OPS-O Plenary: Who Wants to Live Forever?, Z-flip, the Key to Immortality

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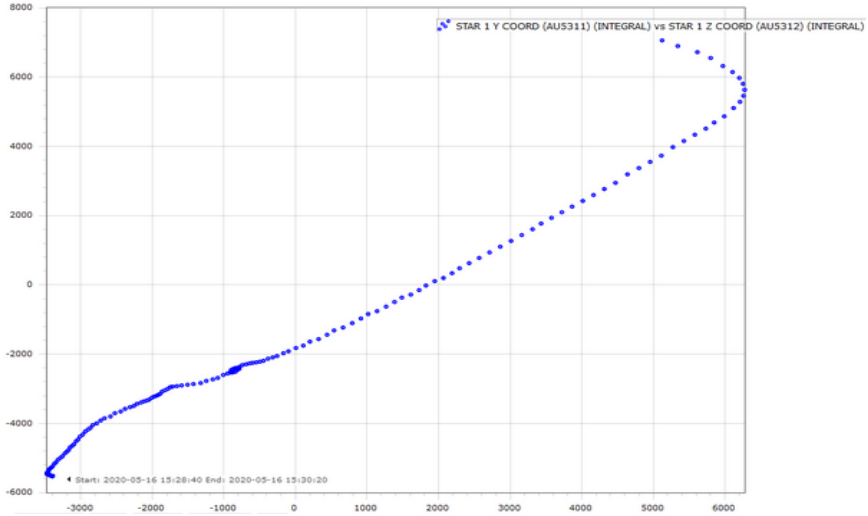
01/12/2020

Safe Mode #8- 16/5/2020

- Excess on-time demand on thruster 2 during reaction wheel momentum offload operation causes safe mode (ESAM)



- De-pointing also observed (Guide Star)
- ESAM stable (RCS-B)
- Suspicion of RCS-A or thruster 2A anomaly

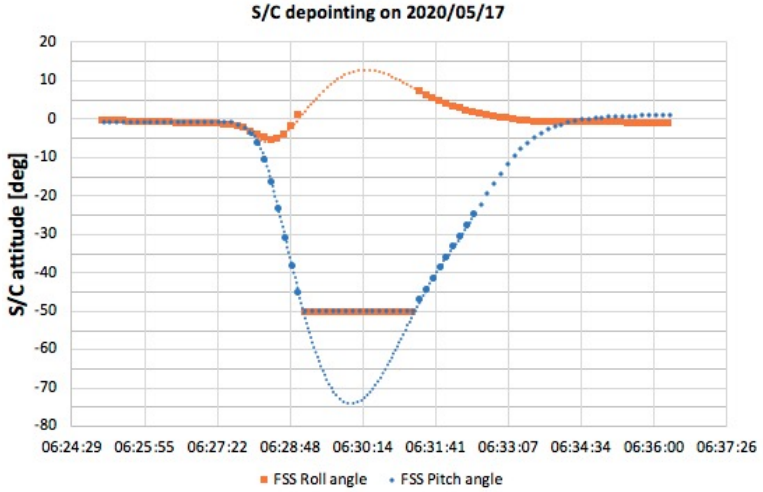
=> recover on RCS-B next morning

Safe Mode Anomaly – 17/5/2020

Before starting recovery

Huge depointing under ESAM Control

- Pitch 75DEG, Roll 13DEG (estimated)
  - Eclipse transition observed!!
  - Controller recovers within 7minutes
  - => anomaly not restricted to one RCS branch
  - Concurrent drop in RCS pressure of about 0.2bar
- Fast recovery to wheel controlled mode – new procedure
- Simulations show the controller can cause such a depointing in case of thruster 3B under performance
- Thruster calibration indicated reduced (55%) and intermittent performance on **both RCS branches**.



Summary of Possible Failure

It is likely that 20 to 30kg hydrazine are still in the Tanks (8 to 10 years op's.)

