ESSE2361/4361 Space Systems Eng/ Space Mission Design

LASSONDE SCHOOL OF ENGINEERING | YORK UNIVERSITÉ UNIVERSITY

Dr. Franz Newland

Course outline – subject to change!

ESSE2361/4361 Fridays 5.30-8.30, Location TBA

	Lecture	Assignment		Lecture	Assignment
January			*February*		
10th	Introduction Reasons for Space Missions (SME - Chap 1)		28th	Margins and Contingencies, Estimation (SME 11)	**Yr 2: Draft Report upload, Assignment 4 upload** **BASIC TRADE STUDY** **DRAFT SYSTEMS REPORT**
17th	Space communities and their differences (SME - Chap 2) Mission and Systems Engineering (SME - Chap 3)	**Yr2, Yr4 - Assignment 1 - share in class** **MISSION NEEDS**	*March*		
24th	Define Mission Goals for Project **MISSION CONCEPT PRESENTATION**	**Yr2, Yr 4 - Assignment 2 in-class presentation and presentation upload**	6th	Space Mission Geometries, orbit choices, orbital manoeuvres (SME 8, 9)	**Yr 4: Assignment 5 upload, Assignment 6 in-class presentation** **FULL TRADE STUDY/PRESENTATION**
31st	Mission and Systems Architectures and Alternatives (SME - 4.1, 4.2)	**Yr2 - Assignment 3 upload** **MISSION REQUIREMENTS**	13th	Orbit evaluation (SME 10)	**Yr2: Assignment 5 upload** **Yr4: Assignment 7 upload** **ORBIT ANALYSIS**
February			20th	Propulsion annd launch systems (SME 26)	
7th	Operations Concepts and Driving Requirements (SME - 4.3, 4.4)	**Yr 4 - Assignment 3 upload** **MISSION REQUIREMENTS**	27th	Final presentations	**Yr2: Final report upload** **FINAL REPORT**
14th	Mission and Systems Analysis and Trade Studies (SME - 5.1, 5.2, 5.3)	**Yr4: - Assignment 4 in-class presentations** **MISSION BASELINE PRESENTATION**	*April*		
21st	*Reading week*		1st	Revision	**Yr2, Yr4: Final presentations in class** **PRESENTATION** **Yr 4: Final report upload** **FINAL REPORT**
					Final exam date TBA **EXAM**

It all starts with NEED

- What is necessary for, or desired by, the user
- Declared or undeclared; existing or a potential need.
- For the space community, needs are often called a mission statement

Who is the user?

- The person or organization for which the product is designed and which exploits at least one of its functions at any time during its life cycle.

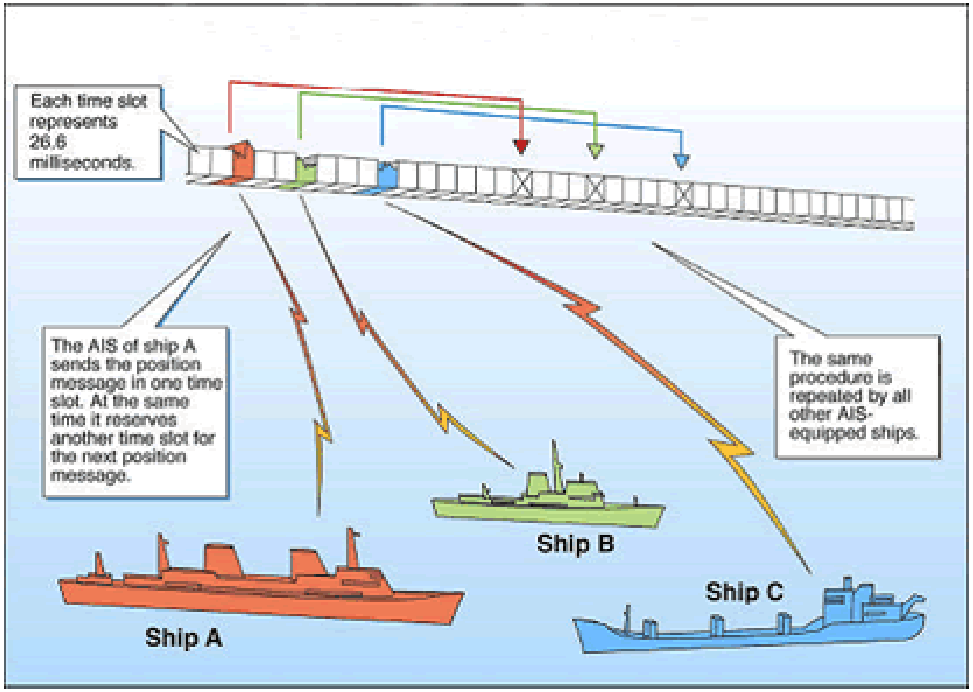
- Often users do not know their need. Also be careful of want vs. need

Example

- Science community proposes a new approach to monitoring ship transmissions from space – science is also new (unproven)
- Data would likely be useful globally, to a large number of government and commercial users
- The payload uses an antenna with a large field of view
  - Link budget consideration
- Preliminary instrument concept has following estimated characteristics:
  - COTS AIS receivers are small and light, but may not be suitable for space
  - Data collection rate: 3Mbps of raw data, 25kbps of processed data
- Systems engineering has to cover
  - Proof of concept
  - Plan to roll out a full operational system

Automatic Identification System (AIS)

- Automatic Identification System (AIS) is a terrestrial line-of-sight, ship-to-ship and ship-to-shore broadcast system, operating in the VHF maritime band
- AIS transmitters send ship information such as identity, position, course, speed, voyage data
- System can handle over 4,000 reports per minute and updates information as often as every two seconds
- AIS uses a Self-Organising Time Division Multiple Access (SOTDMA) communication protocol



Terrestrial, Line-of-sight system, Self Organized within Cells ~40 nm.

Not designed for reception from space

So we have an idea of a mission… what next?

- A good baseline is to use systems engineering standards
- Company policies and work instructions generally define standard practices
  - Necessary for ISO 9000 / AS9100 compliance

- Many references in this presentation taken from European Cooperation for Space Standardization group's system engineering documentation:
  - ECSS-E-ST-10C 6 March 2009 Space engineering: System engineering general requirements
  - ECSS-E-10A 19 April 1996 Space engineering: System engineering

http://www.ecss.nl

SMART requirements

SMART requirements

Letter	Most common	Alternative
S	Specific	(Strategic and specific)
M	Measurable	
A	Achievable	Agreed, attainable, action-oriented, ambitious, aligned with corporate goals, (agreed, attainable and achievable)
R	Relevant	Realistic, resourced, reasonable, (realistic and resourced), results-based
T	Time-bound	Time-based, time limited, time/cost limited, timely, time-sensitive, timeframe

