The Importance of Systems Engineering at NASA

Presentation to GE

15 September 2014

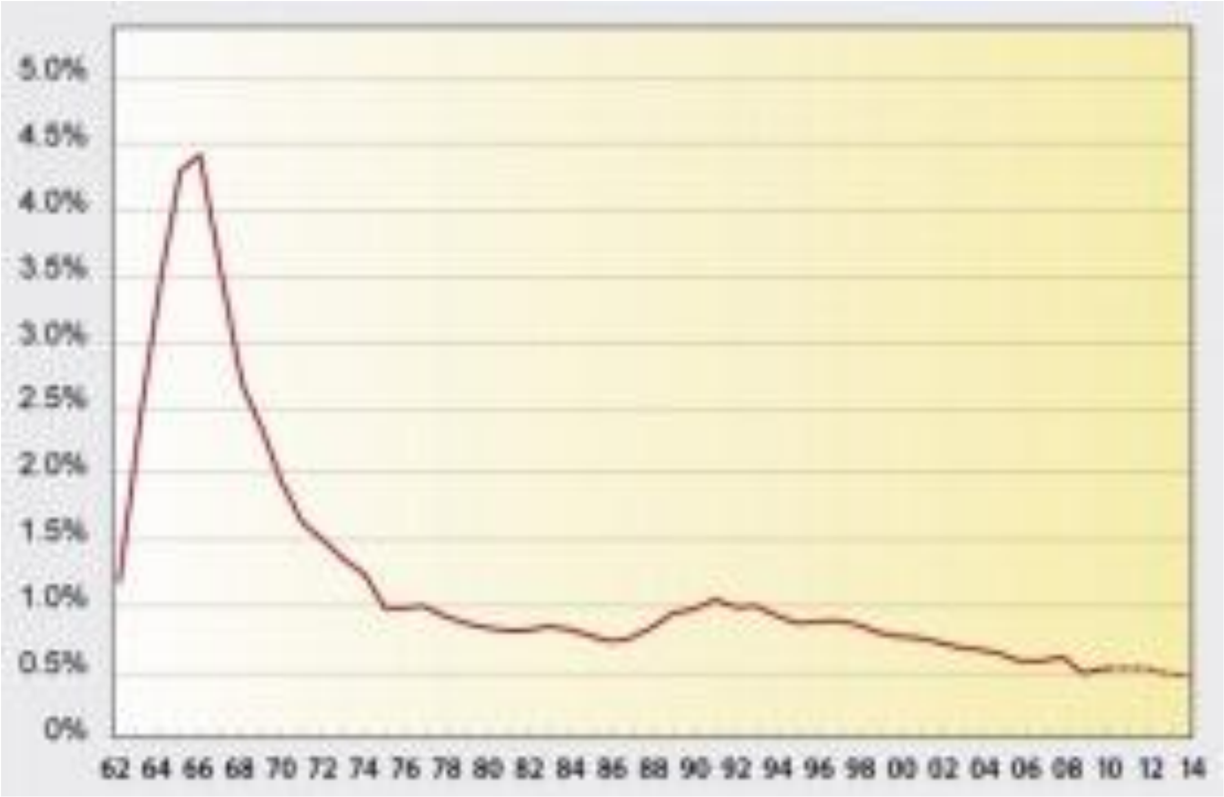
SE and the Apollo Program

What Made Apollo a Success?

- A clear and compelling goal that came from the top
- Sufficient resources to accomplish it
- A systems approach to managing complexity
- The optimum solution could win
- Reduced risk by designing for simplicity and redundancy
- Test, test, test under flight conditions
- What-if thinking
- Accountability at all levels of the program
- Luck

Management Lessons of the Moon Program – Andrew Chaikin
https://www.youtube.com/watch?v=RaskWhy5pYE

NASA's Budget History



NASA's budget as percentage of federal total,
from 1962 to 2014 (projected)

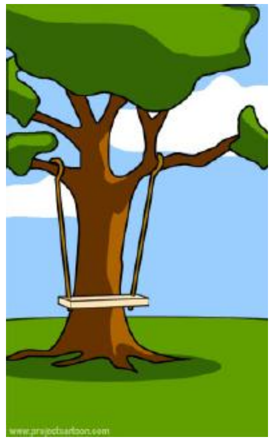
Systems Engineering

> **"The objective of systems engineering is to see to it that the system is designed, built, and operated so that it accomplishes its purpose in the most cost-effective way possible, considering performance, cost, schedule and risk."**
>
> ***NASA Systems Engineering Handbook SP6105***

- Systems engineering is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system.
- A "system" is a collection of different elements that together produce results not obtainable by the elements alone.
  - Elements can include people, hardware, software, facilities, policies and documents.
  - All things required to produce system level results.
- Systems engineering is the art and science of developing an operable system capable of meeting requirements within imposed constraints.
  - Not dominated by the perspective of a single discipline.
  - Is the responsibility of engineers, scientists, and managers working on NASA missions.

