Aspects of Spacecraft Operations and the Space Environment

Dan Allred
National Systems Group
Mission Operations

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Agenda

An operations perspective to the space environment

- Background – to provide perspective
  - *The lexicon – for subsystem reference*
  - *Top priorities*
  - *Enabling Engineering*
  - *Anomaly management*
  - *Impacts of anomalies on operations*
- Relationships of operations with:
  - *The spacecraft developer*
  - *The ground system developer*
  - *The users*
  - *The research community*

Many operations personnel are unfamiliar with the space environment and the myriad of possible impacts to operations

Background – Major spacecraft subsystems

A lexicon for discussion for common spacecraft functions

- Structures: S/C body, deployables, decks, mountings, cabling, mech. interfaces
- Electrical Power Subsystem – EPS: Provides and distributes primary electrical power to the spacecraft bus and payload(s)
  - *Solar arrays, RTGs, reactors, batteries, distribution systems - voltage regulated?*
- Telemetry and Commanding – T&C: Control of the spacecraft and understand performance and responses via telemetry
- Thermal Control: Keeping the vehicle within operational temperature limits
- Attitude Control - ACS: Attitude Determination (AD) and Attitude Control (AC)
  - (AD) Star Trackers, Horizon (limb) Sensors, Inertial Reference Units, Kalman Filter
  - (AC) Spinners, 2-axis control (RA and Dec), 3-axis control: Reaction control system (propellant), Reaction wheels, Control Moment Gyros
- Comms: – Communications with the ground or through relays
  - *Payload data, bus data, telemetry, command links*
- Ephemeris and Timing: Spacecraft location and clock source
- Payload(s): – Perform the function(s) for which the spacecraft was funded

Understanding of environmental impacts to subsystem and lower levels helps to better guide anomaly responses and fosters better component designs.

Spacecraft mission priorities and functions

Priority number one:

1. Assure spacecraft health and safety

   – *Health: kind of like a person: component, subsystem, or system state-of-health*

   – *Safety: avoid situations which could harm the vehicle or its subsystems, if feasible*

Spacecraft, since they operate for years without relief from their environments, will experience numerous low probability events over their lifetimes

Operate and conduct the mission

Priority number two:

2. Keep the payload data flowing: perform all operations and maintenance functions necessary for the spacecraft to perform its mission(s)
   - *Work within the program Concept of Operations (CONOP)*
   - *Work within the particular level of automation, i.e. how are humans in the loop?*
     - Is the spacecraft actively commanded or run by onboard script?
     - Is telemetry constantly monitored in real time or sampled, held, and then downlinked?
       - *Who writes the script (OpPlan)? For how long is it good? Who uploads?*
     - Note differences between spacecraft bus and payload commanding
       - *Examples:*
         - Automated ComSat executing telephonic user changes with no bus impacts
       - *Ops Floor: 24-7 shift operations to "lights out" fully automated*
       - *An "offline" engineering staff almost always will manage vehicle configuration (as opposed to payload configuration)*

No mission – no paycheck.

Sustaining Engineering

A key enabler to maintaining the top two priorities

3. Flight Engineering
   - *Anomaly management*
   - *Subsystem and performance trending*
   - *Power management – solar array positioning – closed vs. open loop*
   - *Flight software maintenance and uploads – use of Space Vehicle Simulator (SVS)*
   - *Preventative maintenance – e.g. battery reconditioning*
   - *Eclipse management*
   - *Momentum management*
   - *Attitude management – AD and AC*
   - *Ephemeris management – determination (GPS, ranging, etc.)*
   - *Orbital management – Station Keeping and/or station changes*
   - *Thermal management*
   - *Communications management*

Ground Engineering

All aspects of ground systems

4. Ground Engineering
   - *Command and Control functions*
   - *Communications*
   - *Telemetry processing*
   - *Mission data processing*
   - *Data distribution*
   - *Development*
   - *Ground software*
   - *Facilities*
     - Primary and backup power
     - Security
     - Ops floor control rooms
     - Office space and personnel support
   - *Management, business functions and interfaces*

Ground system development traditionally lags flight systems which can cause disconnects in schedules and operational performance until rectified

Anomaly Management

Health and safety supersede everything else

- The anomaly process - an anomalous condition/situation is discovered
  1. *Initial assessment*
     a. What are the impacts?
        Bus, payload, both
     b. Severity (examples)
        Least worrisome - minor annoyances with no real impacts
        Worrisome – intermittent mission outages, some bus trends moving toward limits
        Mission impacting – payload (mission) disruption or outage
        More severe – bus issues precluding mission accomplishment
        Very severe – one or more bus functions inoperable, safehold
        Extreme – loss-of-communications, loss of power-thermal stability

The first order of business is to assure the spacecraft is safe.