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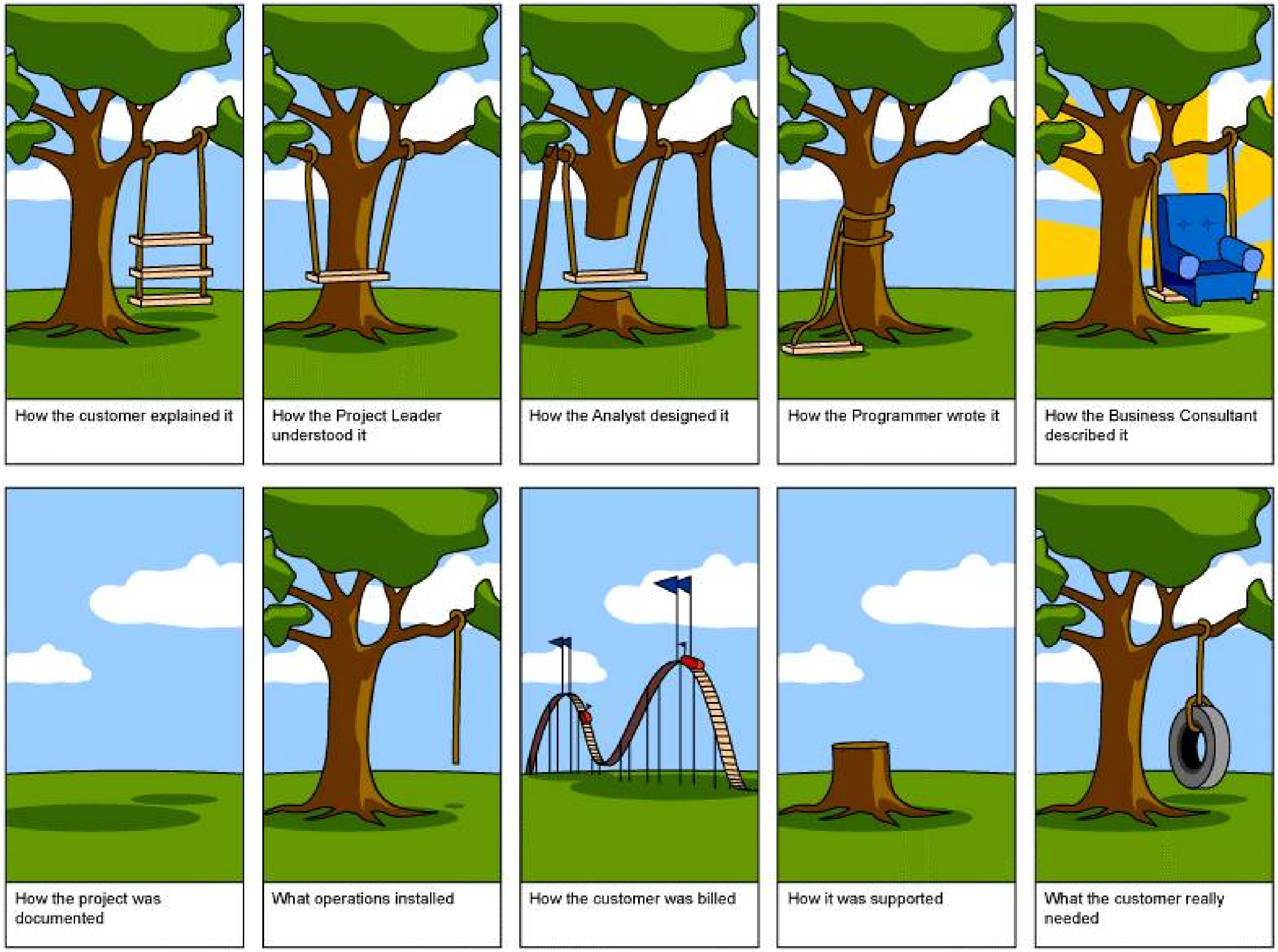

How the customer explained it
How the Project Leader understood it
How the Analyst designed it
How the Programmer wrote it
How the Business Consultant described it
How the project was documented
What operations installed
How the customer was billed
How it was supported
What the customer really needed

Good or Bad? (taken from spacese)

The aircraft shall have three engines (initial DC-3 requirement).

The lunar lander shall include an airlock.

The crew shall have the capability to perform extra-vehicular activities (EVAs).

The spacecraft shall maximize lifetime.

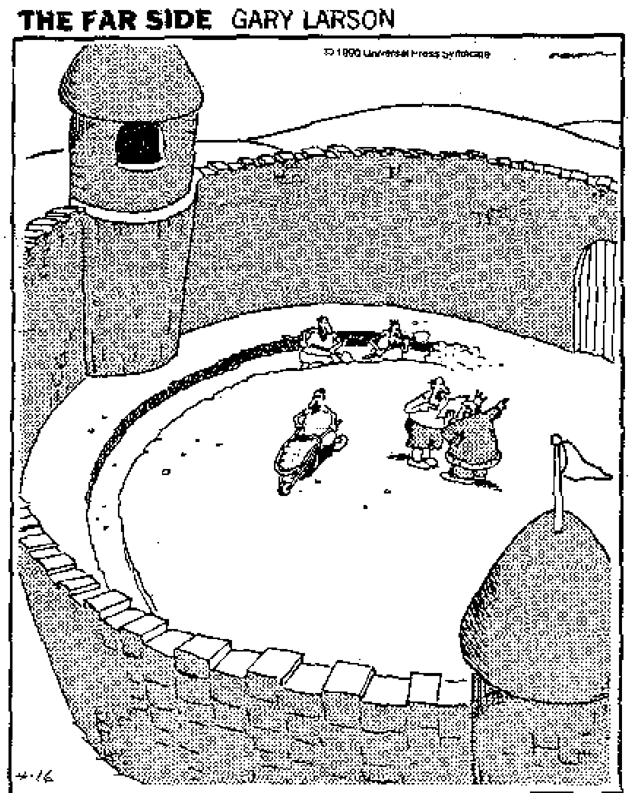
The software shall display data in a user-friendly fashion.

Good or Bad?

- The aircraft shall have three engines (initial DC-3 requirement).
  - The aircraft shall meet the operation requirements with a single engine out.
- The lunar lander shall include an airlock.
  - The lunar lander shall provide the capability for crew to ingress/egress while maintaining pressurization.
- The crew shall have the capability to perform extra-vehicular activities (EVAs).
  - The vehicle shall allow extra-vehicular activities during operations.
- The spacecraft shall maximize lifetime.
  - The spacecraft shall have a lifetime of at least three years.
- The software shall display data in a user-friendly fashion.
  - The software shall display data as described in ICD 2345 Table 3.1.

Akin’s laws

- http://spacecraft.ssl.umd.edu/akins_laws.html



Suddenly, a heated exchange took place between the King and the moat contractor.

