Project Management Challenges in the Space Shuttle Flight Design Program

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Presentation Overview

- NASA: Organized into Centers.
- Johnson Space Center (JSC) – Home of the Astronauts.
- Space Shuttle Overview.
  - Systems.
  - Mission Profiles.
  - Flight Phases.
- Space Shuttle Flight Design.
- Space Shuttle Flight Design Projects.
  - Environment.
  - Challenges.
  - Risks.
- Example Shuttle Projects.

NASA: Rockets, Space Exploration, and Much More

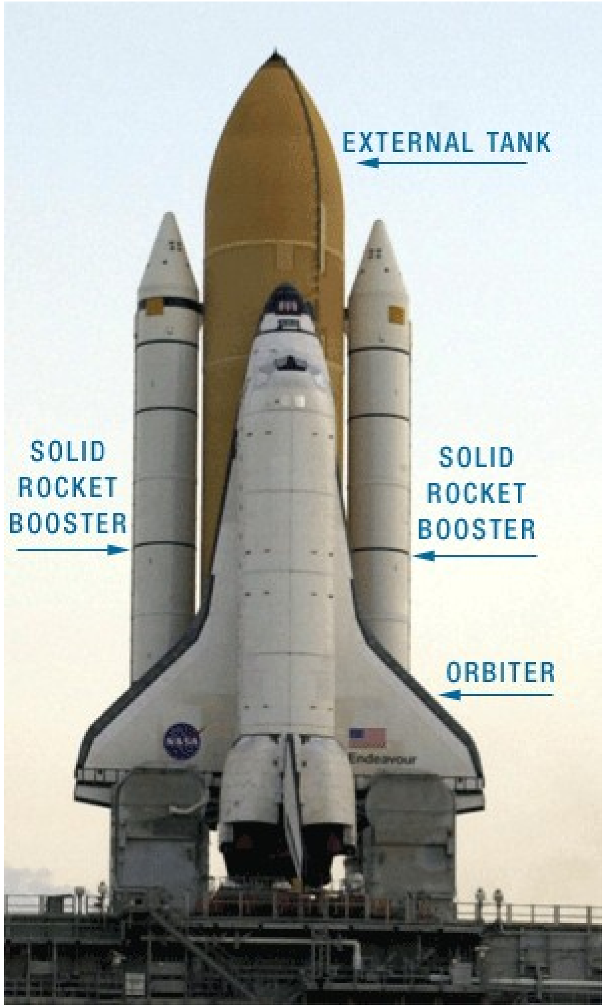
- NASA is organized into centers.
  - Headquarters (Washington, DC).
  - Ames Research Center.
  - Dryden Flight Research Center.
  - Goddard Space Flight Center.
  - Jet Propulsion Laboratory (JPL).
  - Johnson Space Center (JSC).
  - Kennedy Space Center (KSC).
  - Marshall Space Flight Center (MSFC).
  - Glenn Research Center.
  - Langley Research Center.
  - Stennis Space Center.
- NASA does much more than just launch space missions.
  - Aeronautics, communications, aviation, robotics, networks.
- Each center has a core function. Examples:
  - KSC: Prepare and launch missions around the Earth and beyond.
  - Marshall: Space transportation and propulsion technologies.
- Centers have other, secondary responsibilities.
  - Example: The moon rocks which were brought back by Apollo were analyzed at JSC.

Johnson Space Center: Home of the Astronauts

- Location: Houston, Texas, between Houston and Galveston.
- Organized into directorates: *Mission Operations*, *Flight Crew Operations*, *Engineering*, etc.
- The Mission Operations Directorate is tasked with planning and executing manned spaceflight missions.
- Key Mission Operations facilities:
  - Mission Control.
  - Weightless Environment Training Facility.
  - Shuttle Mission Simulators.
  - Shuttle Mock-Up facilities.
  - Crew Training and Isolation facilities.

