pounds of thrust per SRB at launch)
- Jettisoned after reaching an altitude of nearly 28 miles and recovered and later reused
- The weight of the SRB consists of 192,000 pounds composed in the exterior shell, nozzle and motor. Another 1,100,000 pounds are attributed to fuel weight.

The Orbiter

- The orbiter is coated with thousands of thermal tiles that shield from heat during re-entry
- It is designed to be a ‘shorts and t-shirt’ environment in space
- Only portion of the shuttle stack that operates in orbit
- Orbits with underside facing away from earth as the dark tiles shield from strong solar radiation

The Orbiter



Space Shuttle Orbiter, External Tank and Solid Rocket Booster
Rudder/speed Brake
Fixed Radiator Panels
AFT Pods
Payload Bay
AFT Bulkhead
Main Engines (3)
Deployable Radiator Panels
Orbital Maneuvering System Engines (2)
AFT RCS Thrusters
Observation Windows
Body Flap
Forward Reaction Control System (RCS) Thrusters
Star Tracker Doors
Crew Side Hatch
Remote Manipulator System Arm
Payload Bay Door
Main Landing Gear
Elevons
Orbiter Length 37.24 Meters 122.2 Feet
Wingspan 23.79 Meters 78.06 Feet

NASA's Orbiter Fleet

- Shuttle missions were carried out on one of five reusable orbiters
- Columbia – The first launched orbiter (1981) which was lost in February of 2003 during re-entry
- Discovery – First launched in 1984, and was responsible for the Hubble space telescope deployment
- Atlantis – First launched in 1985 and was responsible for deployment of the Galileo which then made its way to orbit of Jupiter
- Endeavour – The newest of NASA's orbiters; first launched in 1992

The Challenger

- NASA’s second orbiter put into service
- Flew 9 successful flights prior to 1986 and spent a total of 65 days in orbit
- Carried many vital spacelab components into orbit