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DILBERT®
By Scott Adams

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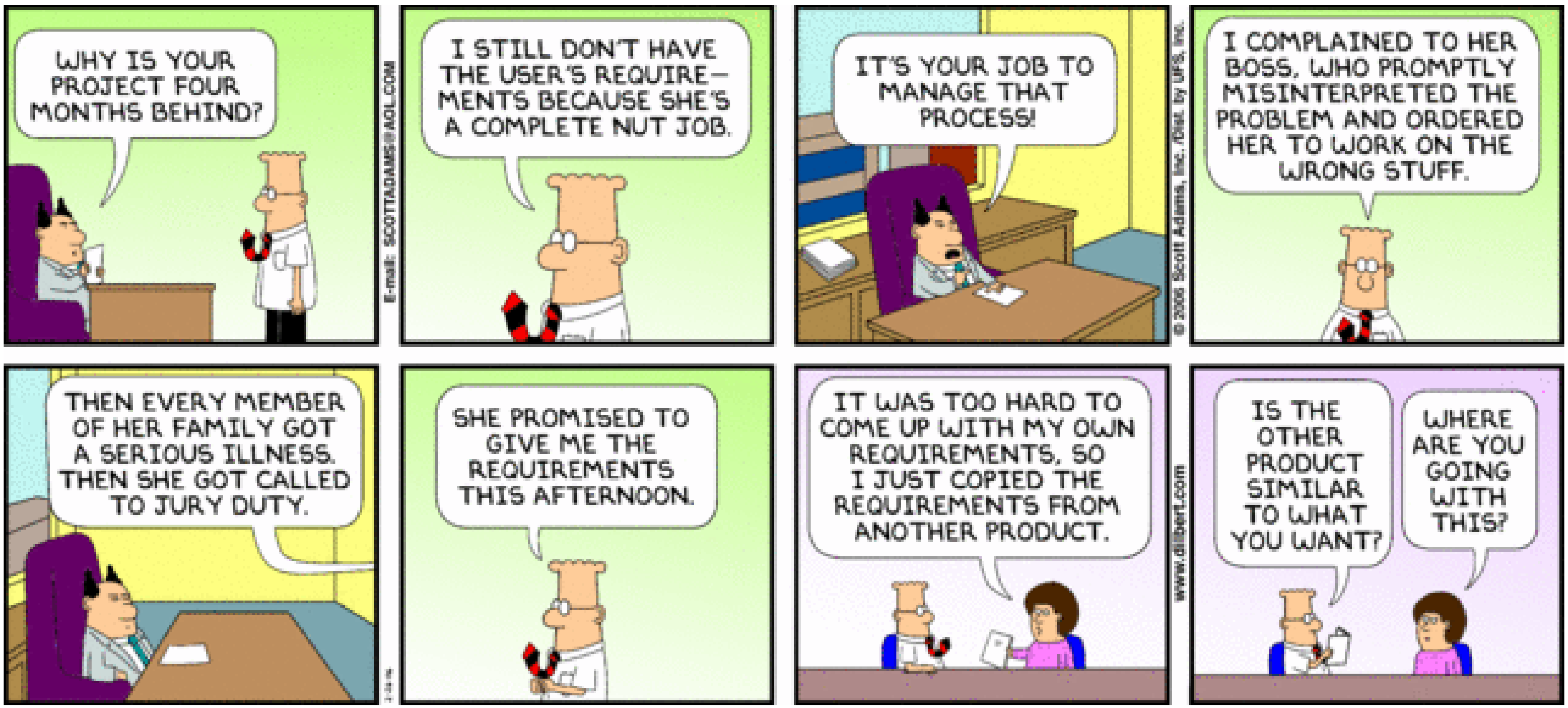
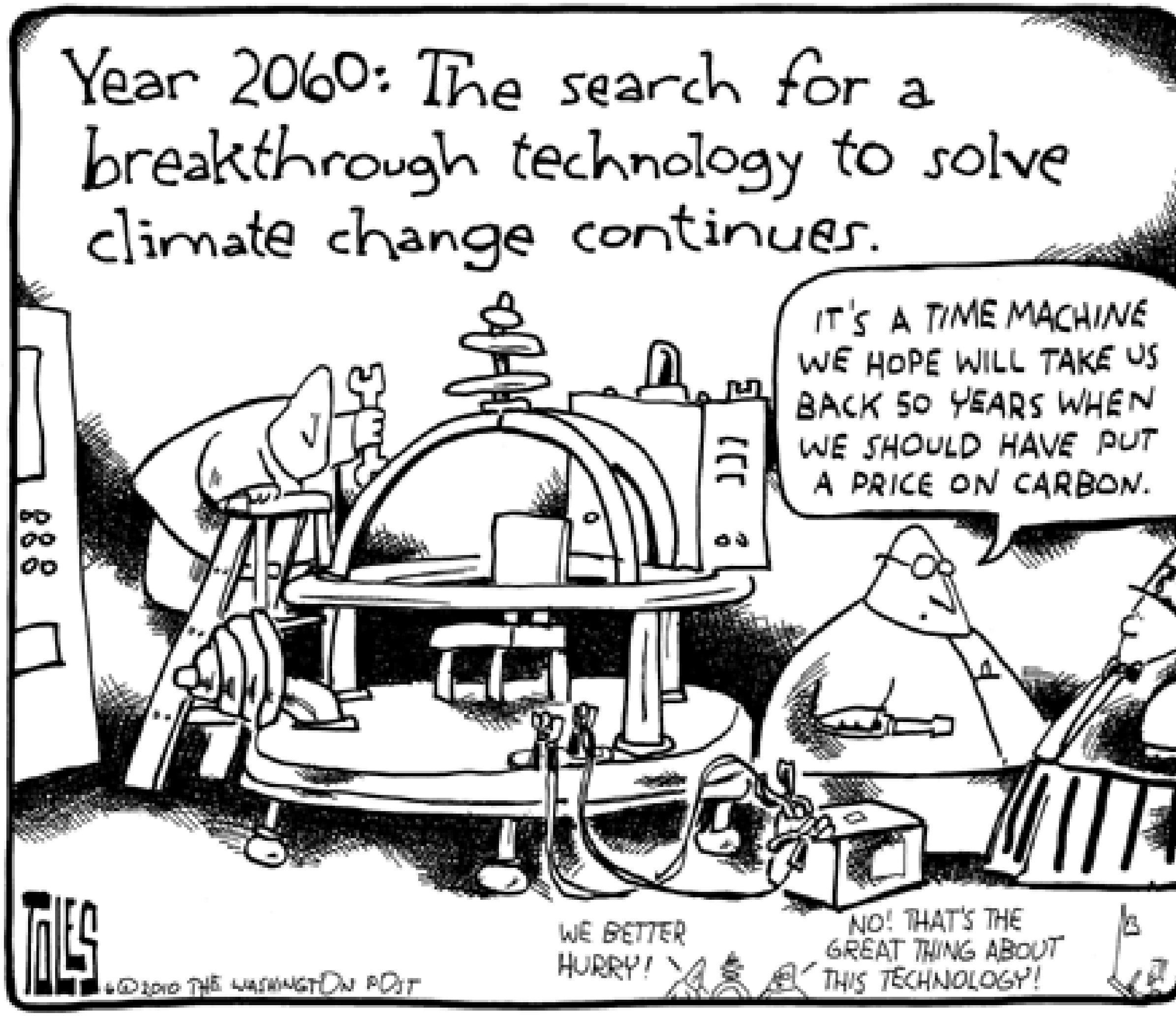
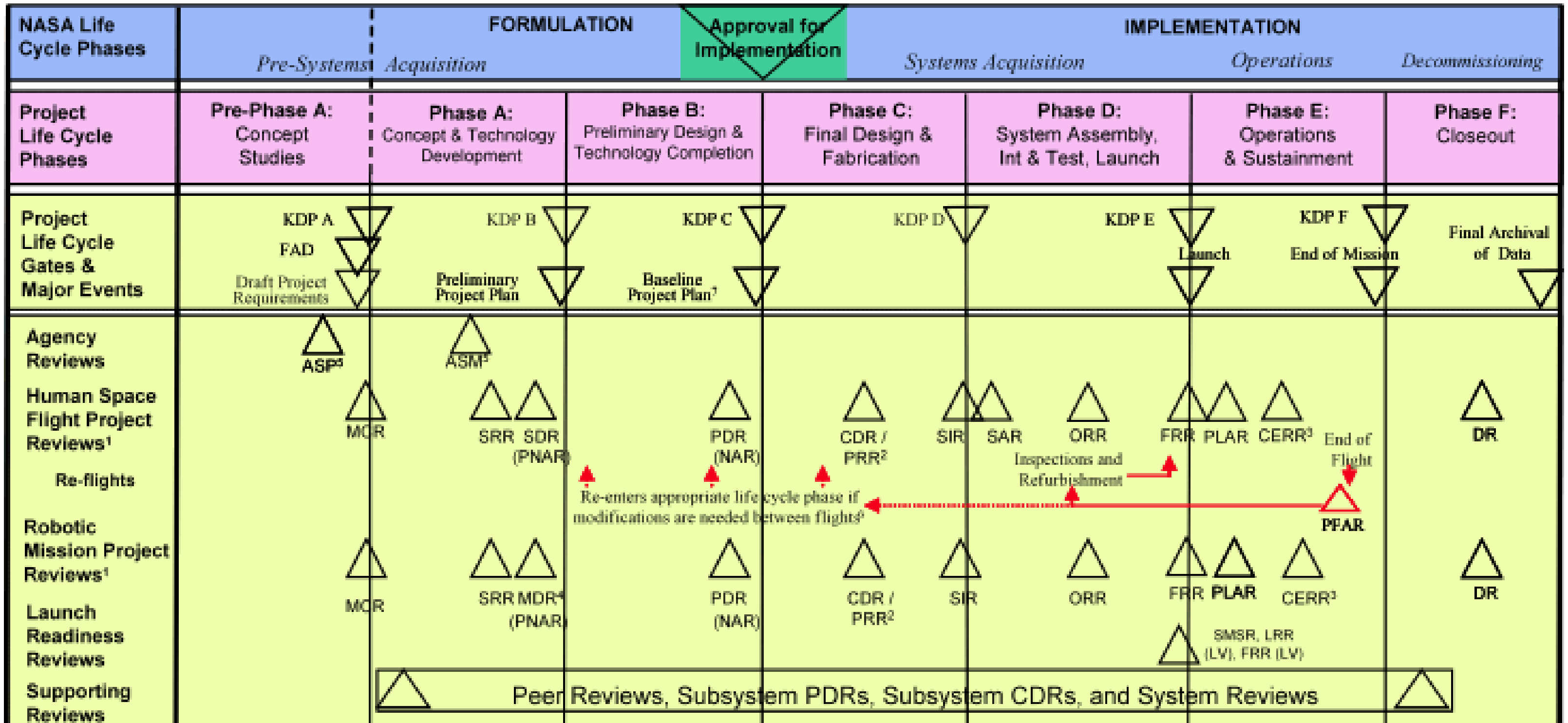