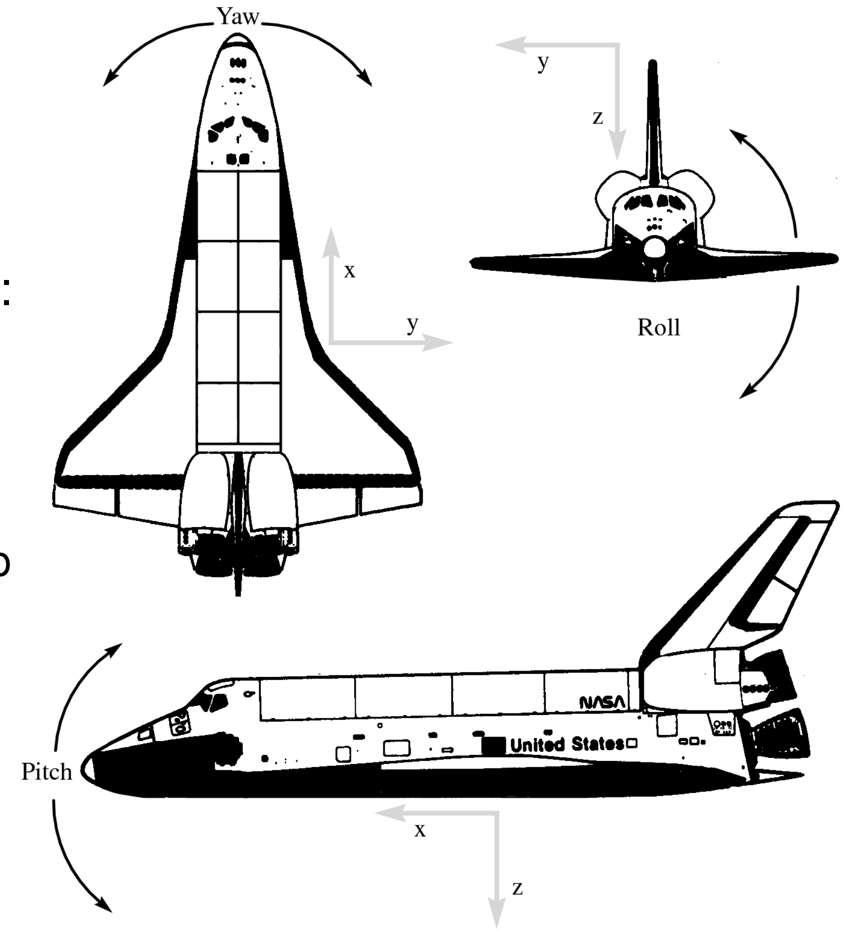
Space Shuttle Systems Overview

- Main Systems:
  - Orbiter (Discovery, Atlantis, Endeavor).
  - Solid Rocket Boosters (SRBs).
  - External Tank (ET).
- Orbiter Systems:
  - Propulsion: Orbital Maneuvering System (OMS) engines, Reaction Control System (RCS) jets.
  - Environmental Control and Life Support (ECLS).
  - Communications.
  - Electrical Power.
  - Caution and Warning.
  - Thermal Protection System (TPS).