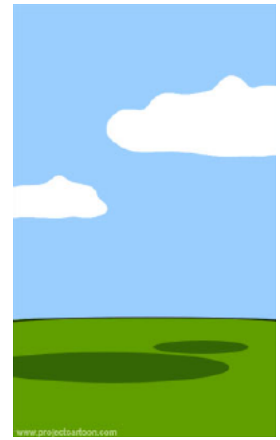
The Tree Swing Project

What the customer wanted



What the PM envisioned

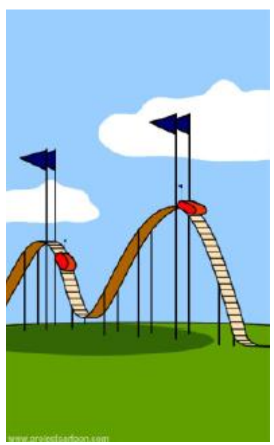
How the engineer saw it



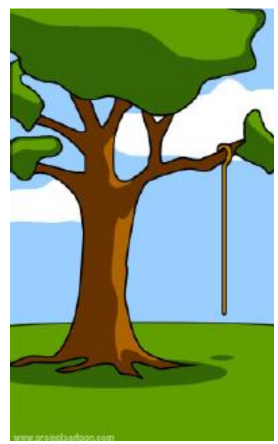
How the requirements were documented

After PDR...

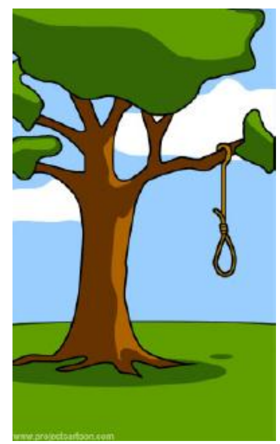
After CDR...



What the project was going to cost



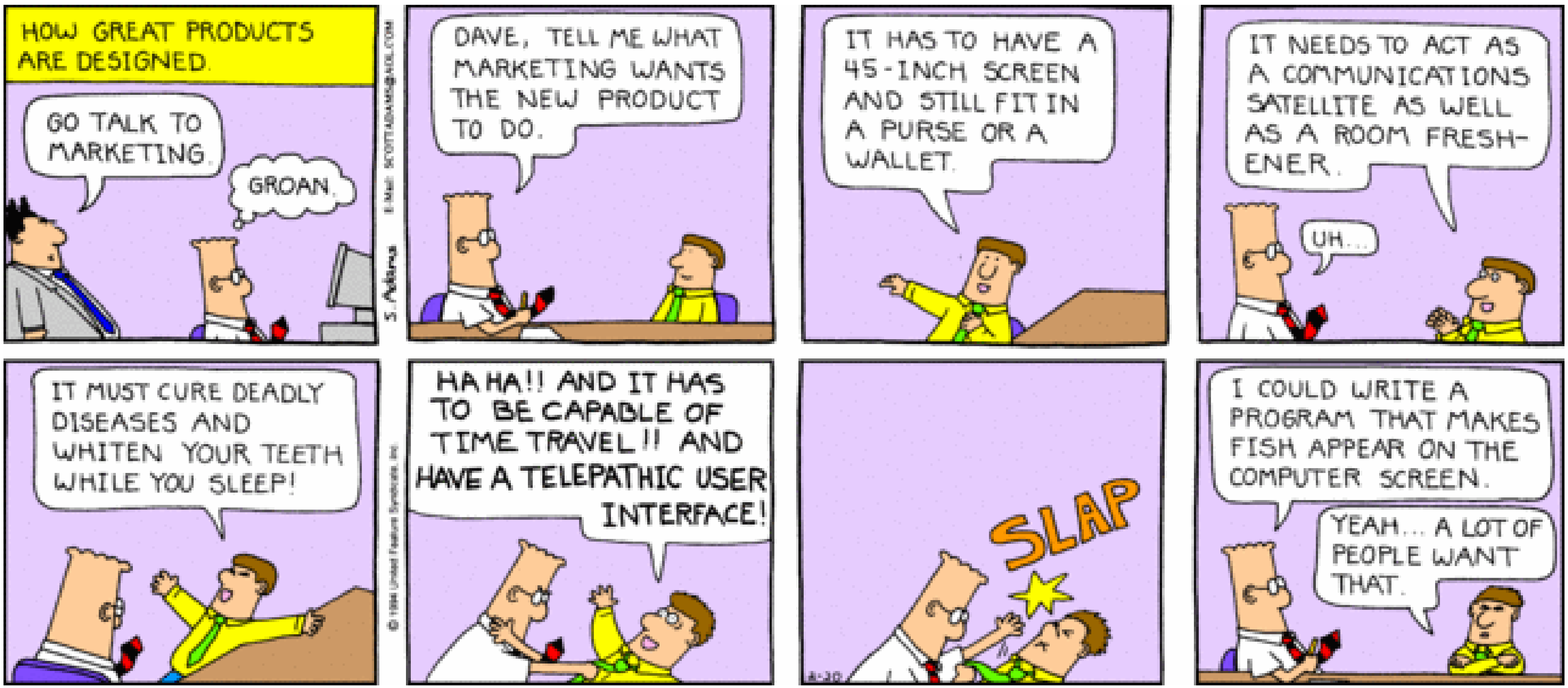
What the project could afford



What the PM prayed for

What the scientists really needed

Stakeholder Needs



Why “They” Don’t “Need” the SE Process

- It’s more fun to design and build the system
- This is the next widget in a series, we just need to make a few tweaks
- It’s an “in-house” build, we’ll just tell the designers what we need
- We don’t have time
- We don’t need the process, we know what we’re doing
- The process will hinder innovation