Mission STS 51-L

- Launch was slated for January 28th, 1986
- Mission objectives included…

… deployment of a Tracking Data Relay Satellite

… a free-flying module designed to observe Halley's comet

… Conduct experiments (Fluid Dynamics and comet monitoring

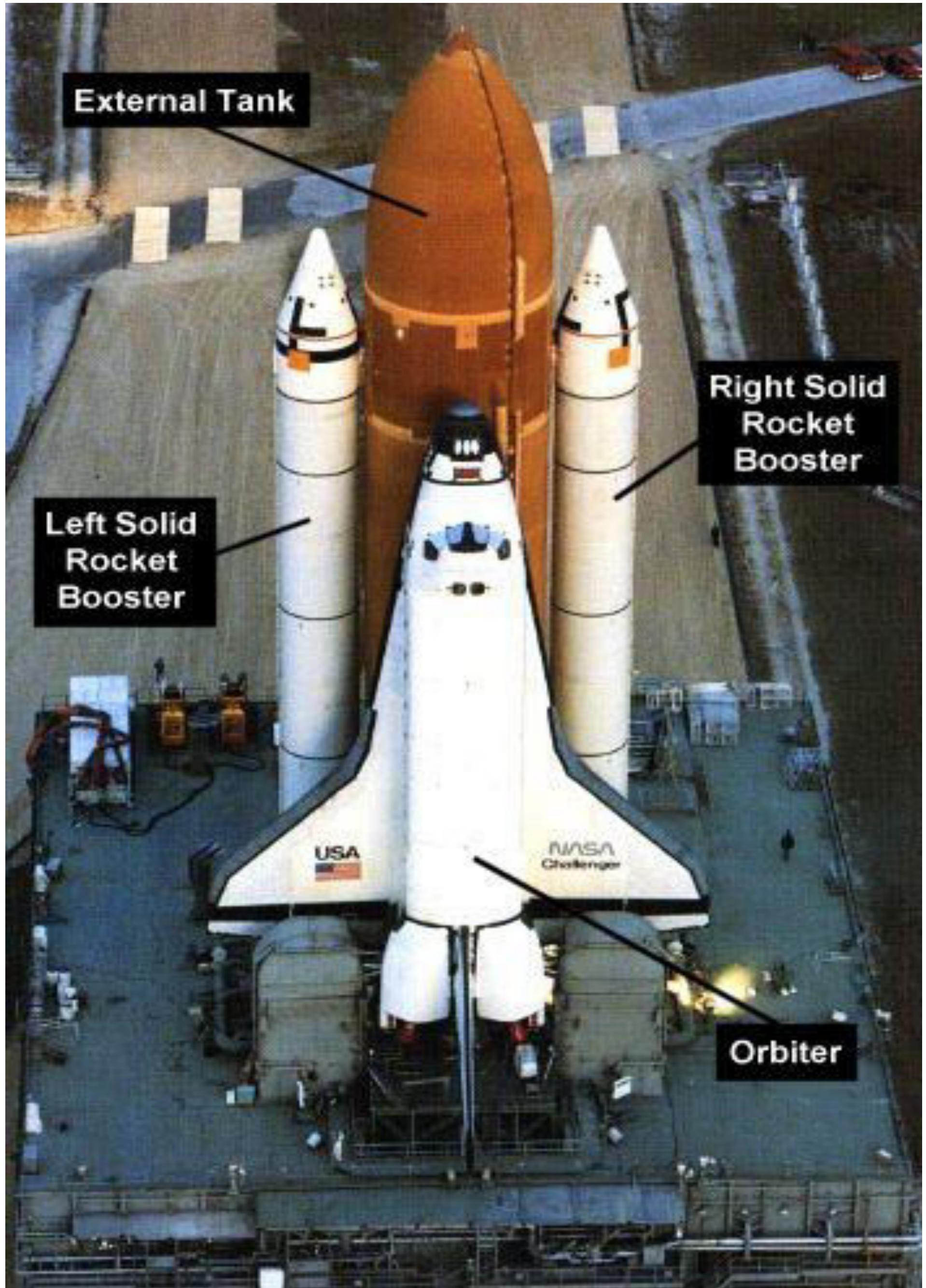
The Crew

- Francis R. Scobee (2), Commander
  Michael J. Smith (1), Pilot
  Judith A. Resnik (2), Mission Specialist 1
  Ellison S. Onizuka (2), Mission Specialist 2
  Ronald E. McNair (2), Mission Specialist 3
  Gregory B. Jarvis (1), Payload Specialist 1
  Sharon Christa McAuliffe (1), Payload Specialist 2

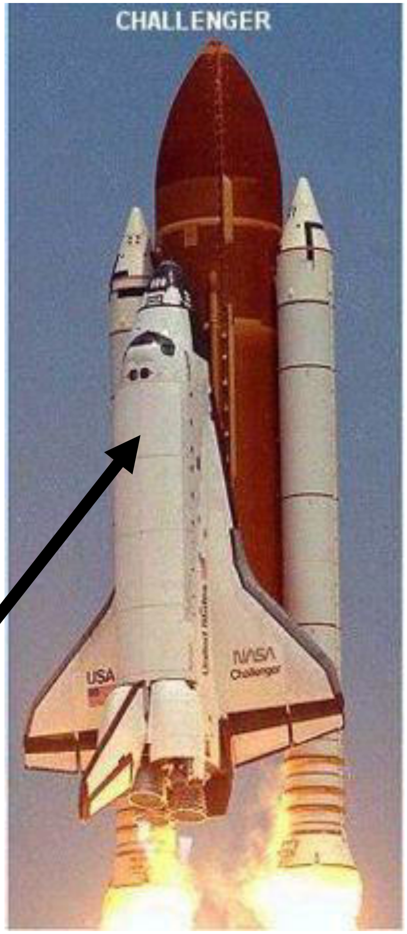
The Crew

* Sharon Christa McAuliffe – First teacher in space

Liftoff of *Challenger*


External Tank
Right Solid Rocket Booster
Left Solid Rocket Booster
USA
NASA
Challenger
Orbiter

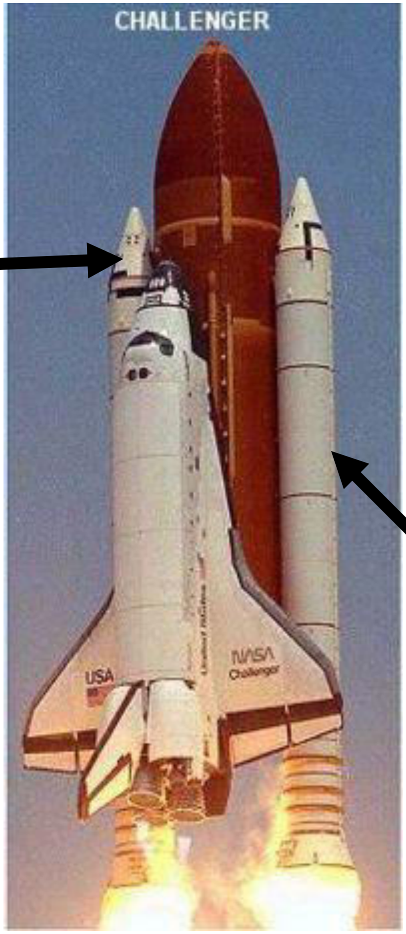
The primary component of the vehicle was the Orbiter, the reusable, winged craft containing the crew that actually traveled into space and return to land on a runway.



Orbiter containing flight deck and crew

However, the Orbiter alone did not generate enough thrust or carry enough fuel to get into orbit. The additional thrust was provided by the two large Solid Rocket Boosters, each attached to the side of the External Tank by means of two struts.