Defining a safe spacecraft

Present and useable **D**ownlink, i.e. the vehicle state can be ascertained

Present and operable **U**plink, i.e. the vehicle is commandable

The vehicle is in the proper **A**ttitude and controllable

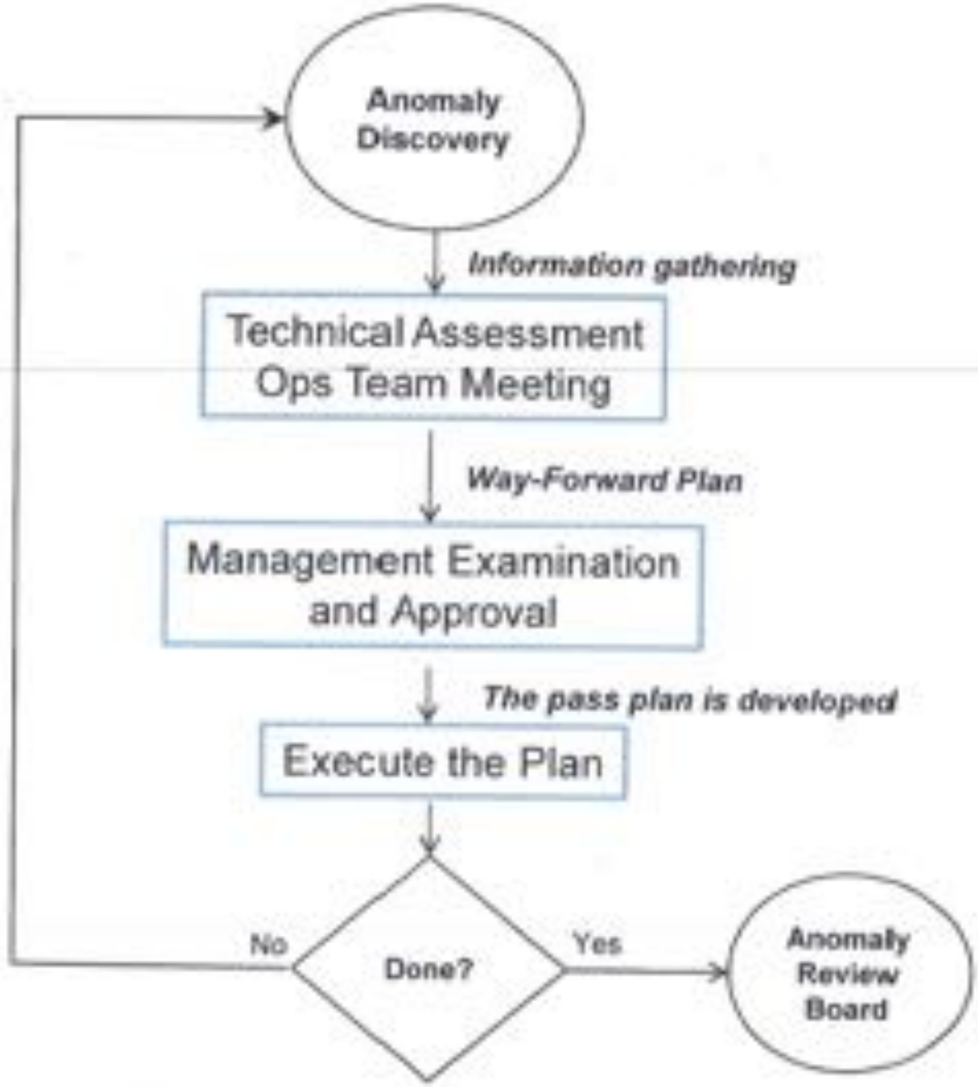
The vehicle's electrical **P**ower system is functioning nominally

The vehicle is **T**hermally stable

The spacecraft's **A**utonomous self management functions are functioning nominally

The anomaly process

One model in use



Anomaly processes are developed to guide complex work toward achievable steps.