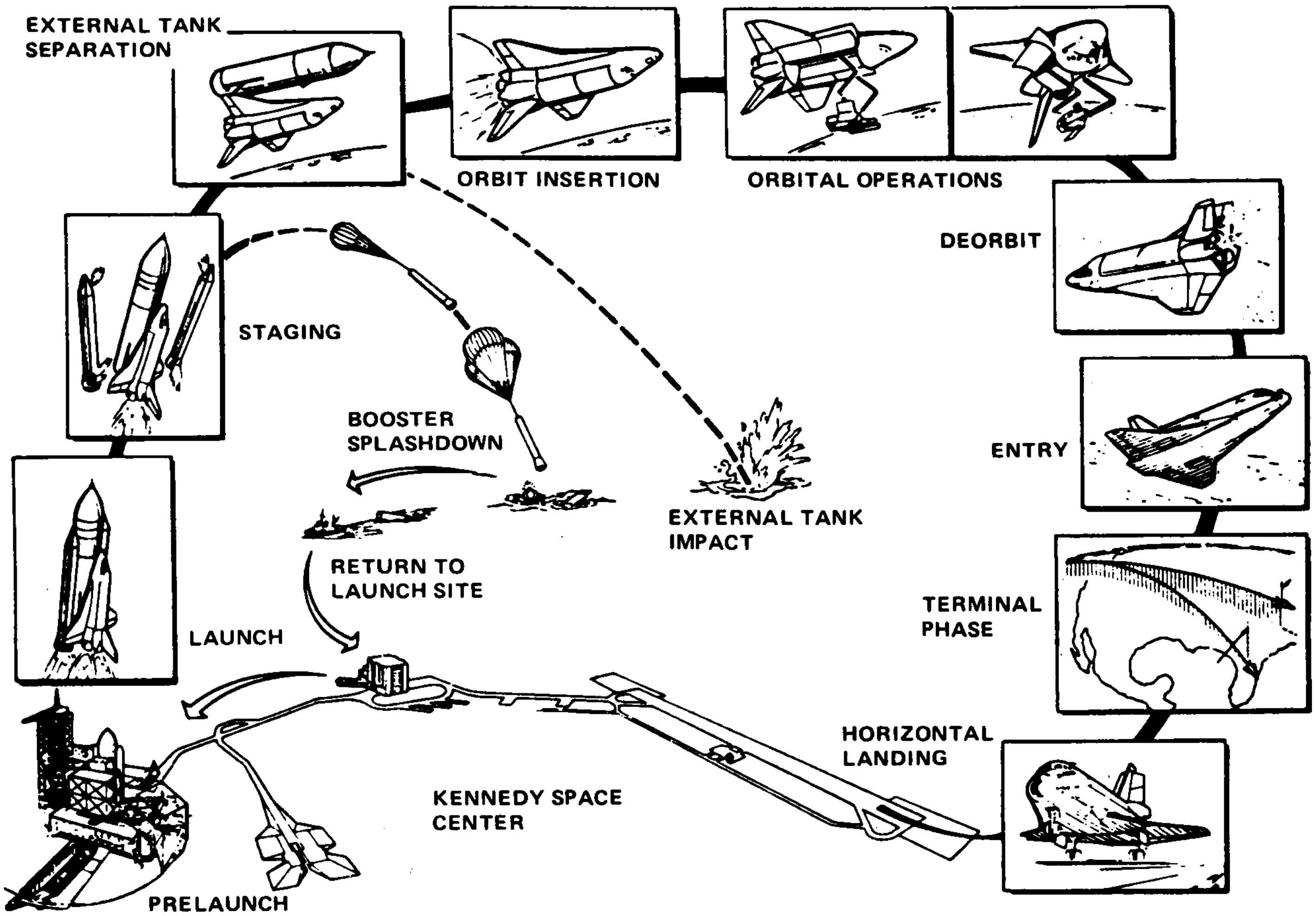


Space Shuttle Systems Overview (Con't.)

- Orbiter Systems (Con't):
  - Aero Control: RCS, elevons, body flap, rudder.
  - Guidance, Navigation, and Control (GN&C).
  - Hydraulic Power Systems.
- Systems are designed for redundancy. Example:
  - Five general-purpose computers (GPCs).
  - Four run the Primary Avionics Systems Software (PASS).
  - The fifth runs an independently-developed Backup Flight Software (BFS).
- Other examples:
  - OMS de-orbit backup/downmode to forward RCS.
  - Contingency de-orbit targeting software on crew laptops (part of the SPoC software).