Left Solid
Rocket Booster

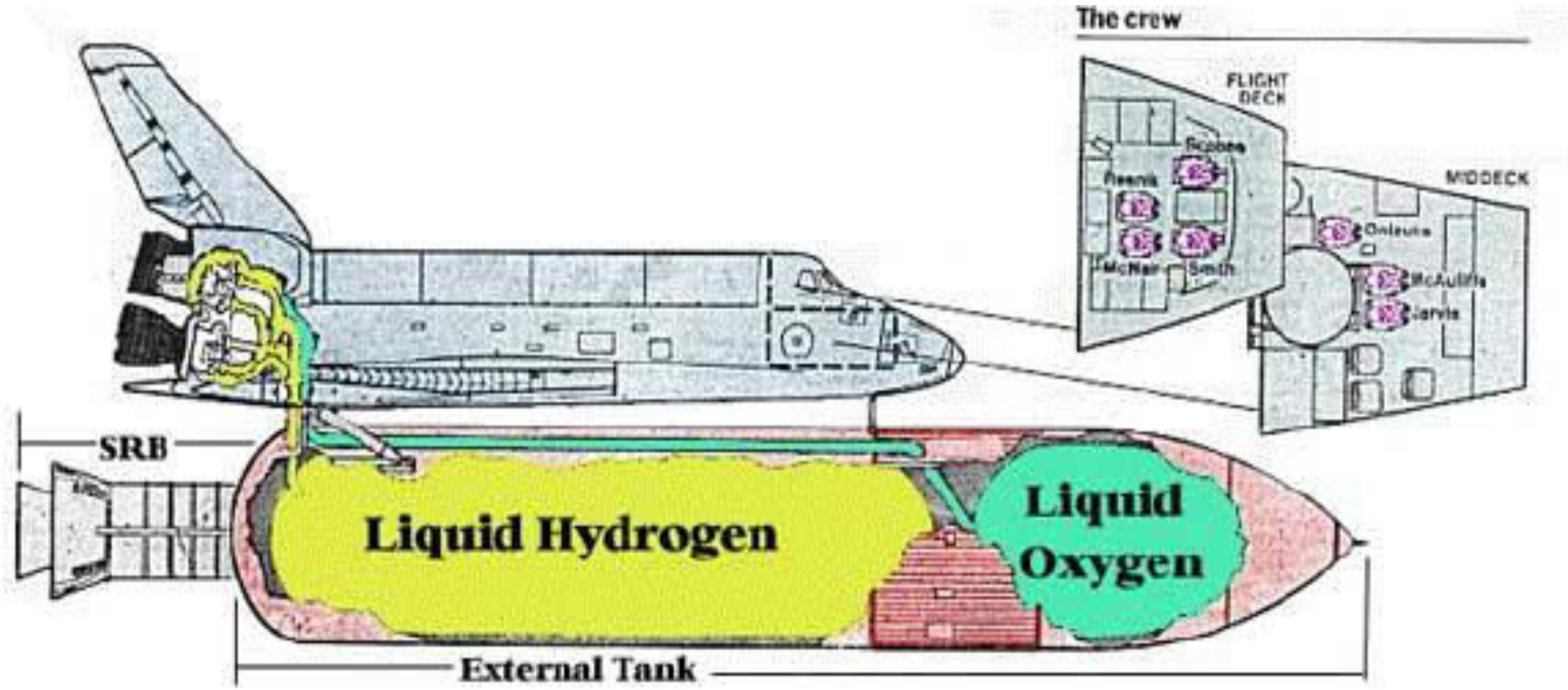


Right Solid Rocket
Booster

Once the two solid rocket boosters lifted the Shuttle to an altitude of about 45,760 m (roughly 28.4 miles), they would be jettisoned.