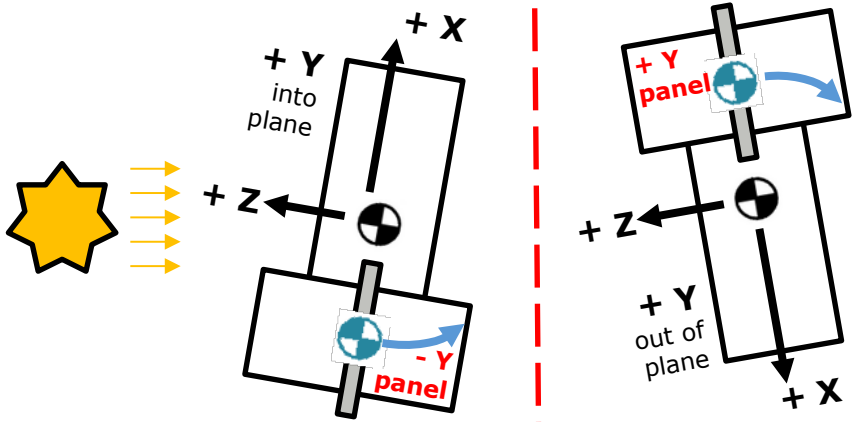
- Probably migrated behind the tank membrane! – unusable
  - All tank membranes are fully extended
- The RCS piping capacity about 2kg: contains a mix of hydrazine and Nitrogen
  - Concurrently Nitrogen pressurant has migrated in the opposite direction

The Problems we face

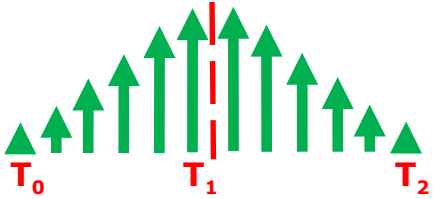
- Thruster performance is unpredictable and weak
- Almost no available propellant
- The mission cannot be continued as before – no reaction wheel offloading
- How can we continue?

Z-flip Theory

Z-flip theory (D Salt)



Spacecraft total angular momentum vector ($\hat{H}$)