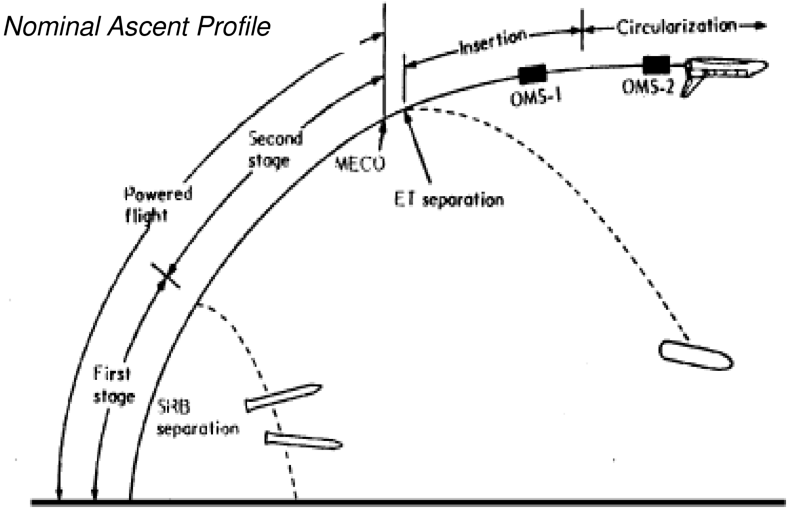
Space Shuttle Flight Phases



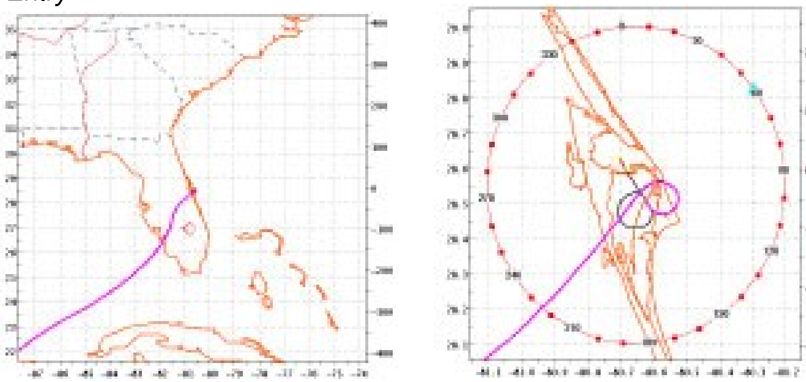
Space Shuttle Flight Phases (Con't.)

- Three phases: Ascent, Orbit, Decent.
- Ascent (OPS 1): two stages.
  - SRBs burn out and are jettisoned approx. 122 seconds into flight ("*SRB Sep*").
  - ET is jettisoned after main engine cut-off ("*MECO*"), approx. 512 seconds after launch.
- Orbit (OPS 2): nominal mission objectives.
- Decent (OPS 3): De-orbit, Entry, and Landing.
  - De-orbit burn using the OMS engines, about half way around the world from the landing site.
  - Entry: from orbit to TAEM (Terminal Area Energy Management) interface.
  - Approach & Landing: from TAEM to wheel stop.
  - Entry & landing is un-powered (no engines).

Nominal Ascent Profile



Entry



Space Shuttle Mission Profiles

- Nominal: 160nm circular orbit at 28.45 orbital inclination.
- Payload to orbit delivery.
  - Originally one of the “core” shuttle mission profiles.
  - STS-51A: Deployed Canadian Communications Satellite TELESAT-H, Synchronous Communication Satellite IV -1 (SYNCOM IV-1).
  - STS-37: Deployed Gamma Ray Observatory (GRO) deployment.
- Retrieval or Repair.
  - Orbit profiles (altitude, orbital inclination) dictated by the payload in orbit.
  - STS-32: Retrieve Long Duration Exposure Facility (LDEF).
  - STS-72: Retrieve Japanese microgravity research spacecraft Space Flyer Unit (SFU).
  - STS-61, STS-82, STS-103: Hubble Space Telescope servicing.
- DoD: let's just say “some interesting mission profiles.”
  - Example missions: STS-51J, STS-27, STS-33, STS-36, STS-44.