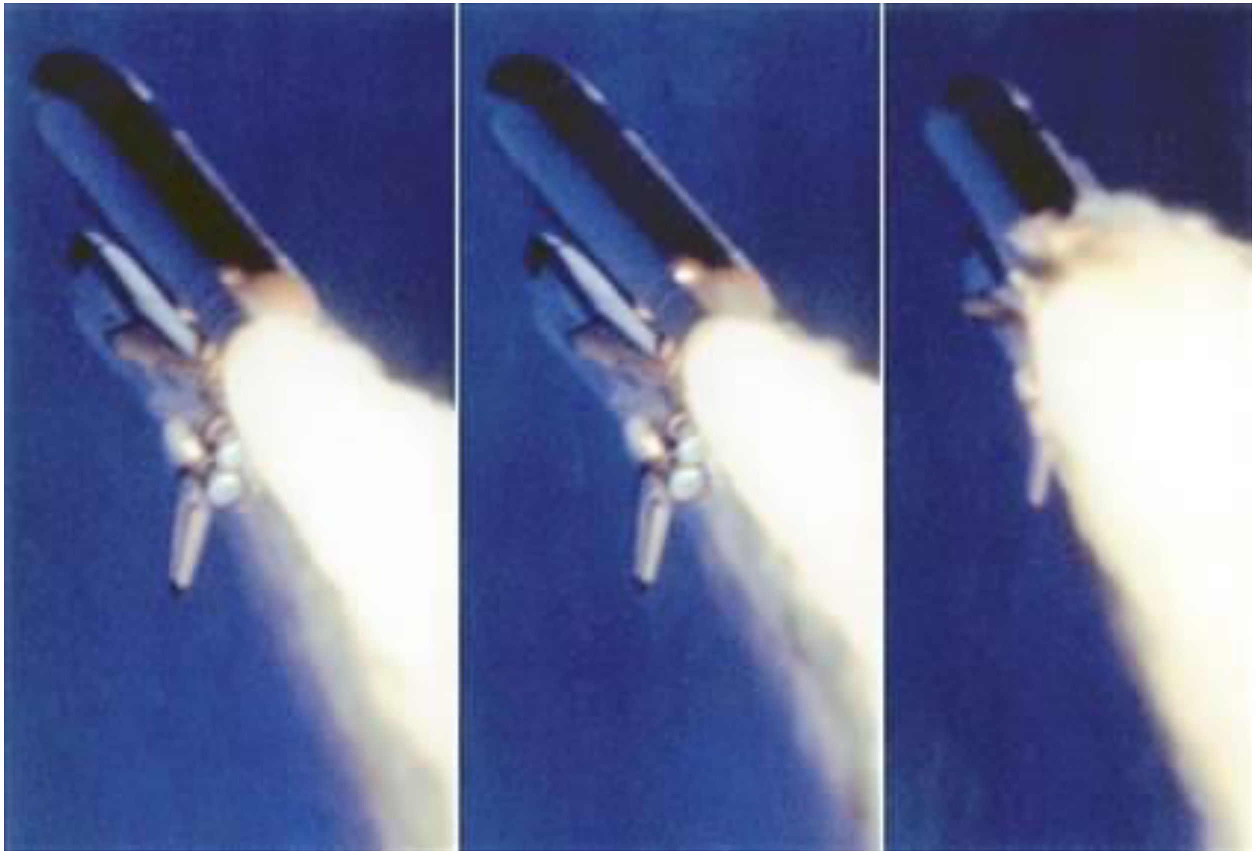
External Tank

Three main engines of the orbiter

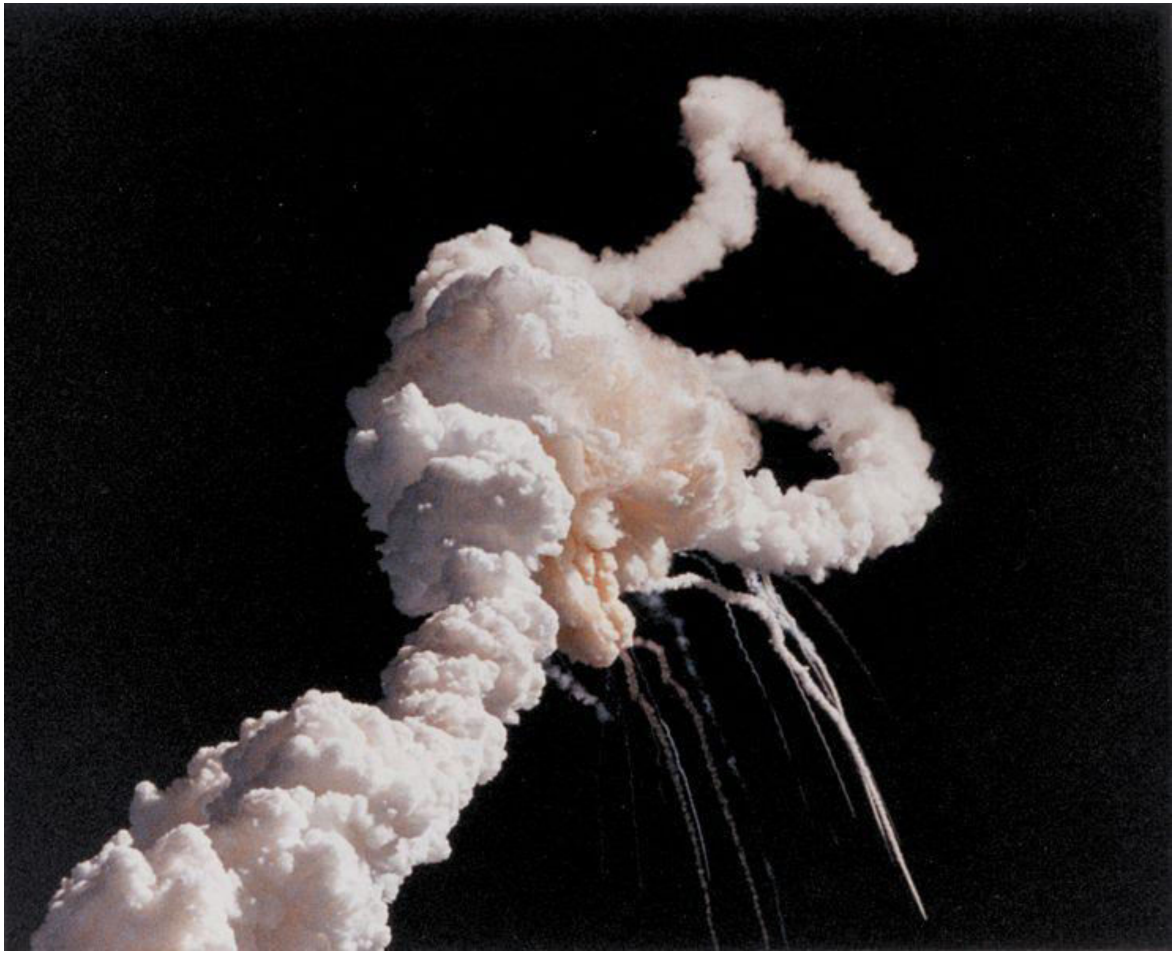


Two-thirds of the External Tank was filled with liquid hydrogen; the top third with liquid Oxygen. This fuel supplied the three main engines of the Orbiter until about 8 1/2 minutes after liftoff. Then the External Tank would be jettisoned at about 111,355m (roughly 69.2 miles) .