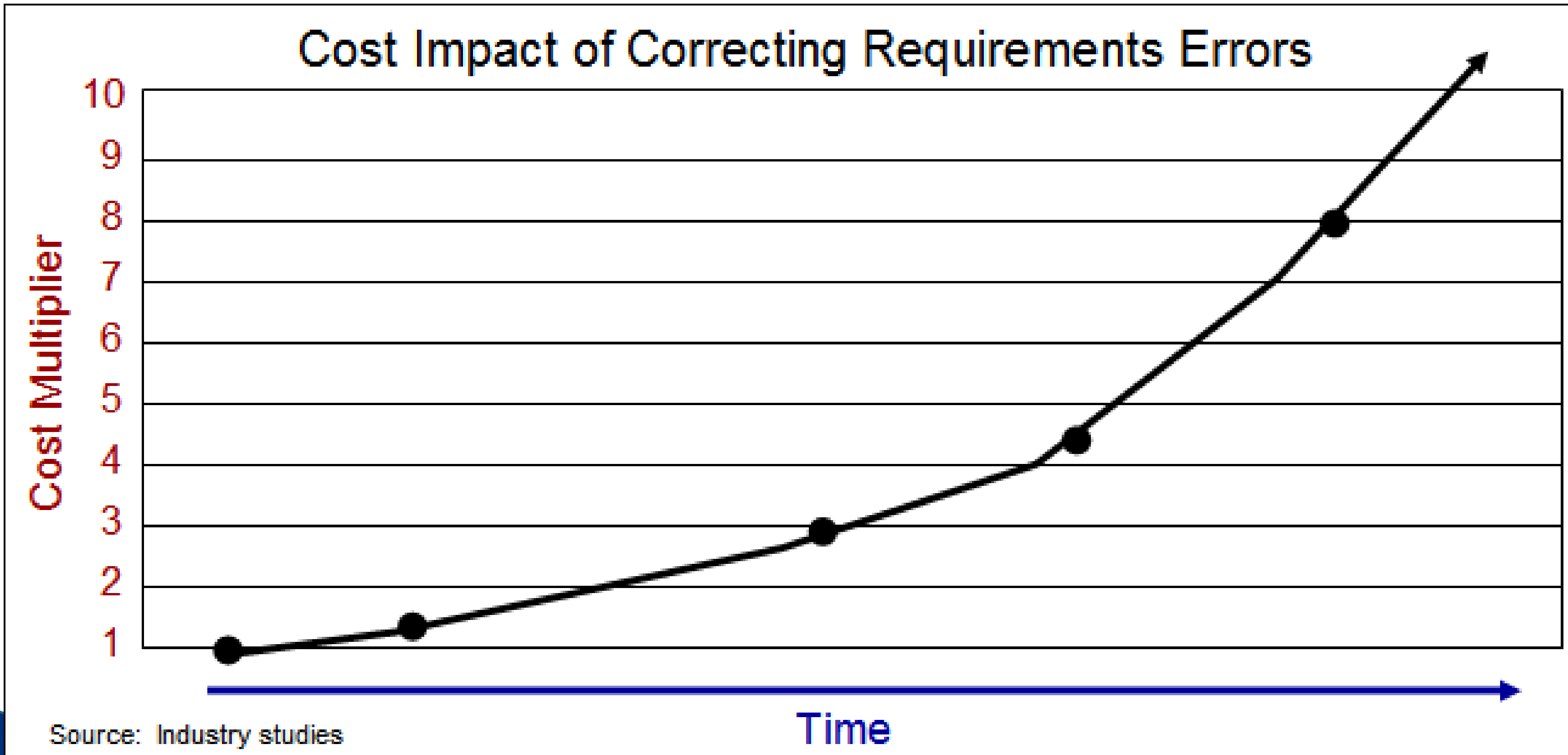
What "They" Do

- Copy requirements from past systems
- Develop requirements without proper systems engineering
- Develop requirements in parallel with trade studies and Concept of Operations
- Proceed to design and build the system without requirements

What Happens

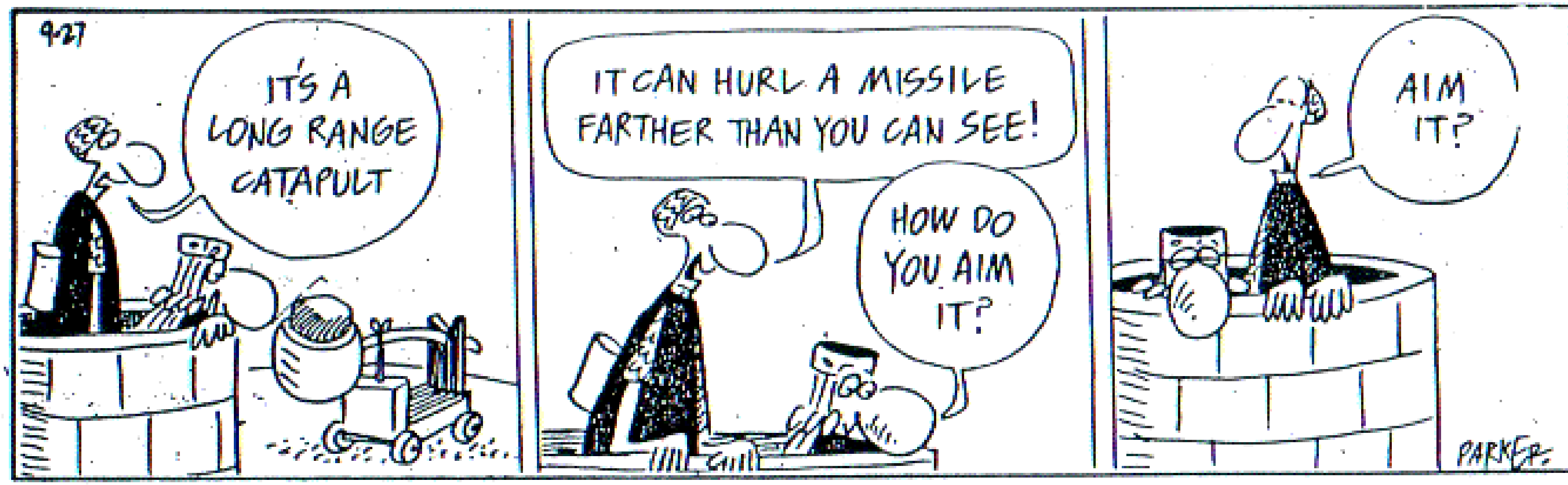
- Systems that meet requirements but fall short of meeting customer expectations
- Systems that are difficult to verify
- Systems with interface issues
- Projects cancelled due to failure to stay within budget and schedule limitations