WHY IS YOUR PROJECT FOUR MONTHS BEHIND?
E-mail: SCOTTADAMS@AOL.COM
I STILL DON'T HAVE THE USER'S REQUIRE-MENTS BECAUSE SHE'S A COMPLETE NUT JOB.
IT'S YOUR JOB TO MANAGE THAT PROCESS!
© 2006 Scott Adams, Inc./Dist. by UFS, Inc.
I COMPLAINED TO HER BOSS, WHO PROMPTLY MISINTERPRETED THE PROBLEM AND ORDERED HER TO WORK ON THE WRONG STUFF.
THEN EVERY MEMBER OF HER FAMILY GOT A SERIOUS ILLNESS. THEN SHE GOT CALLED TO JURY DUTY.
SHE PROMISED TO GIVE ME THE REQUIREMENTS THIS AFTERNOON.
IT WAS TOO HARD TO COME UP WITH MY OWN REQUIREMENTS, SO I JUST COPIED THE REQUIREMENTS FROM ANOTHER PRODUCT.
www.dilbert.com
IS THE OTHER PRODUCT SIMILAR TO WHAT YOU WANT?
WHERE ARE YOU GOING WITH THIS?


Year 2060: The search for a breakthrough technology to solve climate change continues.
IT'S A TIME MACHINE WE HOPE WILL TAKE US BACK 50 YEARS WHEN WE SHOULD HAVE PUT A PRICE ON CARBON.
WE BETTER HURRY!
NO! THAT'S THE GREAT THING ABOUT THIS TECHNOLOGY!
TOLES
© 2010 THE WASHINGTON POST

Mission Phases



FOOTNOTES

1. Flexibility is allowed in 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. These reviews are conducted by the project for the independent SRB. See Section 2.5 and Table 2-6.
2. PRR needed for multiple (≥4) system copies. Timing is notional.
3. CERRs are established at the discretion of Program Offices.
4. For robotic missions, the SRR and the MDR may be combined.
5. The ASP and ASM are Agency reviews, not life-cycle reviews.
6. Includes recertification, as required.
7. Project Plans are baselined at KDP C and are reviewed and updated as required, to ensure project content, cost, and budget remain consistent.

ACRONYMS

ASP—Acquisition Strategy Planning Meeting
ASM—Acquisition Strategy Meeting
CDR—Critical Design Review
CERR—Critical Events Readiness Review
DR—Decommissioning Review
FAD—Formulation Authorization Document
FRR—Flight Readiness Review
KDP—Key Decision Point
LRR—Launch Readiness Review
MCR—Mission Concept Review
MDR—Mission Definition Review
NAR—Non-Advocate Review
ORR—Operational Readiness Review
PDR—Preliminary Design Review
PFAR—Post-Flight Assessment Review
PLAR—Post-Launch Assessment Review
PNAR—Preliminary Non-Advocate Review
PRR—Production Readiness Review
SAR—System Acceptance Review
SDR—System Definition Review
SIR—System Integration Review
SMSR—Safety and Mission Success Review
SRR—System Requirements Review

Figure 5-2 – The NASA Project Life Cycle

Mission Phases

- **Phase 0: Mission analysis-need identification**
- **Phase A: Feasibility**
  MISSION REQUIREMENTS DEFINED
- **Phase B: Preliminary definition**
  PRELIMINARY DESIGN REVIEW
- **Phase C: Detailed definition**
  CRITICAL DESIGN REVIEW
- **Phase D: Qualification and production**
  Pre-shipment review, operations readiness review, launch readiness review
  GO FOR LAUNCH
- **Phase E: Operations / utilization**
  Commissioning review
  ROUTINE OPERATIONS
- **Phase F: Disposal**

Phase 0

- System Engineering
  - Mission objectives – requirements tradeoff
  - System concepts – Possible candidate systems, TRL, risks and risk reduction
  - Programmatic trade space (cost, schedule) – critical path, project plan
  - Engineering budgets

- Requirement engineering
  - Mission requirements document
  - Compliance matrix

- Simulation / analyses
  - Operating constraints
  - Evaluation criteria for design
  - Risk analysis and management approach

- Verification and test engineering
  - Means to verify a concept has met its requirements