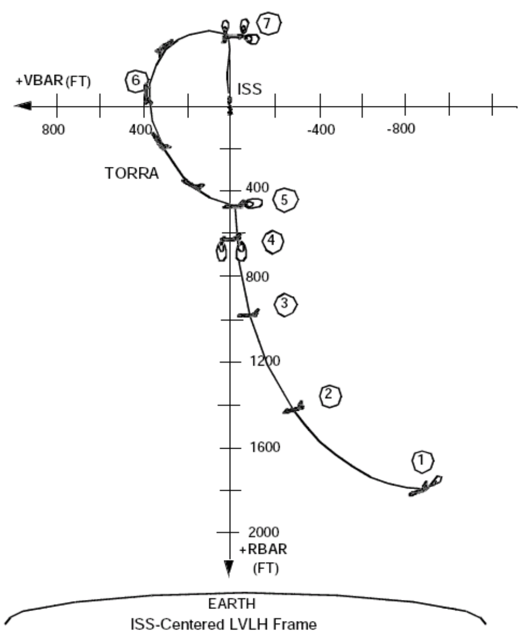
Space Shuttle Mission Profiles (Con't)

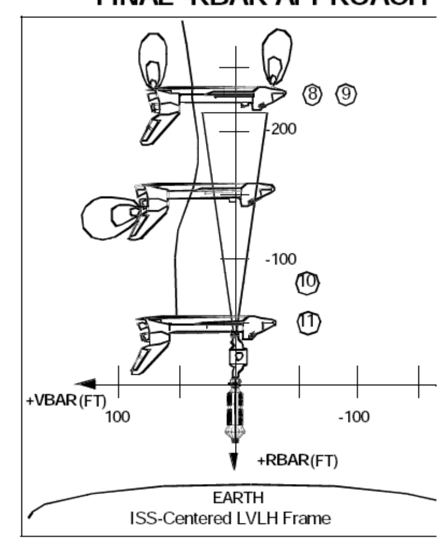
- Science/research.
  - STS-42: International Microgravity Laboratory-1 (IML-1).
  - STS-45, STS-56: Atmospheric Lab for Applications & Science (ATLAS-1 and ATLAS-2).
  - STS-47: Spacelab-J (SL-J) science laboratory.
  - STS-58: Spacelab SLS-2 Life Sciences.
- MIR and Space Station.
  - Seven MIR missions: STS-71, STS-74, STS-76, STS-79, STS-81, STS-84, STS-86.
    - Delivery of crew and supplies.
  - Space Station assembly and servicing missions is the dominant mission profile as the Shuttle program nears retirement.
  - Latest mission (STS-122) delivered the European Space Agency's (ESA) Columbus laboratory.
    - Launch Window: 5 Minutes.
    - Altitude: 122 NM (140 Miles) Orbital Insertion.
    - 185 NM (213 Miles) Rendezvous.
    - Rendezvous Inclination: 51.6 Degrees.

Space Shuttle Flight Design

- Flight Design & Dynamics Division (DM) is one division of Mission Operations.
- Responsible for all aspects of the vehicle trajectory design and analysis.
  - Data loaded into the GPCs for all flight phases.
  - Mission analysis and support software.
  - Trajectory design and analysis software.
- Flight Design is the process of determining the data values which direct the Space Shuttle to fly a specific trajectory profile.
  - Constrained by mission flight rules.
  - Depends on the Space Shuttle Flight Software (written in HAL) release, or "OI." For STS-122, the flight software version is OI-32.

Rendezvous Profile





Space Shuttle Flight Design Projects

- Flight Software configuration for missions.
  - Determine all the data (called “I-Loads”) to be used by the GPCs, Mission Control, etc. Examples: flight corridor graphics displays, engine-out abort limits.
- Analysis projects: find ways of doing things. Examples:
  - Increase payload to orbit capability.
  - Improve safety.
  - Test new systems and features, e.g., drogue chute analysis, modeling, test & checkout.
  - New algorithm development, test, and deployment, e.g., Simplex Optimization.
- Tools development.
  - Example: New trajectory simulation tools.
    - One of the main tools: Fortran program from the Apollo era called Space Vehicle Dynamics Simulator (SVDS).
    - Replacement simulator: Spacecraft Trajectory and Mission Planning Software (STAMPS).
  - Example: Tool consolidation. Many specialized tools have been developed over the years.