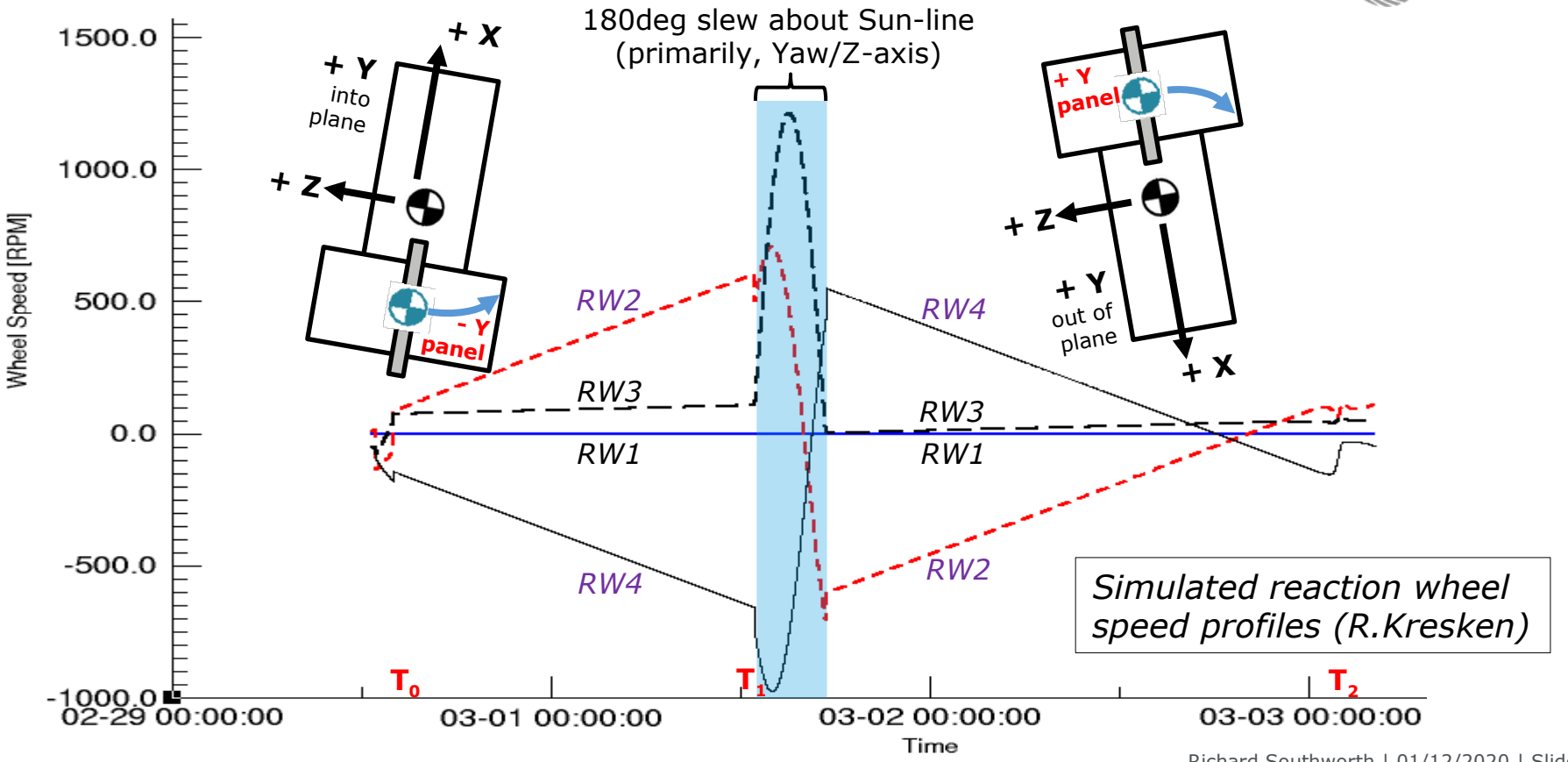
Evolution over time

Main disturbance is Solar Radiation Pressure (SRP)

System Angular Momentum stored in reaction wheels

1) **T_0 (*17/7/2020*) established total angular momentum vector ($\hat{H}$) at a low value**
2) **SRP imposes an external torque on the S/C**
   - **'anti-clockwise' in the inertial frame, increasing $\hat{H}$**
3) **180deg slew on reaction wheels about the Sun-line at T_1 when $\hat{H}$ reaches upper threshold**
   - **$\hat{H}$ is conserved throughout the slew, but transferred between wheels 2 and 4**
4) **SRP imposes an external torque on the S/C**
   - **'clockwise' in the inertial frame, decreasing $\hat{H}$**
5) **180deg slew on reaction wheels about the Sun-line at T_2 when $\hat{H}$ again reaches low value**
   - **Step 2) to 5) can now repeat indefinitely**

Z-flip Simulation



Z-flip In Flight Test

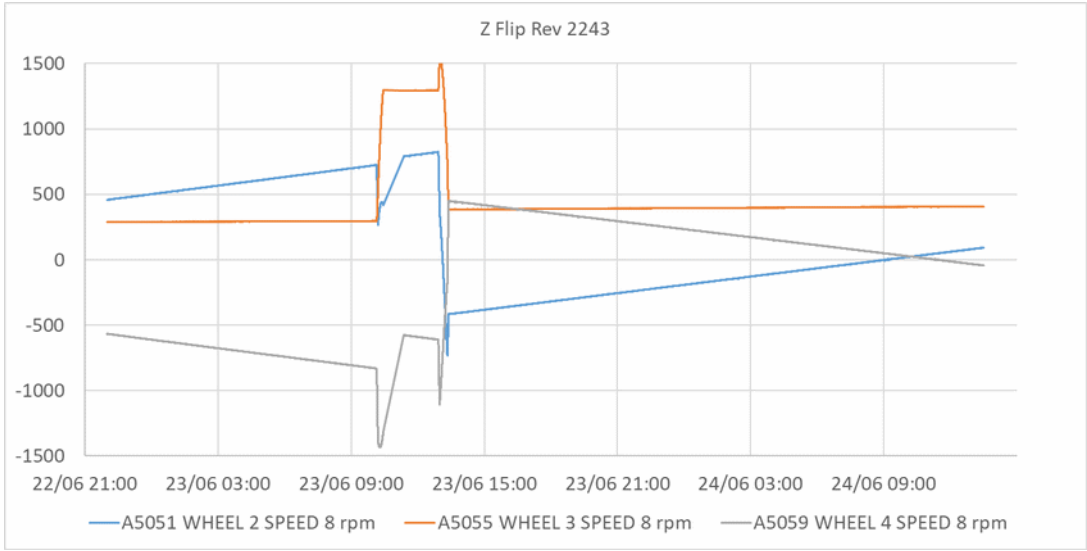
2 slews, total magnitude of 155DEG.