Requirements engineering

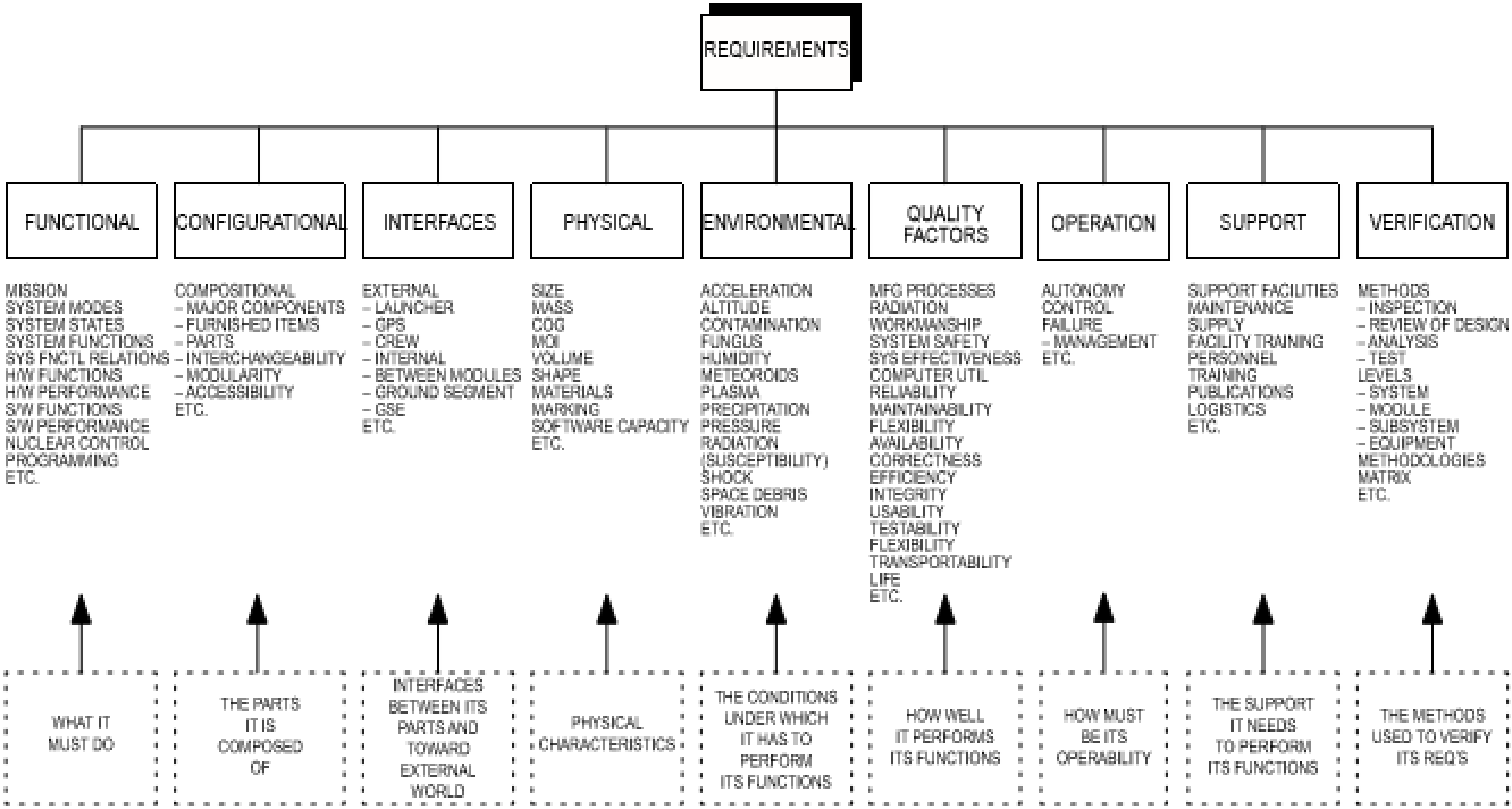
- Precise, or path to precision identified
- Testable / verifiable
  - And consider *how*: Categories: Design, Analysis, Test
  - Level of testing: unit, subsystem, system, mission
  - Timing of testing
- Flowdown
  - Able to be used by next level of system engineering
  - Specification “tree”
  - Understand interdependence of requirements

i.e. SMART: Specific, Measurable, Attainable/Appropriate, Realistic, Timely/Testable

- Requirements standards:
  - EIA 632, IEEE 1220, ISO/DIS 21351, ECSS-E-10, ISO 14300, ECSS-M-30

Why capture requirements?

- And which principal player is invested in each requirement?



Notes: H/W = Hardware, S/W = Software, GPS = Global Positioning System, GSE = Ground Segment Equipment, COG = Centre of Gravity, MOI = Moment of Inertia

Key terms

- **Acceptance**: evidence that a product meets the requirements and is free of failures.
- **Qualification** provides evidence that the design meets the requirements
- **Requirement:** a singular documented need or expectation of a function to be performed, a performance level to be achieved, or an interface to be met
- **Specification:** an explicit set of criteria that apply to a material, product, process, or service, as a response to a requirement set.
- **Validation** ensures that the product actually meets the user's needs, and that the specifications were correct in the first place. Confirms that the product, as provided, will fulfill its intended use.
- **Verification** Confirmation that specified requirements have been fulfilled. Ensures that the product has been built according to the requirements and design specifications.

Risk

- Two key parameters:
  - Probability
  - Consequence
- If either are high, or both are medium, may need to develop mitigation strategy

- Track risk, update mitigation strategies as required

- Cost/schedule margins should include contingency in case risks are “realized”
  - Cost may be “technical cost” (mass/power/…)
  - Probability and consequence can be used to carry appropriate margins

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Technology readiness level

Achieved status of development of a technology. TRL levels 1 to 9 are defined as follows:

TRL1: Basic principles observed and reported

TRL2: Technology concept and/or application formulated

TRL3: Analytical and experimental critical function and/or characteristic proof-of-concept performed

TRL4: Component and/or breadboard validated in the laboratory environment

TRL5: Component and/or breadboard validated in the relevant environment

TRL6: System/subsystem model or prototype demonstrated in the relevant environment (ground or space)

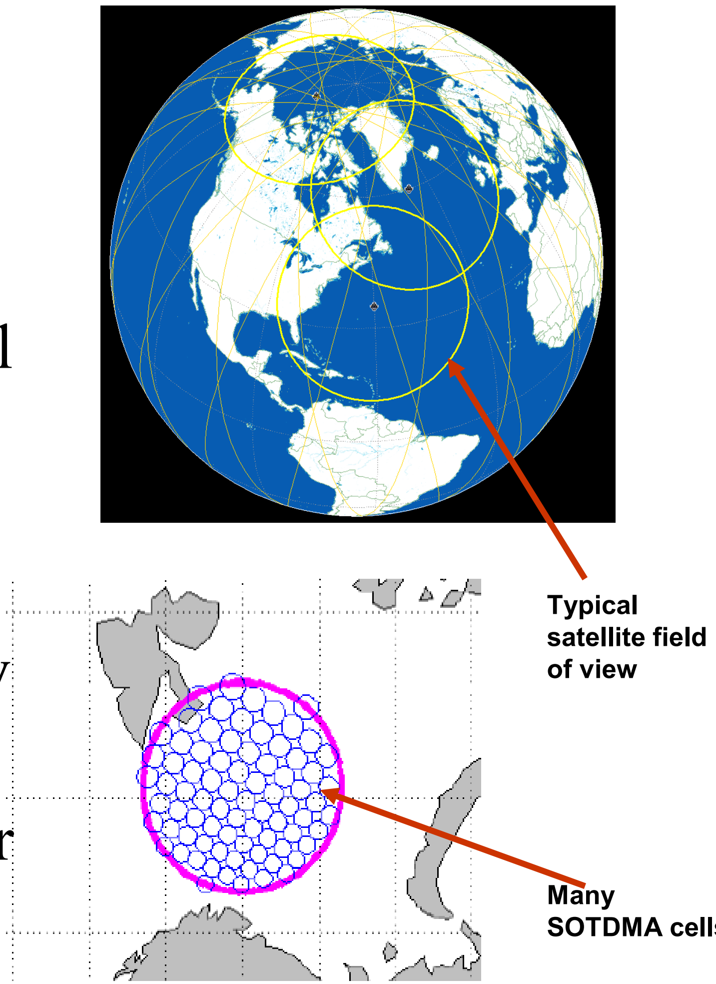
TRL7: System prototype demonstrated in a space environment

TRL8: Actual system completed and flight-qualified through test and demonstrated (ground or flight)