Anomaly Management –initial management meeting

Process continued – Determining the way forward

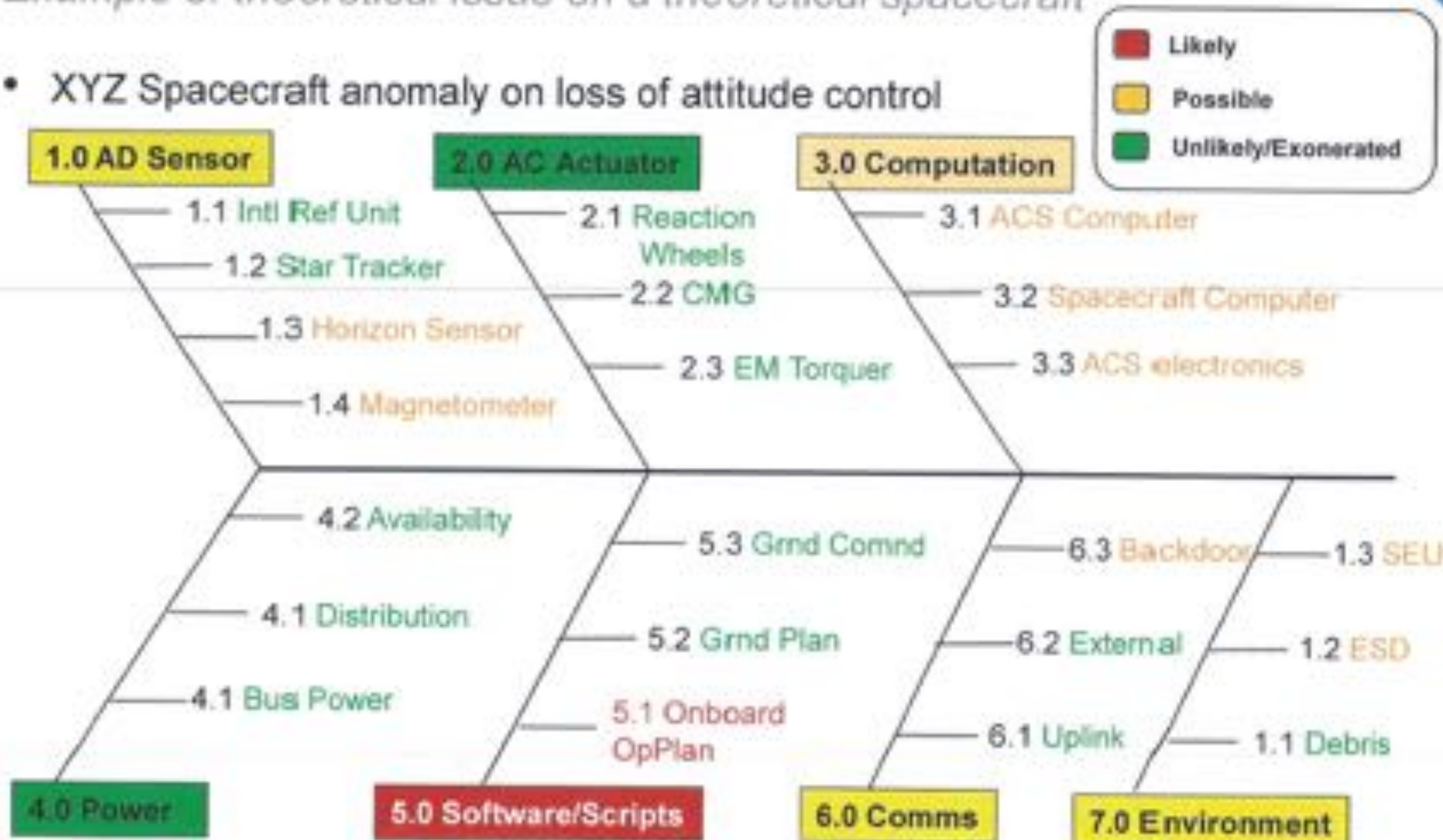
- Anomaly team meets
  - *Anomaly Manager (Owner's rep) is fully engaged – either present or remotely*
  - *Meeting Agenda*
    - Current system state including H&S
    - Event timeline – what was seen and when
    - Initial assessment is provided
    - Comparison to known signatures, issues or concerns
    - Initial root cause candidates
    - Way forward options discussed and weighed
    - Decision made for the recommendation for presentation to upper management
  - *Considerations in the discussion*
    - Impacts of affected components, subsystems, and other systems
    - Personnel schedules – 24x7 or 8x5
  - *Who's involved?*
    - Spacecraft operators, spacecraft systems, ground systems, other experts as needed

The result is a recommendation for a decision maker to move forward.