Disintegration of the shuttle occurred 73 seconds into its flight.



73 seconds after lift-off, smoke was seen billowing out from the right solid rocket booster followed by several explosions.

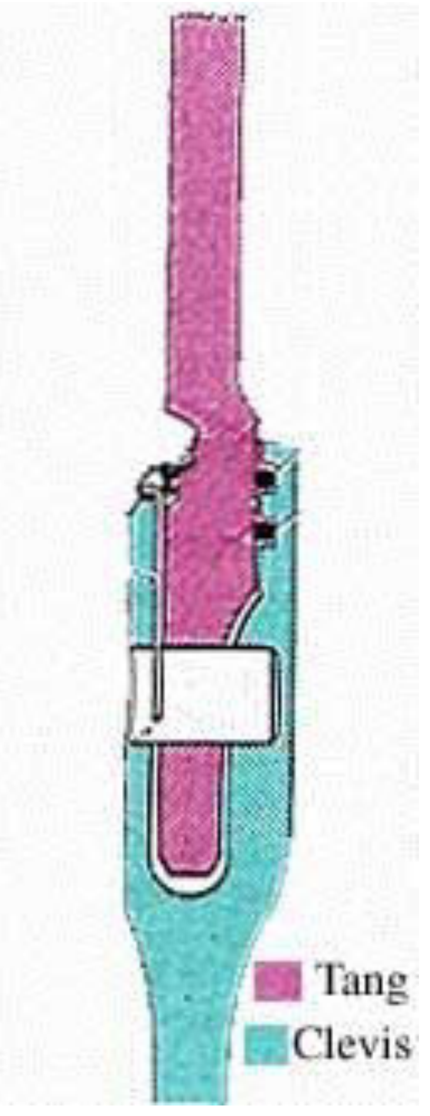


Smoke plume of the Space Shuttle, *Challenger* at 73 seconds after launching.

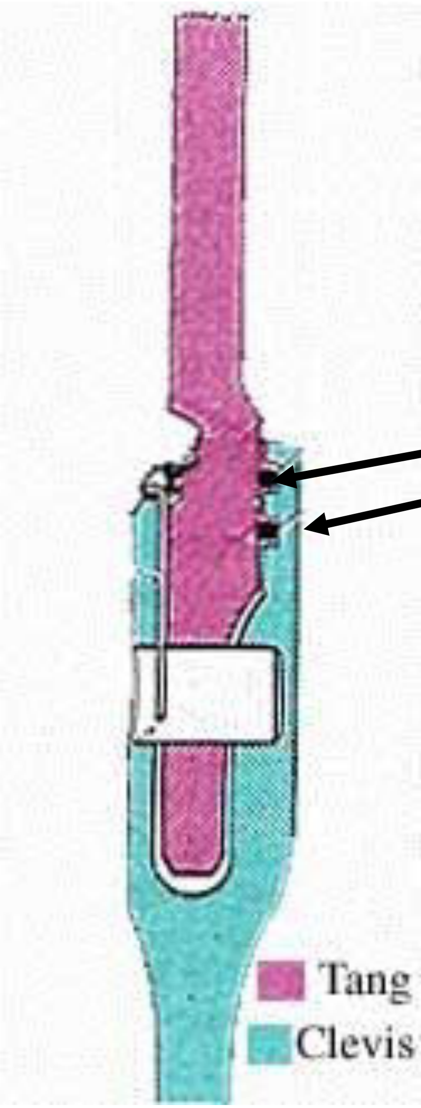
Why did the shuttle explode and disintegrate?

The segments of each booster was joined into three major sections. The sections were interlocked by what is known as a tang and clevis joint.

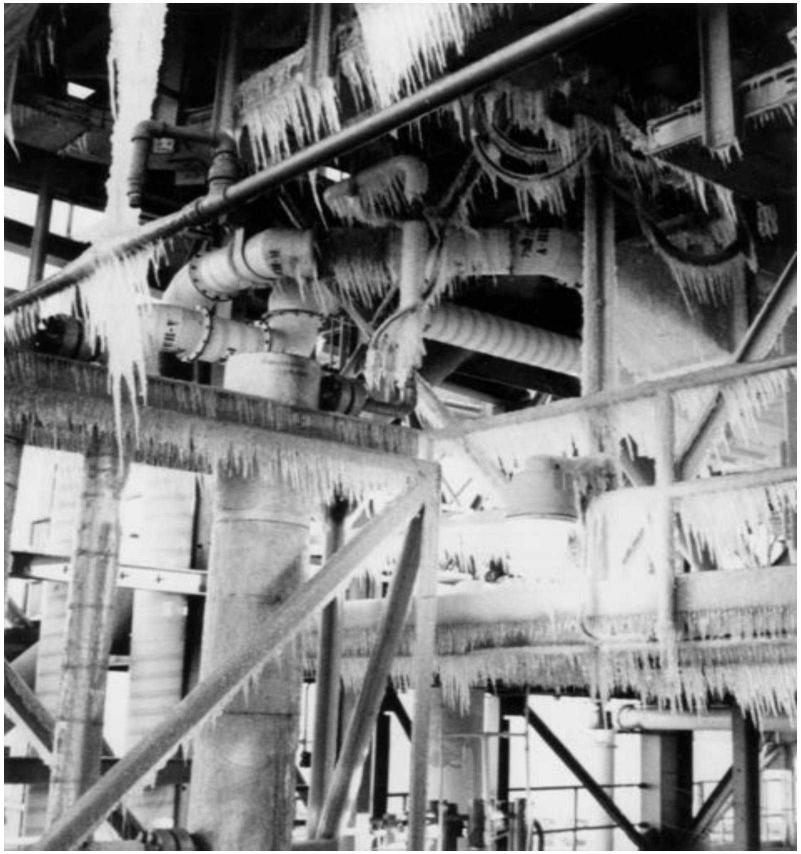
The Tang and Clevis joints used to interlock the segments of the solid rocket boosters