TRL9: Actual system “flight-proven” through successful mission operations

AIS From Space

- Some significant technical questions need to be addressed:
  - AIS signal strength from space
    - Ships pitch/roll and use dipole antennas with deep overhead null
    - Gain/size of antenna on satellite [vs. size of satellite]
  - Field of view from space
    - Many cells in view simultaneously
    - Signal 'collisions'
  - Covering the globe in a timely manner
    - Constellation design
    - Launch cost
    - Ground segment deployment vs. data latency



AIS mission - Some issues to think about

- Instrument need not be heavy or power-hungry – may be appropriate to fly on a small platform
- Earth observation mission – consider what spectrum would be used (S- or X-band) – data volume is not necessarily small…
- Need to cover the globe, but desired orbital height may be low
  - Circular low orbit costly to maintain in propellant
  - Maybe consider novel solutions, e.g. elliptical orbits…
  - Constellation design, and launch options
- What are the unstated requirements?
  - Duty cycle, revisit time, data latency – for a demo mission, maybe these can be poorer than required operationally? Also drives ground segment requirements
  - How quickly is the data needed by the community?
  - Does the data need to be used in conjunction with existing sensor data – driving coherent collection plans, …
- Can other mission needs be satisfied by the same platform?
  - Synergistic secondary/tertiary payloads offer better mission cost-effectiveness

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Mission timescale

- How long, what steps needed for mission approval?
- How long or development, and are there any external dates driving the schedule?
- What is the planned operation start date, lifetime? What is the impact of a late/early start, short/long lifetime?

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How to make qualitative needs quantitative?

- Functional vs. Performance
  - What the system must do, and how well
- Operational
  - How the system interacts with the stakeholders
- Constraints
  - Limitations to the range of approaches to be considered.. Regulatory, schedule, cost, …

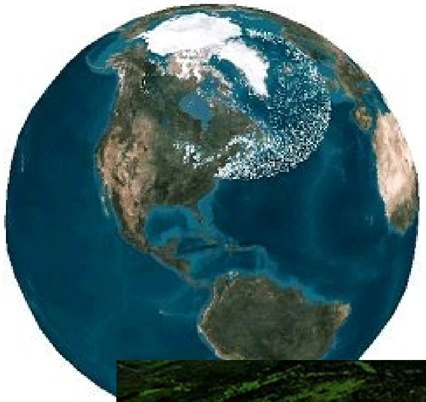
Platform options

Alternative concepts or designs

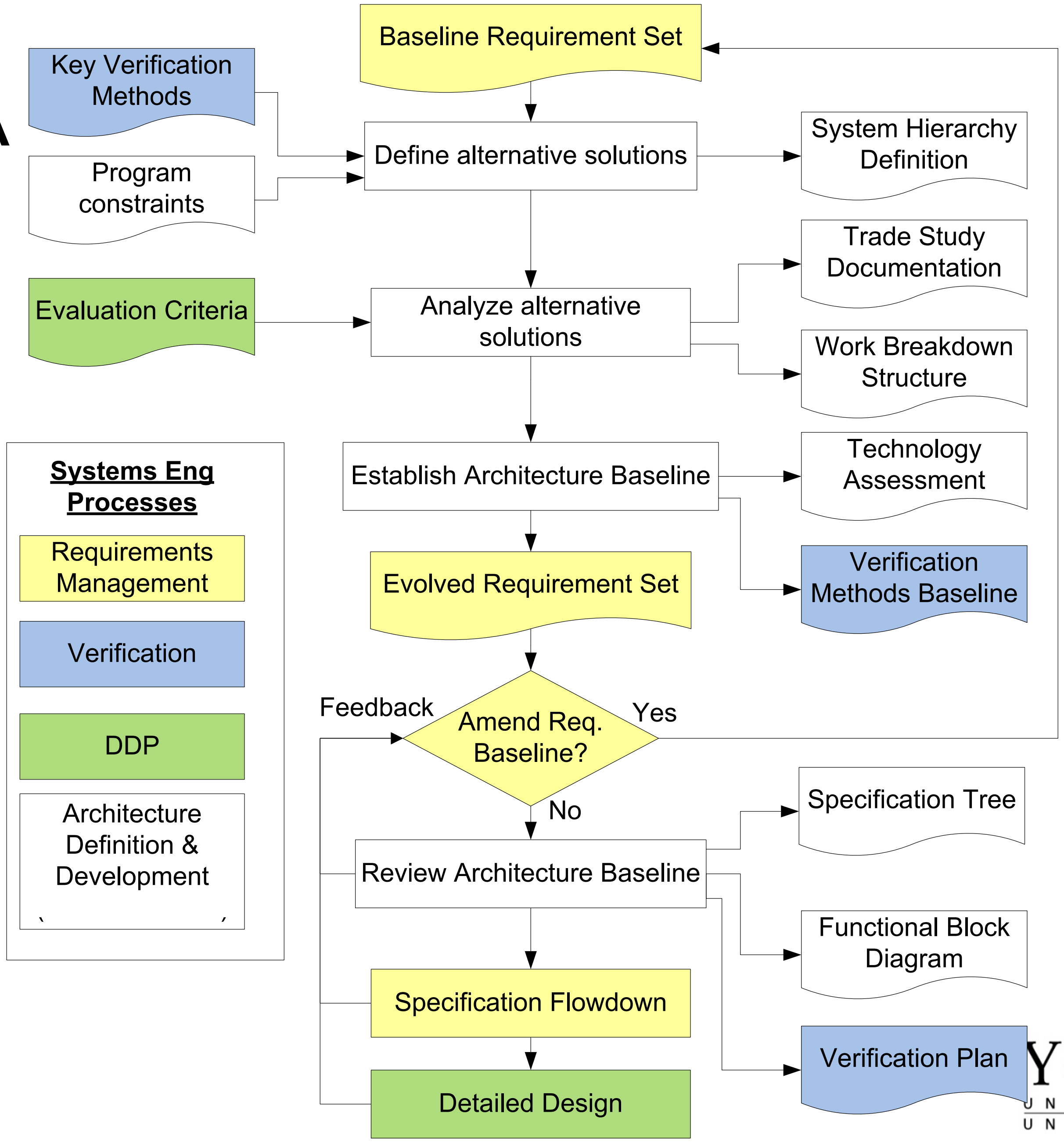
- And possible pathways through the alternatives

Path to AIS Feasibility

- High-fidelity simulations
- Harbour testing in Vancouver & Halifax
- Aircraft AIS trials
- NTS AIS nanosatellite
- Operational platform
  - Early adopters
- Operational constellation
  - Driven by largest customer need



Phase A



Baseline Requirement Set
Key Verification Methods
Program constraints
Define alternative solutions
System Hierarchy Definition
Evaluation Criteria
Analyze alternative solutions
Trade Study Documentation
Work Breakdown Structure
Establish Architecture Baseline
Technology Assessment
Evolved Requirement Set
Verification Methods Baseline
Feedback
Amend Req. Baseline?
Yes
No
Specification Tree
Review Architecture Baseline
Functional Block Diagram
Specification Flowdown
Verification Plan
Detailed Design
Systems Eng Processes
Requirements Management
Verification
DDP
Architecture Definition & Development

Architecture

- Space segment
  - Bus
  - Payload
- Ground segment
- Mission operations
- TT&C architecture
- Orbit
- Launch segment

- Consider alternative architectures!