Space Shuttle Flight Design Projects (Con't.)

- Flight Design process improvements.
  - Automating production and/or delivery of Products (outputs of a Flight Design process).
  - Knowledge capture.
  - Workflow/process automation.
- Assess impact of Shuttle systems changes. Examples:
  - Hardware updates require the software models of the hardware to be updated and tested.
  - Flight Design techniques ("*rules of thumb*") must be re-visited and re-validated.
- New technology adoption and upgrade (tools, techniques, methods, etc.).
- Payload support projects.
  - Many smaller experiments are flown on missions, e.g., student experiments.
- Crew training and support.

Flight Design Project Environment

- Teams spread across NASA sites and contractor sites.
  - Matrixed project resources.
  - Most located on-site at JSC or nearby.
  - The team landscape has changed and evolved over the 20 year program lifespan.
- Priorities have changed over the program lifespan.
  - Initially focused on performance improvements, post-flight analysis, and risk identification/ mitigation; many new projects and ideas.
  - Later focus shifted to a more operations-oriented maintenance and productivity improvements emphasis; few new projects and ideas.
- Technology Tools & Techniques: A **wide** mix of the new and old.
  - Punch card readers to USB flash drives.
  - Fortran to Java/J2EE.
  - Apollo-era custom data formats to the latest XML tools.

Flight Design Project Environment (Con't.)

- Project Management Methodologies: custom with some best practices sprinkled in.
  - PM process varies with the type of project.
  - Incident and Issue Research and Resolution projects are the highest priority projects. Organization and structure are ad-hoc. "Tiger Teams" focus on getting answers.
  - Flight Configuration projects are very structured, and are the next highest priority projects.
    - A program-wide Flight Readiness Review (FRR) is conducted for each flight.
  - Tool and Technique projects are structured and follow management plans but are usually lower-priority projects.
  - Analysis projects are the most free-form.
- Project Organization.
  - Flight-related:
    - Large: co-lead by NASA and contractor PM.
    - Small: contractor PM, with a NASA coordinator or steering committee.
  - Tools/Techniques, Analysis: Mix of both NASA and contractor PMs; usually there is a steering committee.

Flight Design Project Challenges

- People Challenges.
  - A “not invented here” (NIE) attitude due to the large, diverse environment with many entitles (contractors and NASA).
  - People new to a discipline (Ascent, Navigation, Orbit, etc.) often encountered a “you haven't paid your dues” bias.
  - Common problem: competition between contractors.
  - Common problem: wide range of skill, motivation, interest, etc.
  - Resistance to change: the tools, techniques, etc., in use at the start of the Space Shuttle Program become the de-facto “standard.”
  - Resistance to change: engineers (NASA and contractor) who move up the management ladder favor tools, techniques, etc., that they know.
  - Key NASA stakeholders such as astronauts wield considerable influence.
  - Common problem: turf battles (“*That's my computer you're using!*”).

Flight Design Project Challenges (Con't.)

- Resource Challenges.
  - Government procurement rules limit updating and replacing tools, systems, etc.
  - Common challenge: people with the highest expertise are most in demand.
- Technical Challenges.
  - Common challenge: broad technical expertise can only be obtained by experience.
  - Security: bringing new tools and technologies into a secure environment.
- Administrative/Management Challenges.
  - Resistance to new ideas: Many projects are pitched, accepted, and started. Most either fail or deliver less-than-promised results.
  - Difficulty adhering to project management plans, e.g., scope, time, quality, risk, due to the reluctance of contractor management to tell the client (NASA) that something can't be done.
  - Resistance to training: seminars and training classes are often considered a waste of time.