At a SRP drift rate of 20RPM/hour we compensated for about

- 55hours drift on wheel 2
- 64hours drift on Wheel 4

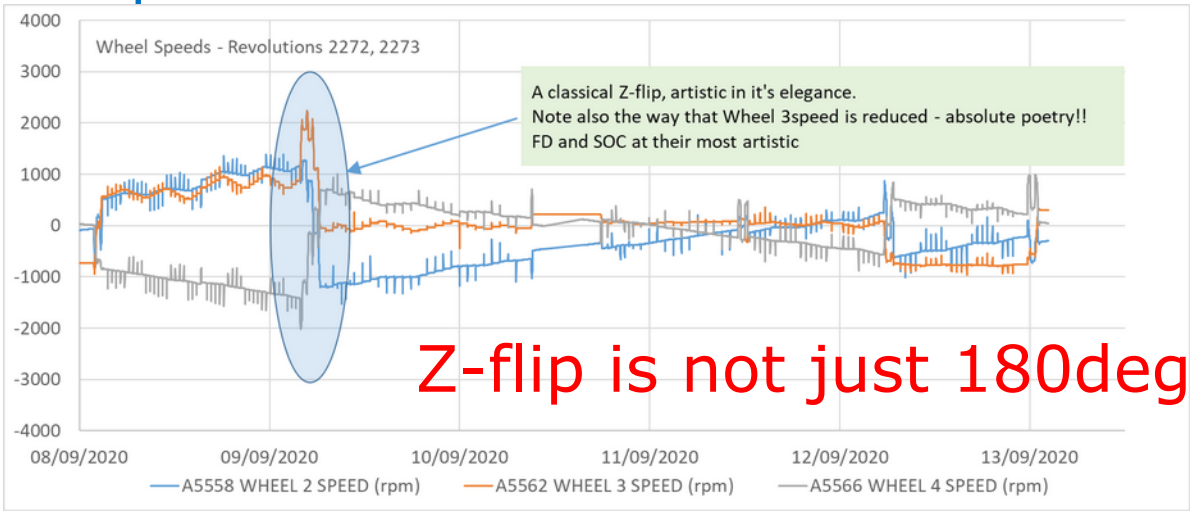
Wheel 3 drifts only slowly – no SRP compensation (can be controlled using gravity gradient)

In flight data demonstrates Z-flip acts as expected



=> Angular momentum can be controlled without biasing

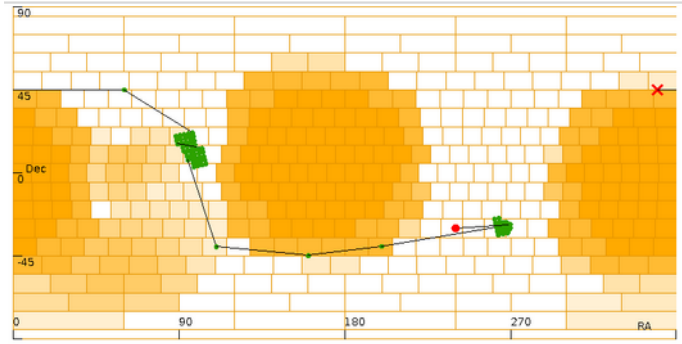
Z-flip - What we have Achieved

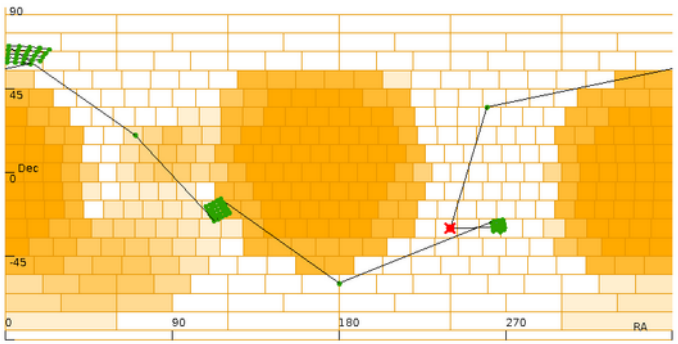


INTEGRAL has regained it's full observing efficiency!