Iterate

- What are the system design drivers?
- What are the key requirements?
  - Common key reqts: size, weight, power, fuel, communications, pointing, number of spacecraft, orbit, scheduling, operations
- Evaluate mission utility
- Define a baseline mission concept and architecture
- Revise requirements and constraints
  - Allocate requirements to systems

Phase A

- Requirements Management
  - strategy for coping with requirements gaps until they are resolved
  - allocation strategy for sub-system requirements
  - ranking process for requirements (e.g. critical, desirable, flexible) as well as the method used to capture the results of this ranking process
- Verification and Validation Approaches
- Architecture and design
  - process to be applied
  - products and outputs
- Overall hardware/software development methodology
- Testing/integration process
- Description of how interfaces will be developed and managed.
- Functional trade-offs

Expectations: architecture may seem obvious from heritage or may be predetermined by customer expectations; a strong driver and/or innovative thinking may produce a change. Define a proposed architecture at the top level as a strawman to compare subsequent concepts against.

Key requirements: Requirements review with respect to proposed architectures must include performance, environment and interface requirements but care must be taken not to overlook reliability, etc.

Manufacturability: is there a gap in in-house capabilities and experience verses the availability of a trusted sub-contractor with the capability.

Qualification and verification: It is generally good that subsystems can be qualified and tested prior to integration at a higher level and/or that testing can happen early in design/development. What method will be used to verify each requirement?

Schedule: An architecture which offers *some* desirable features may be ruled out if parts present schedule risks.

Cost: It is important to be able to define the minimum performance/requirements to allow cost to be optimized.

Phase A

- Functional Block Diagram and description
- Equipment Breakdown Structure and sourcing
- Key Performance Indicators and tracing through all levels of the design
- Model requirements for all equipment (based on risk, TRL):
  - Prototype: to demonstrate proof of concept for an element of the system.
  - Breadboards: built to a higher level of fidelity than a prototype, give an indication of the performance that can be expected from the final design for some or all of its requirements.
  - Engineering Models: normally a complete representation of the final deliverable equipment - flight representative in most aspects but may deviate from the flight design in a known manner.
  - EQM: Flight representative complete design, used to demonstrate functionality, qualification and performance.
  - Qualification Models: flight representative, subjected to full set of testing, and may need refurbishment to be suitable for flight.
  - Proto-Flight Model: Flight Model that is subjected to a testing regime more strenuous than expected in service but without requiring refurbishment for flight use.
  - Flight Model

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AIS Mission analysis

- Constellation roll-out launch options
  - Dedicated launch, multiple spacecraft per plane
    - Bus with propulsion capability
  - “Brownian” secondary launch opportunities
    - Lower-cost launch, bus, more busses
- Early service vs. target operational service level
- Detection performance vs. revisit time
- Right metrics:
  - Latency, revisit

  Vs
  - “Age of data”, “Time to next update”

Ground segment analysis

- Locations
  - Data volumes, latency
  - Station availability, size, …
  - TT&C vs. data downlink
  - Spectrum Licencing
  - Security / nationality issues
- Architecture
  - Local vs. Central control, processing
  - Spacecraft operations centre, payload operations centre? User interfaces?
  - Operations concept
    - Complexity of operations (lights out vs. large ops team, flight dynamics needs, network needs, data processing/handling needs)

Phase B

- ICDs
- Budgets
- Component selection
- Make/buy decision for non-standard technology
- Preliminary drawings
- Risk register
- Preliminary verification plans

- And don’t forget GSE and test system design (from stimulus to measurement)!

Technical budgets and margins

- Power budget
- Mass budget
- On-board processing (OBC, payload)
- Pointing control and knowledge, magnetic moment
- Orbit control and knowledge (delta-vee budget)
- Rf link budgets
- Data budget
- Command and Telemetry (space-ground and on-board)

- Preliminary design margins and low TRL component margins should be high
- Margins can reduce as design matures
- Can be useful to track evolution over the project

Interface requirements and control

- Space-ground interface is most commonly planned for but
- ALL unit-to-unit, assembly-to-assembly, spacecraft to payload, ground segment element interfaces need controlling
- Internal or cross-team, and especially contractor-subcontractor
- Interfaces cover at least:
  - Mechanical (location, mounting, materials etc.)
  - Electrical (grounding, bonding, power including ripple, EMC)
  - Thermal (paths, expected environment, need for thermally controlled environment)
  - Command and control

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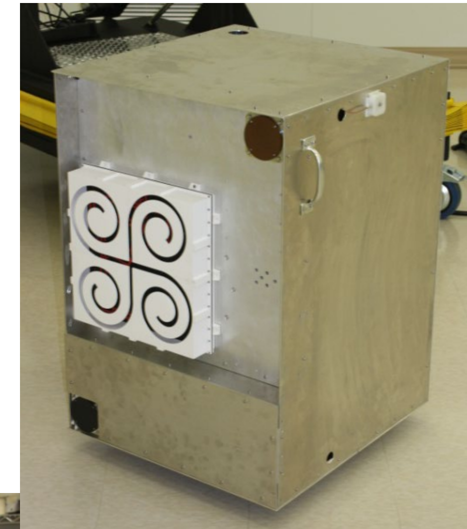
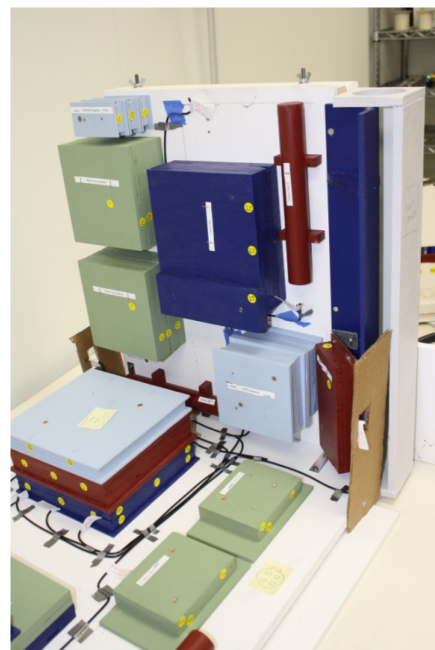
Phase C, D

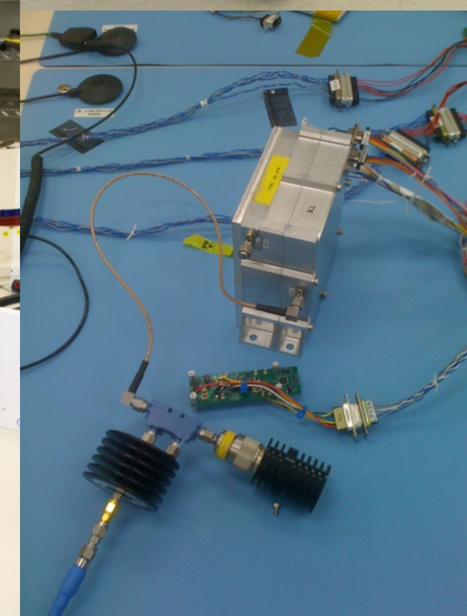
- System reviews
- Requirements management
- Traceability, verification status
- Test review
- System test and integration procedures
- Operational handbook development