The tang and clevis joint is sealed by two rubber O-rings. Through the heat generated by the burning propellant from the boosters, these rubber seals expand to fill the joints of the three sections and prevent the hot exhaust from escaping.



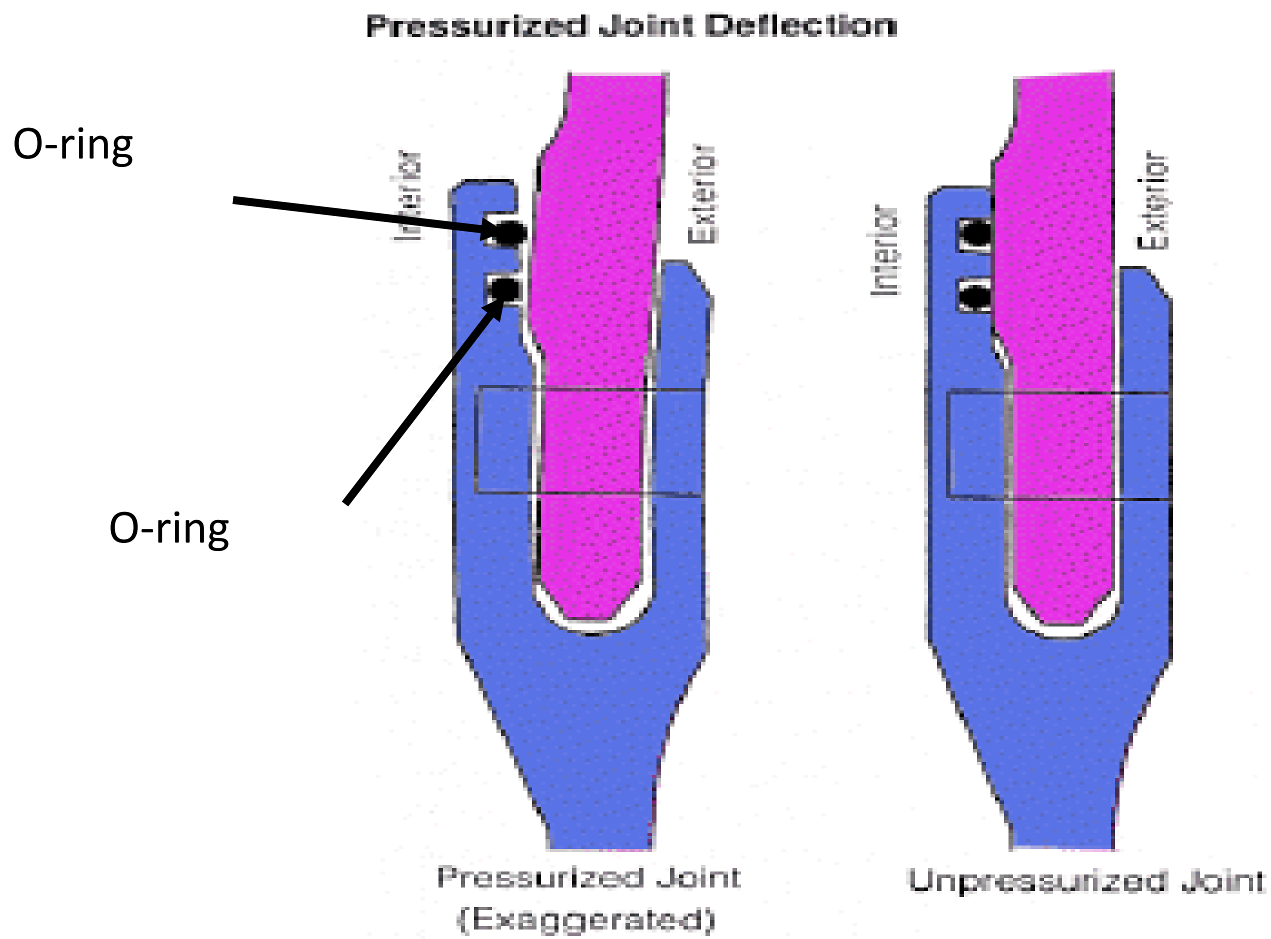
O-rings which expand from the heat of the burning fuel and seal the section joints.