Planning supporting tools developed by FD

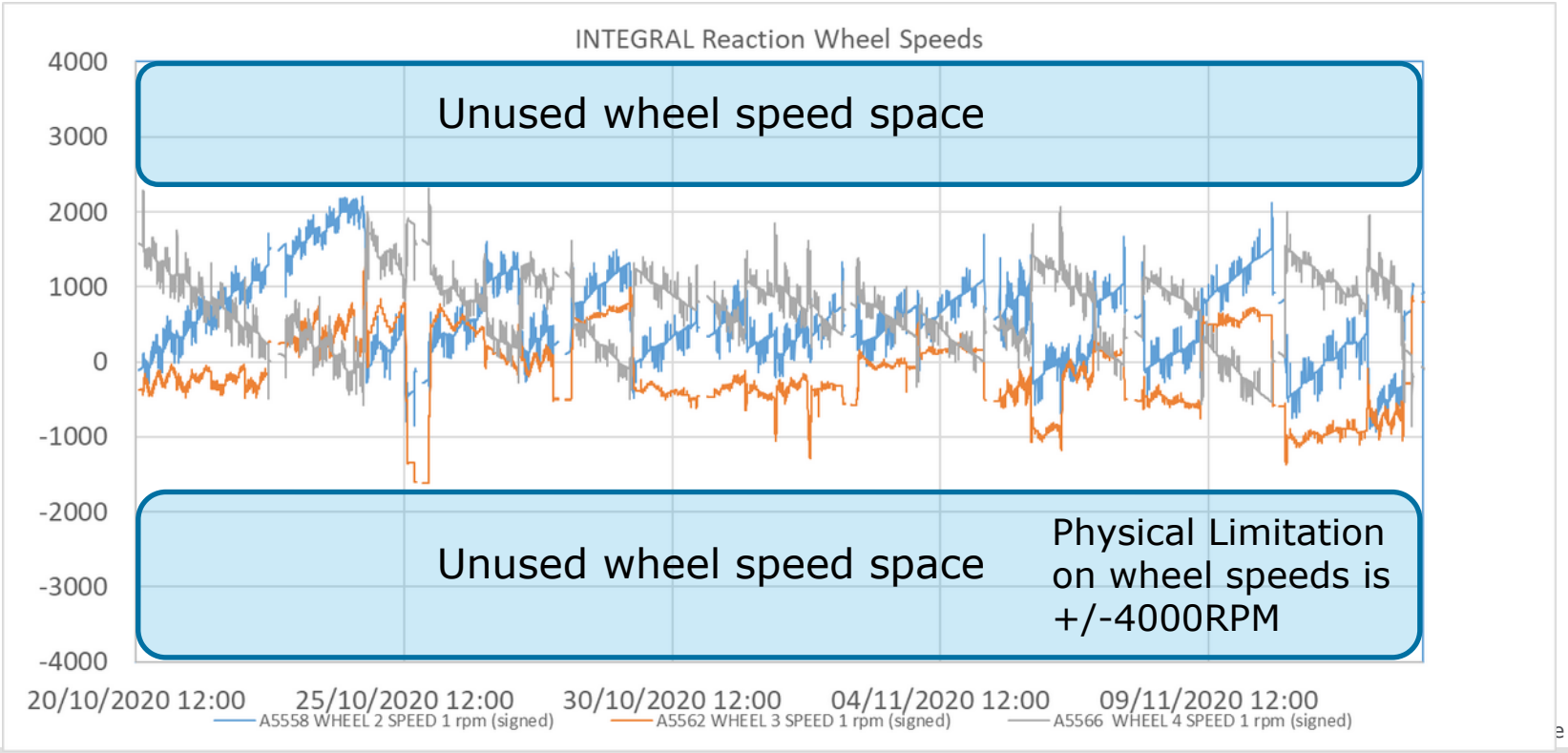
Z-flip is not just 180degree slews!!!





Z-flip – can we Improve it?

Z-flip concept is proven and is effective - Can it be improved?



Z-flip Constraints – why?

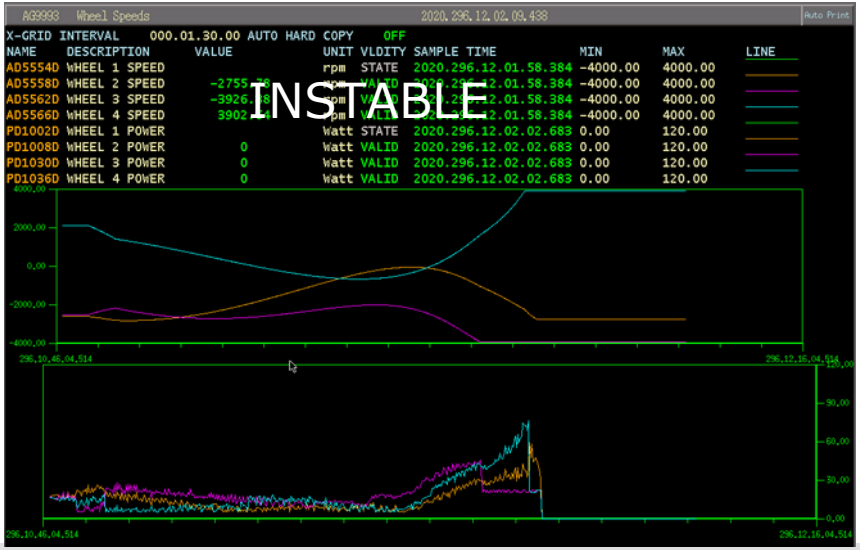
SOC plan observations to balance system angular momentum over planning period