M3MSat

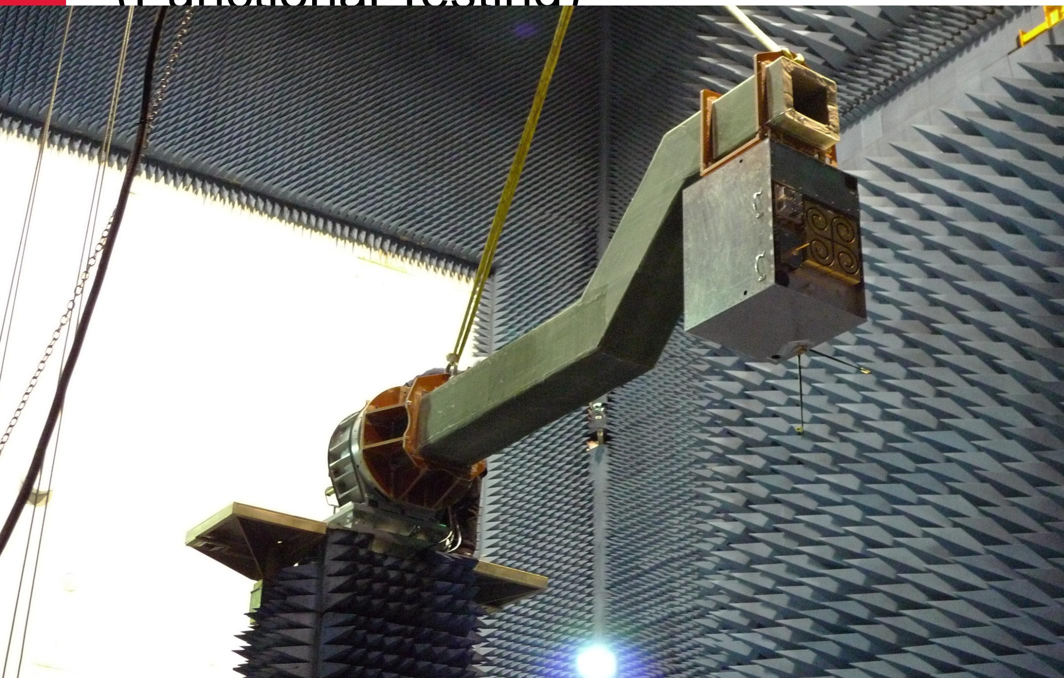
- Project Kick-Off: June 2008
- Launch: watch this space!
- Mission Objectives:
  - Primary: Monitor AIS signals from space
  - Secondary: Demonstrate a low data rate (LDR) messaging system
  - Tertiary: CSA-furnished demonstration payload
- Current Status:
  - Spacecraft is in formal test at DFL





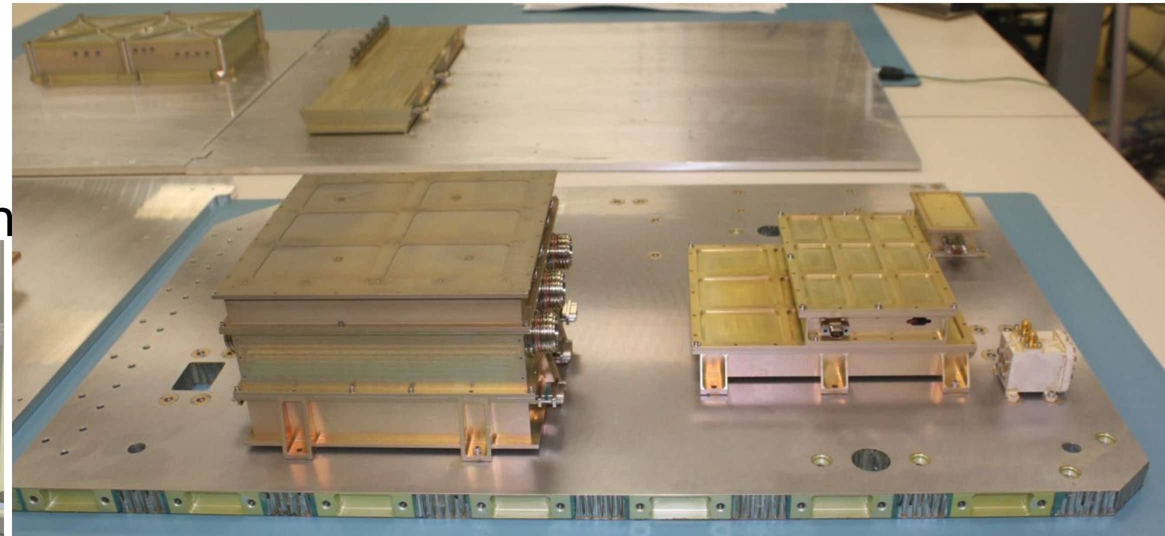


M3MSat
(Functional Testing)



M3MSat

(Structure and Integration



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Change and nonconformance control

- Understand and track changes from PDR/CDR baselines and reasons for changes
  - Risk should reduce (cost/schedule/technical/…)
- Understand when partial or non-compliances arise, ensure no/small mission impact
- Actively manage and avoid requirements creep
- Test review board
- Determine which nonconformances require correction, can be used as is, or even require scrapping (MRBs)
- RFW/RFD

Phase E/F

- Commissioning review
- Lessons learnt
- Anomaly handling, feedback to design

- End-of-life passivation
- IADC guidelines
- Replenishment plan
- Obsolescence plan

So…

- Mission analysis and system engineering cover all phases of mission lifecycle
- Involve knowing what you don’t know, knowing what to worry about, managing risk, maintaining trades, keeping mission needs in mind
- Standards and best practices help avoid missing things, or discovering them too late
- Regular reviews also help find holes and problems early – structured reviews with targeted purpose help (MRR, PDR, CDR, TRR, PSR, ORR, LR, CRR…)

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exactView-2

- Project Kick-Off: June 2009
- Launch: August 2011
- Mission Objectives:
  - Monitor AIS signals from space
- Hosted payload on ResourceSat-2 (an ISRO Earth monitoring satellite)

- Current Status:
  - Spacecraft is in operation

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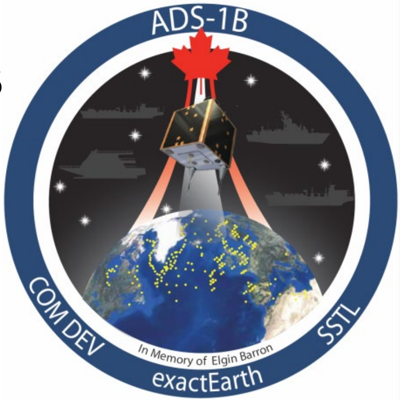
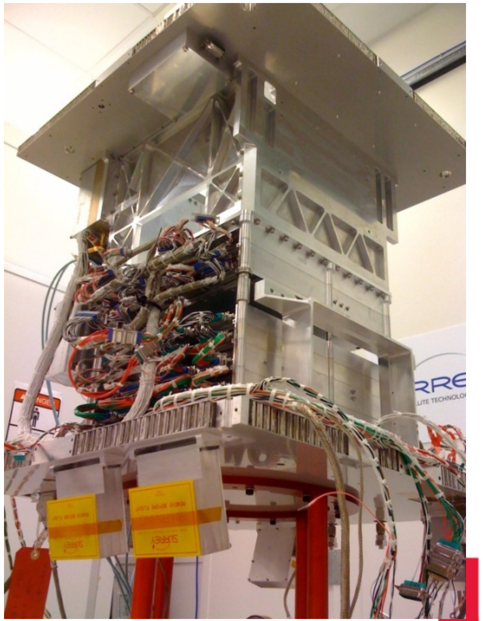
ADS-1B

- Project Kick-Off: Jan 2009
- Launch: Q2 2012
- Mission Objectives:
  - Primary: Monitor AIS signals from space
  - Secondary: Demonstrate an ECSS compliant communications system
- Uses a COM DEV payload and an SSTL bus
- Current Status:
  - Spacecraft is in operation





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Tracking Ships from Space