Flight Design Project Risks

- Inherent risks in a program where lives are on the line, and depend on so many people and so much complex technology.
  - The weight of this can paralyze some people.
  - Failing to keep this risk in mind can have serious consequences.
- Resistance to change: maintaining the status quo minimizes the risk of being blamed if something goes wrong.
- Resistance to independent thinking: people blindly follow written procedures and don't sanity-check their results, and so can't be blamed if something goes wrong.
- Resistance to sharing expertise, and the “pay your dues” mentality.
- Models of physical systems are simplified, limited representations, and cannot be a 100% substitute for the real system.
  - Engineers often run tests using models of systems without considering the model limitations.
  - Common risk: Lack of thorough documentation, e.g., listing model limitations, methods, etc.

Flight Design Project Risks (Con't).

- Time constraints:
  - NASA will not hold up a flight just because you can't meet your deadline!
  - Common problem: Product delivery delays can have a delay cascade effect.
- Common problem: group think.
- Common problem: fear of challenging the “experts” and the status quo.
- Common problem: reluctance by contractors to tell the client (NASA) that something can't be done.
  - This caused a large software project in the mid-1990's to be overloaded to the point where it fell too far behind and was canceled.
- Lack of understanding of the limitations of data analysis, optimization, and other technologies.
  - Example: The difference between interpolation and extrapolation: extrapolation has much higher risk!
  - Presentations of technical studies often do not address these issues.

Project Example: Space Station Freedom Performance-Optimal Orbital Inclination Analysis

- Goals:
  - Increase the Shuttle payload delivery capability for Space Station Freedom missions.
  - No changes to existing mission flight rules.
- Issues and challenges:
  - Move the optimum launch time from near the end of the launch window for a 28.45 degrees (due-east launch from KSC) inclination mission to somewhere in the middle of the window.
  - Wide skepticism from the "veterans" in the Shuttle program ("*It'll <u>never</u> work!*").
  - Tools: Univac mainframe systems with less precise simulation tools-- Fielddata Fortran, outputs on green-bar paper and microfiche.
- Results:
  - Changing the orbital inclination from 28.45 degrees to 28.80 degrees reduced the propellant requirements for the same payload by 800 pounds.
  - Launch window duration reduced by about 4 minutes.
  - Cost savings estimate: (500 to 700 lbs. savings/flight) * $10,000/pound to orbit = $5 to $7 million dollars per flight.
  - At 10 weight-limited flights for station assembly, the total savings > $50+ million.

Project Example: Parallel Distributed Processing (PDP) Capability Proof-of-Concept and Development

- Goals:
  - Reduce the execution time of multi-case simulation tasks by distributing individual trajectory runs across the Flight Analysis and Design System (FADS) workstation network.
  - Optimize FADS workstation utilization.
  - Minimize the changes to existing software and procedures.
- Issues and challenges:
  - Technical: Workstation resource management, scheduling, and communications.
  - Resource sharing: "*You can use our workstations if we can use yours.*" A political problem.
  - Communications: Team and stakeholders to gain acceptance of the new process.
  - Low-priority project: work it as you can find time. Very limited resources.
- Results using prototype PDP software for a Performance Enhancements Project:
  - ~120 different cases at 150 I-load sets per case, and 30 minutes per I-load set.
  - Serial execution: 375 days to complete. Parallel execution: 11.6 days to complete.
  - Rough total calendar time savings estimate: 40+ staff months down to 3 calendar months.
  - Cost savings estimate: $40 million dollars.

For More Information...

- NASA
  - Space Shuttle Program: **http://www.nasa.gov/topics/shuttle_station/index.html**.
  - Principal Space Systems Contractor: **United Space Alliance**.
  - Another NASA Contractor: **Draper Laboratory**.
  - Next-generation space program: **Constellation**.
- Project Management Institute **Aerospace & Defense Special Interest Group**.

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  - PDP Project: **IEEE Presentation**; also published in **NASA Tech Briefs**.
  - Other publication of interest: **Modern Astrodynamics** (*Princeton Univ. Press, 1996*).