Pay Me Now or Pay Me More Later

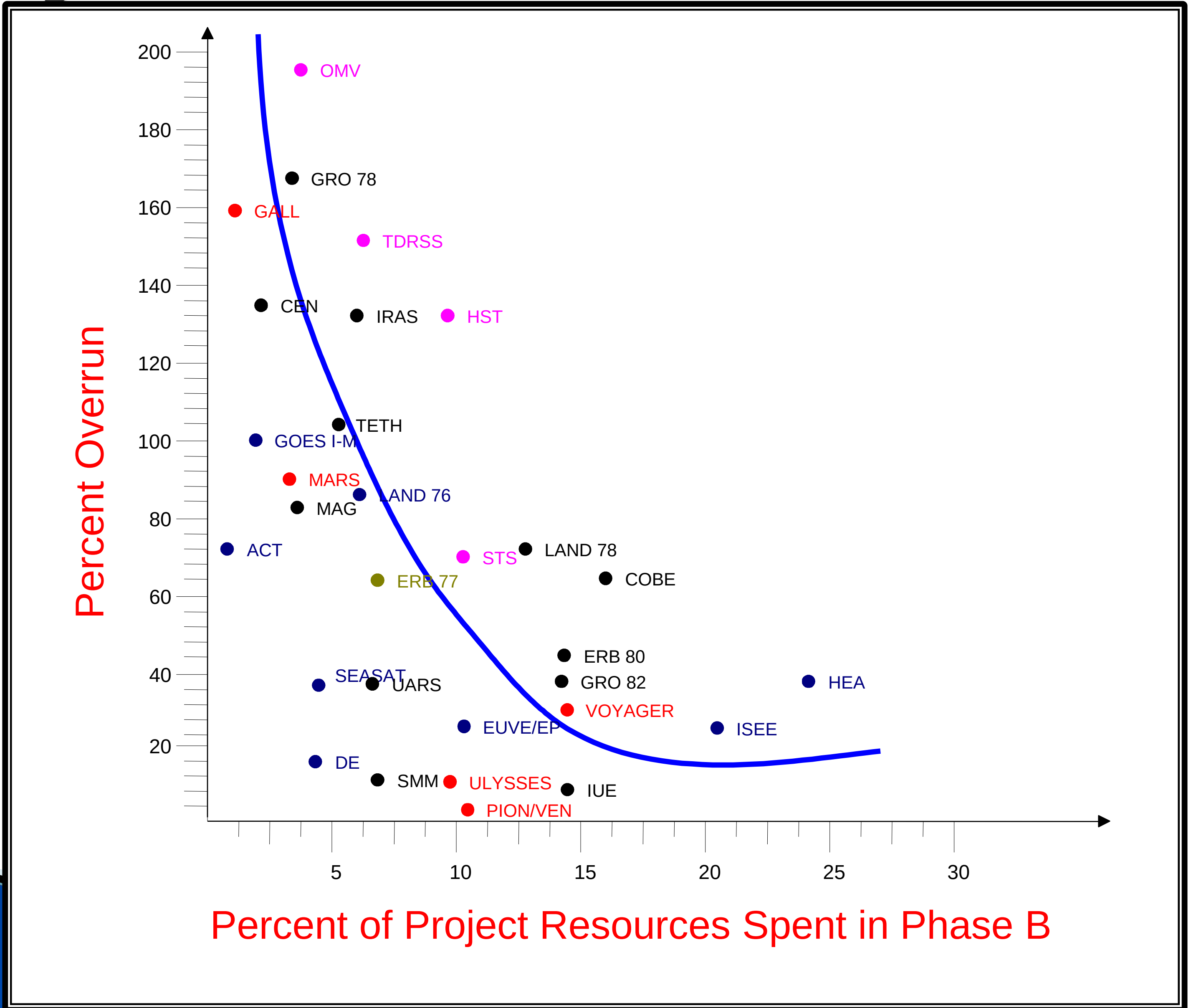


Pay Me More Later

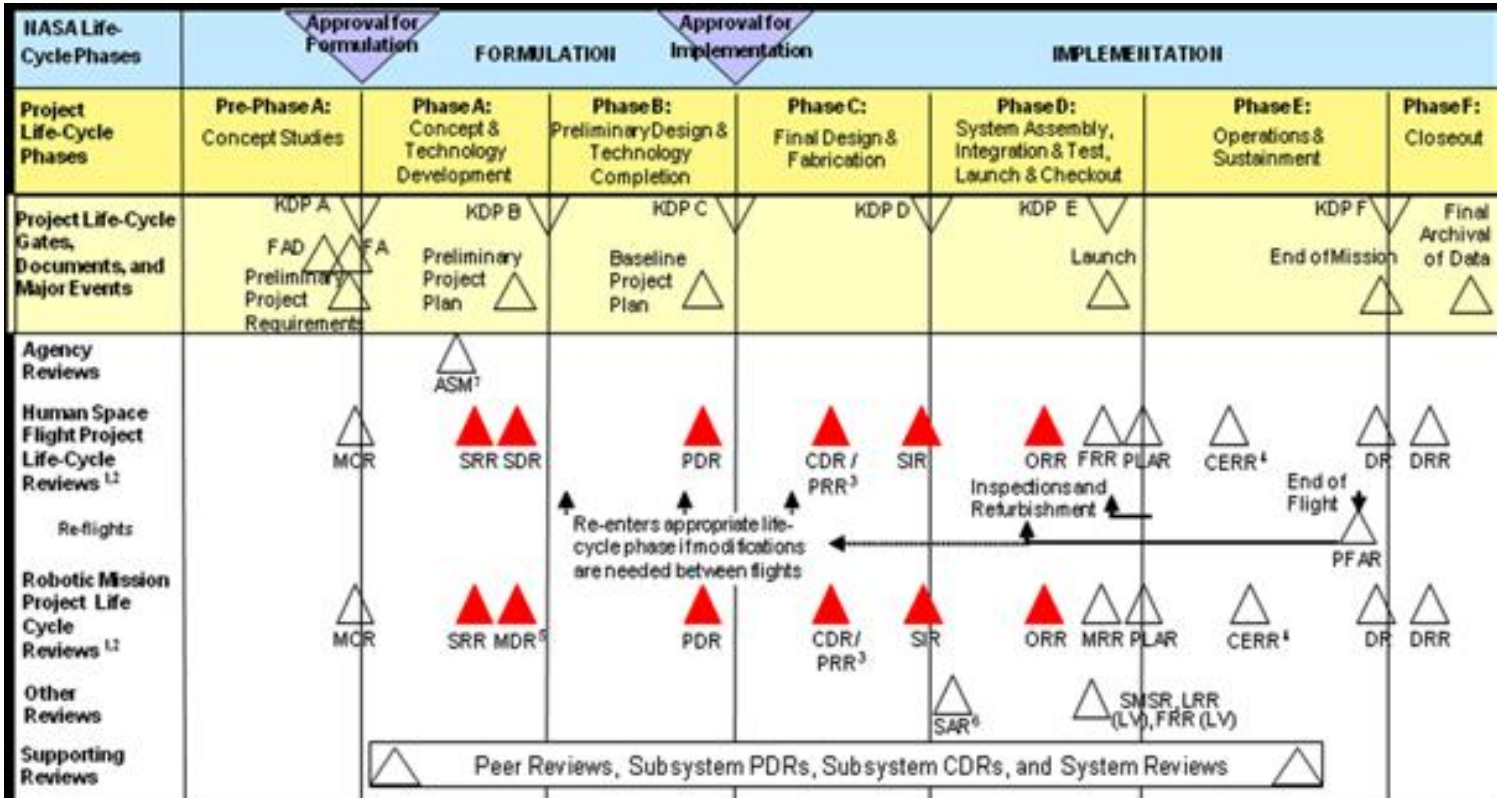
WIZARD OF ID



Project Overruns



Typical NASA Project Life Cycle



FOOTNOTES

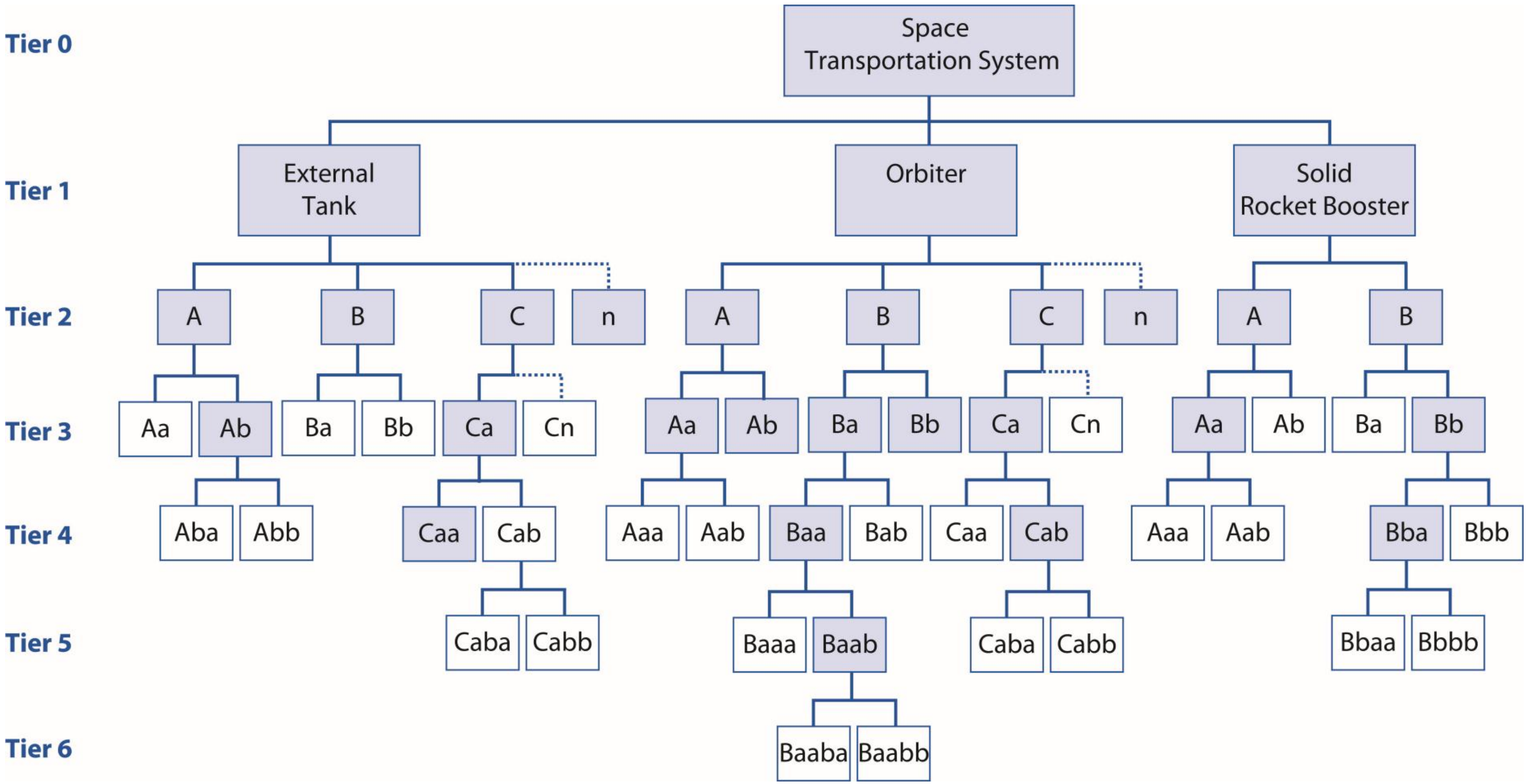
1. Flexibility is allowed as to the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.
2. Life-cycle review objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-5.
3. PRR is needed only when there are multiple copies of systems. It does not require an SRB. Timing is notional.
4. CERRs are established at the discretion of program.
5. For robotic missions, the SRR and the MDR may be combined.
6. SAR generally applies to human space flight.
7. Timing of the ASM is determined by the MDAA. It may take place at any time during Phase A.