Notional Fishbone

Example of theoretical issue on a theoretical spacecraft

- XYZ Spacecraft anomaly on loss of attitude control



Fishbone helps guide the investigation into root cause with a process of exoneration

Anomaly Management – Management Decision

Agenda to obtain approval to make substantive changes

- Convey everything up to that point
  - *Synopsize the event and impacts*
  - *Provide sufficient technical background for management to understand*
    - The anomaly and its impacts
    - The recommendation and its impacts
    - Temporary vs long term needs, effects, costs, further needed work
- Describe the recommendation
  - *Present the execution plan*
    - Schedule – step-by-step
    - Resources – people, locations, funding, equipment, software, communications, contracts, required deliverables
  - *Impacts and risks*
  - *Mitigation – Test all commands in a Space Vehicle Simulator*
  - *Contingencies*
- Upon approval perform according to the plan

Anomaly Management – Execute the plan

Performing the functions through the approved steps

- Convene the team – all required personnel must be in attendance
  - *Walk through the plan in a table-top environment – check for flaws!*
  - *Change the script/pass plan as needed*
    - Test *changes* on the SVS to assure it is correct and achieves the desired result(s)
- Perform the Engineering Activity - *"Plan to fly and then fly the plan"*
  - *Log everything – through software tools and writing*
    - Note actions, times, communications: formal and informal
  - *Ad hoc changes are often bad, usually only considered with unforeseen issues*
    - Circumstances determine how to proceed – press ahead or regroup and reevaluate
      - *Some anomalies last hours, some last years*
    - Above all – avoid making the situation worse
      - *If you don't know what's going to happen when you send a command, don't!*
- If all goes well – return to mission, or at least get to an acceptable state
  - *Reiterate the process as necessary*
  - *Some anomalies may require several Engineering Activities*

The process should get to an acceptable state and hopefully a mission effective one.

Relationship between Ops and the Spacecraft Developer

Two groups joined at the hip

- Developer - builds the spacecraft and much of the ground system
- Writes the Concept of Operations (CONOP)
  - *A detailed, medium level, document on how to operate the satellite and execute its mission*
    - Describes normal ops plus the ability to handle contingencies and anomalies
    - Consists of several CONOPs with full sets of documentation:
      - *Mission tasking and scheduling*
      - *Spacecraft bus operations*
      - *Communications*
      - *Payload operations*
      - *Ground system operations*
      - *Orbital maintenance*
      - *May provide designated interfaces to access space weather data*
- Establishes the technical baseline and provides updates
- Teams on anomaly responses, resolution and isolates root causes
- Funds much of the effort

The prime developer/fabricator/integrator and operations form an indelible partnership throughout the program life cycle

Relationship between Ops and Users

Users: those who need the payload data

- Operator and user interaction spans a wide spectrum depending on program
  - *Often a major design consideration*
  - *A vital element in the CONOP*
- Interaction – notional Examples:
  - *Least Interaction: Geosynchronous Commercial ComSat user – may not even be aware of the spacecraft's existence e.g. Commercial broadcast like Sirus-XM*
  - *Most Interaction: A spacecraft whose primary payload is fulfilling a single user's task on a specific schedule, such as an orbital astronomical telescope looking at an event e.g. post supernova observations*
- In vast majority of cases – space systems have many users
  - *When that isn't the case, single-use spacecraft programs get very expensive for a single user – the cost often gets spread to special organizations and countries*
    - Example: publically funded manned spaceflight for exploration
- User-involvement in the anomaly process
  - *The more dependent a user is on the system, likely the higher level of involvement*
    - From getting information updates to membership in the anomaly teams, potentially even leading it

Users are the life blood of the space business, let alone any business.

Relationship between operations and research

What the space weather community can provide

- Ops needs a highly reliable spacecraft
  - *Provide environmental understanding to the spacecraft developers and their vendors*
  - *Specifications – works best when worked with the developer to understand their needs*
  - *Understand the trades in the RAM space with costs and schedule*
- Space experts for Anomaly Support to Operations
  - *Root Cause analysis for environmentally caused anomalies*
  - *Evaluation of the space environment*
  - *Reproduction of phenomena in the lab for bone exoneration or to lay fault*
    - Insight into the fishbone construction
  - *Tools to evaluate the space environment*
    - Real time – what the environment looks like now
    - Historical – support event analysis
    - Forecast – awareness today, mitigation tomorrow

Operations, development, R&D, and the space weather community should continue to improve communications and exchange information.