This picture was taken on the morning of the Challenger launch January 28, 1986. This was the coldest day in history that a shuttle had been launched.

The O-ring seal in the right solid rocket booster failed to remain sealed.

The O-ring failure allowed a flare of pressurized hot gas from the solid rocket motor to melt the attachment hardware -- the strut -- and to ignite the liquid hydrogen and oxygen in the external fuel tank.



The joint on the left pictures a pressurized joint which by an expanded O-ring causes a section of the solid rocket booster to seal shut.

Roger Boisjoly, chief O-ring engineer at Morton Thiokol, had warned his colleagues that O-rings lose their resiliency at relatively low temperatures.

Jerald Mason was senior vice president at Morton Thiokol where key Challenger engineers, including Roger Biosjoly worked.

Mason learned the engineers could not supply firm figures regarding what temperatures would be unsafe to launch the Challenger.

Jerald Mason told Morton Thiokol supervising engineer, Robert Lund: "take off your engineering hat and put on your management hat."

Without firm figures that determine that the launch was unsafe, the earlier recommendation to delay the launch was reversed.

Some professional goals or virtues of **engineers:**

upholding high standards of *professional* competence and expertise,

holding paramount the health, safety and welfare of the public.

Some professional goals or virtues of **managerial** decision-makers:

Maximizing the well-being of the ***organization or corporation*** in question. This includes **costs, marketing and public relations.**

Upholding ***organizational*** employee morale and welfare.

In the Challenger disaster there was a moral dilemma.

It involved a conflict in professional goals.

But the conflict was between managerial obligations and engineering goals.

The engineers wanted to ensure the safety of the launch. At the same time they wanted to be faithful agents of their employer, Morton Thiokol.

Recall: Jerald Mason (upper ***management*** at Morton Thiokol) told supervising engineer, Robert Lund: “take off your ***engineering*** hat and put on your ***management*** hat.”

There tends to be a conflict between **engineering** and in **managerial professional** goals or virtues.

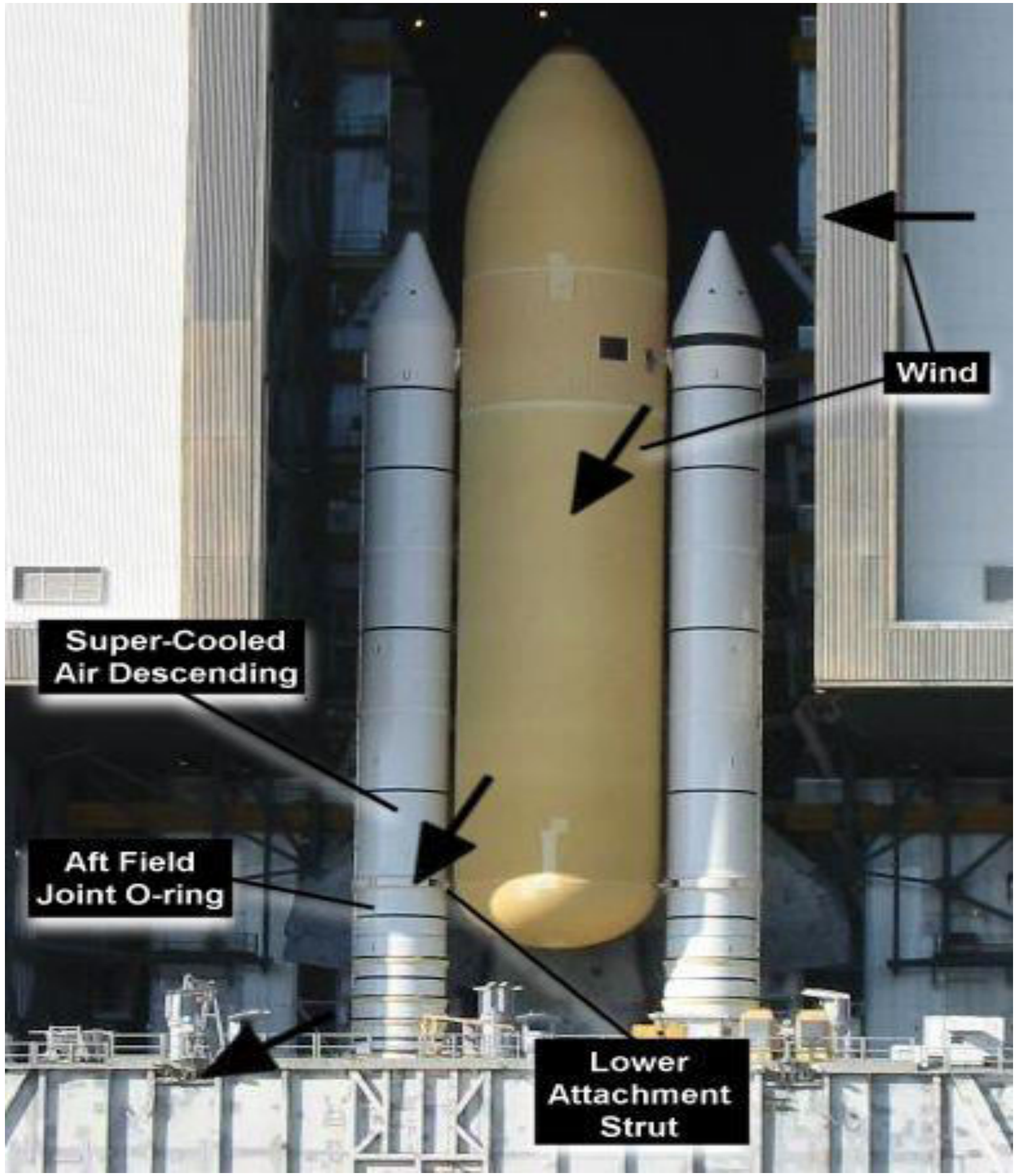
In particular, the engineering decisions regarding *safety issues* will have a different foundation from managerial decisions regarding safety.