ACRONYMS

ASM - Acquisition Strategy Meeting
CDR - Critical Design Review
CERR - Critical Events Readiness Review
DR - Decommissioning Review
DRR - Disposal Readiness Review
FA - Formulation Agreement
FAD - Formulation Authorization Document
FRR - Flight Readiness Review
KDP - Key Decision Point
LRR - Launch Readiness Review
LV - Launch Vehicle
MCR – Mission Concept Review
MDR - Mission Definition Review
MRR - Mission Readiness Review
ORR - Operational Readiness Review
PDR - Preliminary Design Review
PFAR - Post-Flight Assessment Review
PLAR - Post-Launch Assessment Review
PRR - Production Readiness Review
SAR - System Acceptance Review
SDR - System Definition Review
SIR - System Integration Review
SMSR - Safety and Mission Success Review
SRB - Standing Review Board
SRR - System Requirements Review

Red triangles represent life-cycle reviews that require SRBs. The Decision Authority, Administrator, MDAA, or Center Director may request the SRB to conduct other reviews.

System Hierarchy



Why Follow the SE Process?

- Ensure that you deliver the right system that meets your customer's vision
- Avoid scope creep and gold plating
- Bound your system to fit your cost and schedule constraints
- Minimize change traffic that results in increased costs and delays in the schedule

Delivers a system that meets your customer's vision on time and on budget…
leading to increased shareholder value.

How do you get there?

- Define the vision of your system
- Develop a Concept of Operations to capture the system vision
- Secure stakeholder agreement on the vision
- Perform trade studies to determine optimal system solution
- Develop requirements documenting characteristics, features and functions that your system must have in order to meet the Concept of Operations
- Validate the requirements
- Design and build the system
- Verify the system meets requirements
- Validate the system meets stakeholder needs
- Document, deliver and operate the system

Lesson Captured – Apollo 1976

NASA TECHNICAL NOTE

NASA TN D-8249

NASA TN D-8249

CASE FILE COPY

APOLLO EXPERIENCE REPORT - GUIDANCE AND CONTROL SYSTEMS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1976

CONCLUDING REMARKS AND RECOMMENDATIONS

During the course of the development, qualification, and flight programs, the Apollo guidance and control systems performed in an outstanding manner. There were no guidance and control failures or malfunctions that precluded mission completion or that placed the flight crew or the mission in jeopardy.

In general, the approaches that were used to establish and implement guidance and control system interfaces and checkout procedures during the integration of the systems in the spacecraft appear to have been sound. Consequently, few interface problems appeared during the integration of the systems into the spacecraft. Some of the more significant items that deserve careful consideration on future programs are as follows.

1. A strong effort should be made to establish baseline requirements before the start of hardware design and software development processes. For example, changes affecting hand controllers, humidity, and in-flight maintenance caused major redesign efforts.

2. A failure-analysis techni[...] be developed to assist in the identification of single-point failures. The Apollo [...] n which many engineers must search diagrams for problems, is not altog[...]essful for complex systems.

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System Configuration Management

- Initially a tough sell on the Apollo Program
- Maintaining system configuration control is essential to controlling cost and schedule
- Configuration management doesn’t mean that you can’t change it…it means you define at each stage of the game what you think the design is going to be within your present ability. The difference is after you describe it you know what it is when you change it. – George Mueller