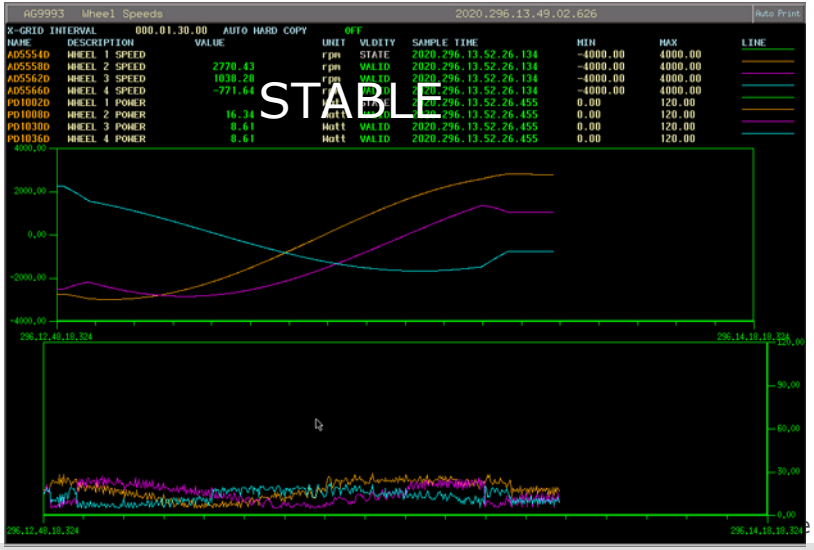
- Respect wheel speed constraint – 4000rpm non-negotiable (handle with care)
- Respect slew stability constraint:
    - Slews > 3° are executed Open Loop about Z axis
        - Z-flip is based on large slews about Z
    - Large slews (>7DEG) about Z are highly constrained by system angular momentum and can easily become unstable and trigger safe mode
        - Safe mode no longer works reliably
    - Forces SOC to move away from targets early

Open Loop Slews Modification - Gyroscope

Software patch **under testing** to use gyroscope output as (Z) reference

- Slew stability constraint no longer applicable - increase wheel speed range
- De-constrains SOC planning
- => allows longer time on target / better ToO response
- Deployment + commissioning Q2 2021





Open Loop Slews Modification – No Sensor

A further SW patch is under development:

- Slew without reference on all 3 axes
- Pure dead reckoning by commanding reaction wheel profiles
  - Relies on a well calibrated spacecraft
  - Less reliance on sensors – robust
  - Accuracy tbd, but probably good
  - Possible applications for momentum control during perigee
  - Minor code change
- Slew stability constraint no longer applicable - increase wheel speed range
- Will be developed and commissioned in Q2 2021
  - Can also be used if Gyroscopes degrade

Open Loop Slews Modification - 4WD

Based on the experience currently being gathered with the slew patches a proposal for a possible fast 4WD implementation for INTEGRAL will be made

- Use 4 wheels for attitude control instead of just 3
  - Pioneered by XMM
- Safety: Include fall back to 3WD in case of anomaly (safe mode #2, #3)
- Advantages for momentum management
  - More flexibility for ToO facilitation / longer observations

Operations Evolution

- Our aim is to present a feasible long term prospect for INTEGRAL
  - Z-flip
  - Safe mode Risk reduction
  - Modified slew modes
  - 4WD

To enable the best possible science

Ultra fast ToO

Team Effort

Fantastic team of teams effort to get to this stage

- At the end of May we didn't have a mission
- Now we have a viable science mission again
- Full observatory utilisation and scope for improvement
- Big thanks to everybody

Some key words:

Innovative	Collaborative
Thorough	COVID
Professional	XMM fuel Migration
Teamwork	Unsocial hours
Determination	webmust archive lost

FCT

FD

SOC

SDC

TEC

ASE / TAS-I

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