- **The engineer's decision will tend to extend *directly to the well-being of the public*.**
- **The managers' decision will tend to extend more to the well-being of *the organization* they work for.**

Let’s return to the challenger case.

The failure and explosion of the Challenger was due to the lack of resiliency of the O-rings under cold temperature. But the reasons for the cold temperatures were actually complex.

As a matter of fact, an usually stiff blew towards the west-northwest on the night preceding the launch. As a result, the super-cooled air around the liquid hydrogen and liquid filled external tank flowed directly into the lower portion of the right solid rocket booster and cooled the lower joint.



Wind blowing over the External Tank and impinging on the aft field (lower) joint of the right Solid Rocket Booster.

But even the unusual direction of the cold wind, deflecting off the External tank and the extremely low day-time temperature on the day of the launch was not enough to make the O-rings fully malfunction.

If the very low day-time temperature on January 28, 1986 and the usually cold west-northwest wind were enough to make the O-rings malfunction, the shuttle would have exploded within a few seconds after take-off. But that’s not what happened. Severe problems did not occur until 50 seconds after take-off.

So in fact there was another unexpected risk factor which caused the O-rings to fully *malfunction*.

This didn’t happen until 56 seconds into the launch, right around the time **‘max Q.’**

‘Max Q’ is the point of maximum air pressure upon the ascending shuttle. It is determined by the relation between increasing acceleration of the missile and the decreasing density of the atmosphere as the shuttle ascends.

Right around the time of ‘Max Q’ the Challenger passed through the **worst wind shear** in the history of the Shuttle program.

So there were three causes which caused the O-rings to malfunction on the day of the Challenger launch:

A very low daytime temperature on the day of the launch. Morton Thiokol engineers had no significant data at how O-rings would perform below 51º F (11ºC).

An unusual strong west-northwest wind that led unusually cold air to be deflected off the liquid hydrogen and oxygen tank onto the right lower O-joint.

The worst wind shear in the history of the Shuttle program at 56 seconds into the launch, the time of ‘Max Q.’

So how does this review of the causes of the Challenger Disaster add to our understanding of ethical problem-solving in engineering?

It obviously underscores the serious consequences that can ensue from poor ethical decision-making.

And we see that ethical problem-solving, even with such historically-significant and carefully deliberated decisions as the Challenger launch turns on a ***conflict of professional goals***.

In particular, with the Challenger Disaster we learn that in engineering ethics a conflict often arises between ***engineering*** professional goals and ***managerial*** professional goals.

In particular we learn that for engineers, the determination of risk to the health, safety and welfare of the public is a crucial consideration.

As risk expert William W. Lowrance explains determining risk is a “compound measure of magnitude and adverse effect”(Lowrance. 1980).

So to determine degree of risk of the Challenger launch, we need to know the probability of--

The O-rings malfunctioning below 51º F (11ºC) atmospheric temperature.

The unusual wind-factors such as the west-northwest wind that deflected cool air to the lower right O-ring.

Wind shear effects on O-rings during the first few minutes after take-off.

It becomes clear, then, that determining the probabilities of safety risk of a system's components -- such as the Solid Rocket Booster's O-rings -- requires a ± degree of error in determining the likelihood of adverse effects.

When Jerald Mason, the high-level manager at Morton Thiokol, learned that engineers, including Roger Biosjoly, could not supply firm figures regarding at what temperatures the Challenger launch would be unsafe, he was asking the wrong question.

Further, when Jerald Mason told Morton Thiokol supervising engineer, Robert Lund: “take off your engineering hat and put on your management hat,” he was promoting bad ethical decision making.

In the cases we’ve consider before, we’ve frequently seen that ethical dilemmas often appear as a ***hard choice***. You have to choose between the lesser of two evils.

In the Challenger disaster, the lesser of two evils choice should have been to delay the launch.

Final Summary

Virtues or ethical goals arise from responses to the human condition which balance the excesses and deficiencies of human needs.

Engineering professional goals or virtues, such as protecting public safety and client and employee honesty, lead to the trust and progress of the engineering profession

Ethical problem solving, whether personal or professional, strives to find a creative ways to reconcile conflicting goals.