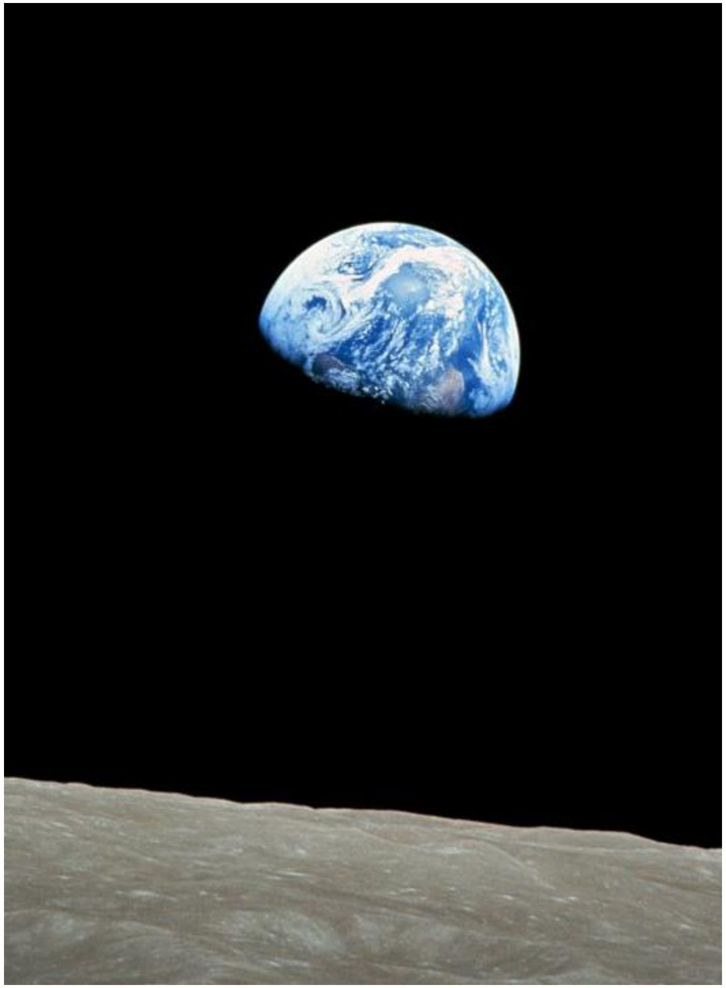
NASA and System Engineering

- Agency Requirements and Guidelines
  - NPR 7123.1B NASA Systems Engineering Requirements and Processes
  - Systems Engineering Handbook
- Formal Training
  - Academy of Program/Project and Engineering Leadership
  - Systems Engineering Leadership Development Programs
  - Center Level Programs
- Mentoring and on-the-job training
- Case Studies
- SE Forums

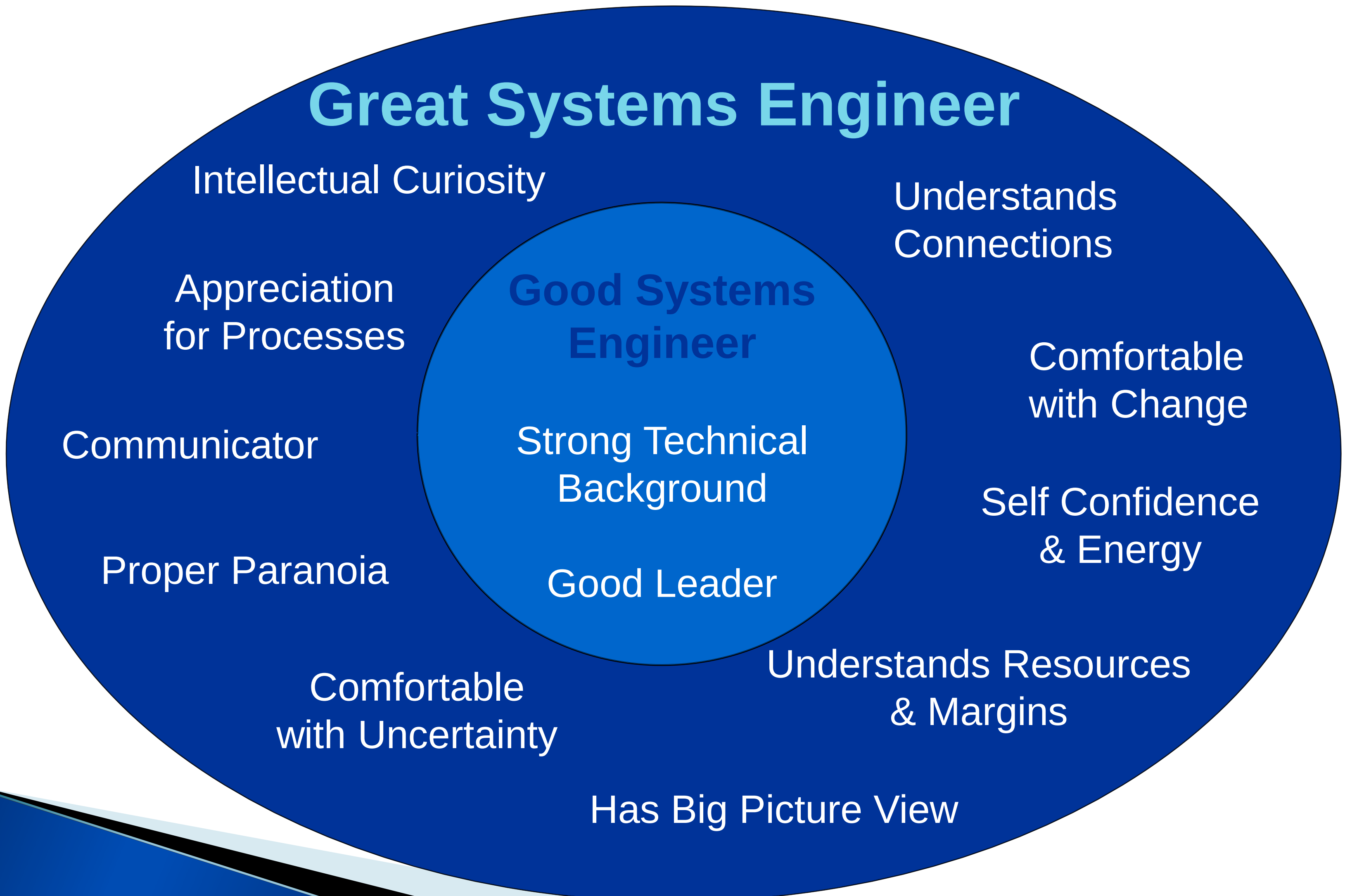
A Lesson from Apollo

In the huge, complex group endeavor that is space flight, human nature is as critical as engineering principles. Neither can be ignored without inviting failure.

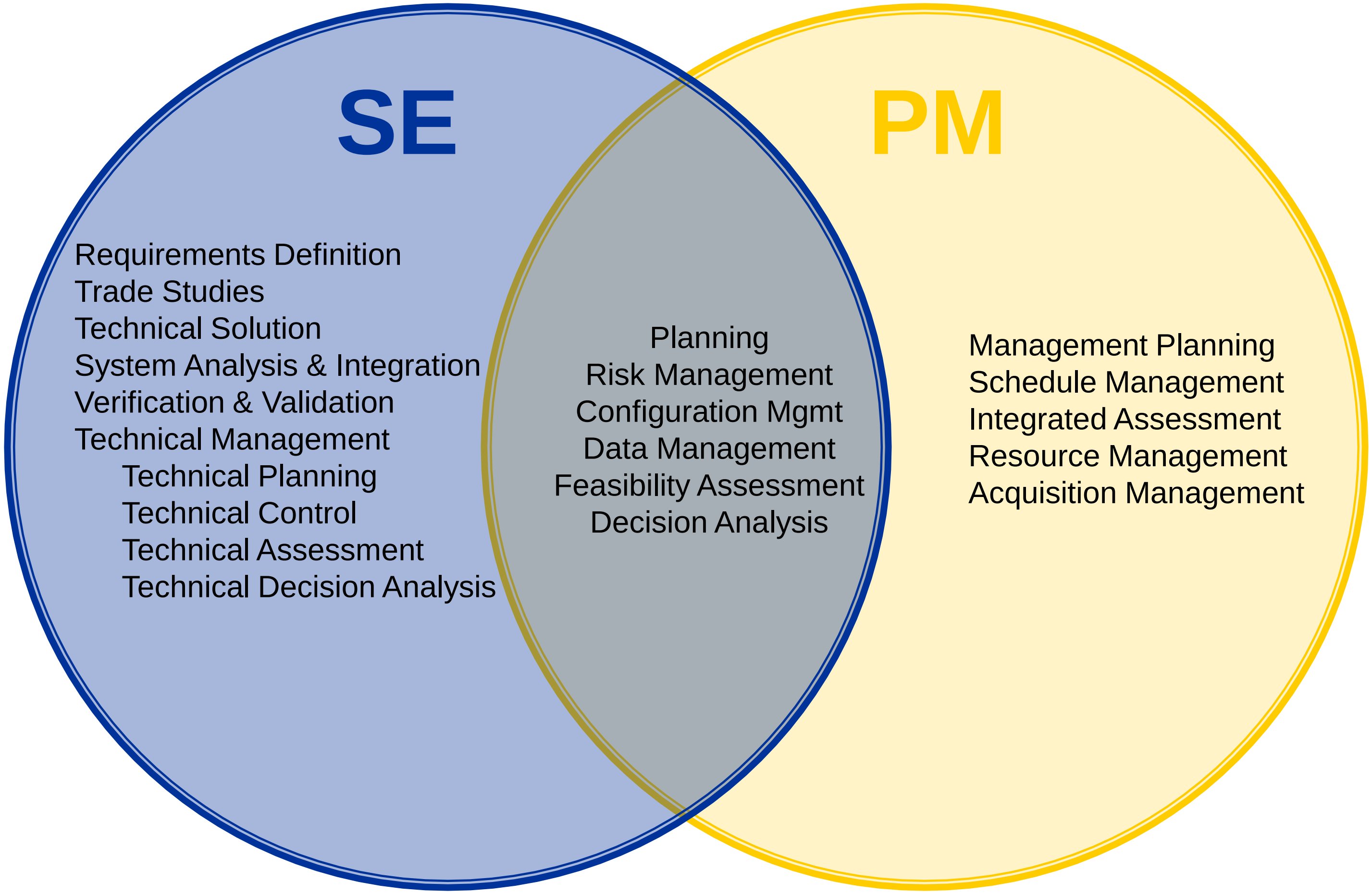
– Andrew Chaikin



Personality Traits of SEs



SE and PM Leadership



Final Thoughts

- Following SE best practices is the key to ensuring
  - The system will meet your customer’s needs
  - The system will be delivered within the cost limit
  - The system will be delivered on time
- It’s not Rocket Science if you follow Systems Engineering Best Practices

Additional Resources

- NPR 7123.1B http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=7123&s=1B
- NASA SE Handbook - http://www.acq.osd.mil/se/docs/NASA-SP-2007-6105-Rev-1-Final-31Dec2007.pdf
- NASA APPEL - http://appel.nasa.gov/
- Management Lessons of the Moon Program – Andrew Chaikin - https://www.youtube.com/watch?v=RaskWhy5pYE
- So you want to be a systems engineer – Gentry Lee http://spacese.spacegrant.org/index.php?page=videos
- Additional SE information and case studies http://spacese.spacegrant.org/index.php?page=presentations