Miniaturised and MEMS AOCS for low cost space missions

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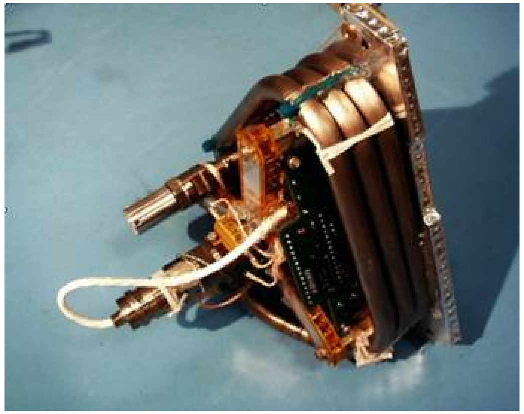
Overview

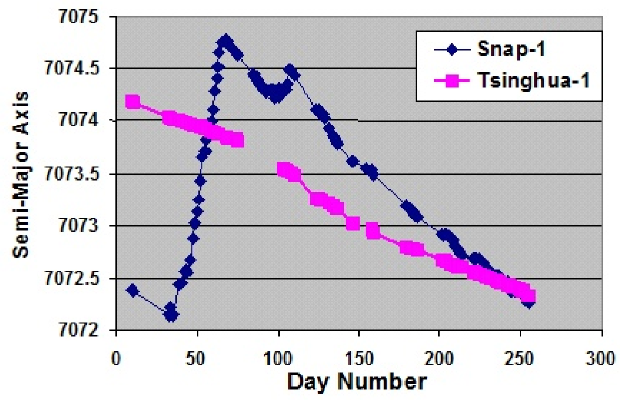
- SSTL's approach is to challenge the conventional definition of 'space-qualified' parts by testing MEMS components alongside existing heritage subsystems in small spacecraft missions, providing heritage by experience without the need for time consuming and costly qualification programmes.
- Ground developments & space flight data for miniaturised AODCS equipment on SSTL low-cost satellites.
  - Miniature kick-motor propulsion system (ESA support)
  - MEMS-based Inertial sensing
    - MEMS gyros (BILSAT, UoSat-12)
    - MEMS Inertial Measurement Units (GSTB-V2/A)
- How NOT to gain the benefits of MEMS in space….
- A brief look at what's next…

MINIATURISED PROPULSION

The need for MEMS propulsion
in smallsats

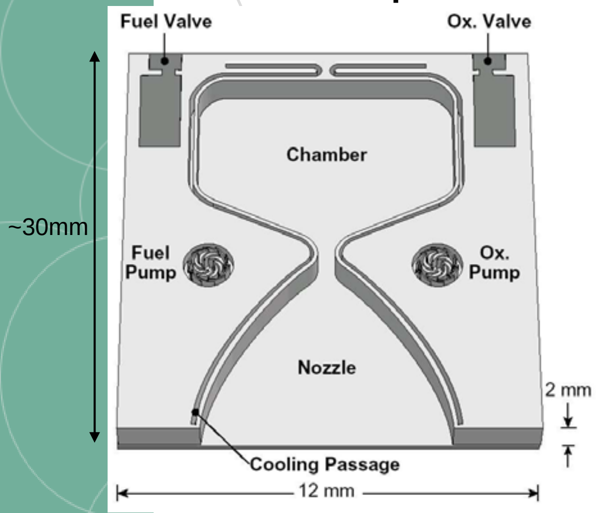
- SNAP example
  - Orbit raised to rendezvous with satellite
  - GPS used to update orbital elements
  - ΔV: 2m/s calc as required, 4m/s provided by prop system
  - Isp: 50s in cold mode (can be augmented to 100s if power available)
  - Still insufficient to offset orbit drag on low ballistic coefficient platform!



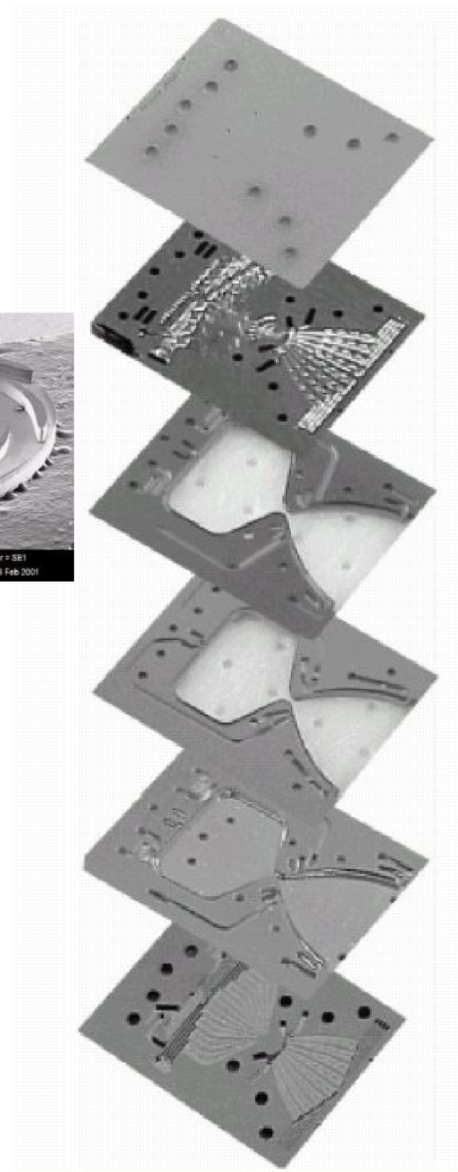


A delightful concept…

Concept



Hardware

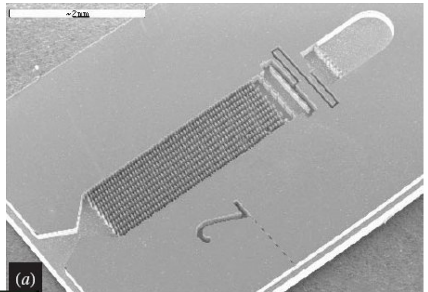


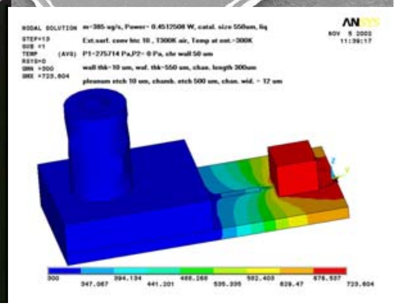
- MIT Gas turbine laboratory (Dept. Mechanical Engineering)
- Funded by US Army, NASA, DARPA
- ‘Rocket Chip’ 6 wafer design, integral cooling channels
  - O_2 / Ethanol or JP7/H202 propellants, Isp 300s target
  - Operation at 125Bar Pc, 15N thrust: T:W 1000:1 (SSME 100:1)
- Microturbines for power generation, micropumps
- **Target application** ***if T:W 1000:1 feasible***
  - Launch vehicles as low as 15kg launch mass to LEO possible
  - Other applications inc. UAVs, wide range of spacecraft

Micro 'kick' motor

- High level objectives
  - Compete on performance (scaled to smaller size) with a 1N hydrazine AOCS thruster
  - Aim for low recurring cost, as associated with MEMS component batches
  - Offer useful performance augmentation to 1-100kg satellite
    (Bolt-on kick motor)
  - Green propellants for easy testing / qualification / loading
  - Potential to be made in Si-based MEMS (but not mandated)
  - Scale-up at later date to MIT bi-prop performance goals

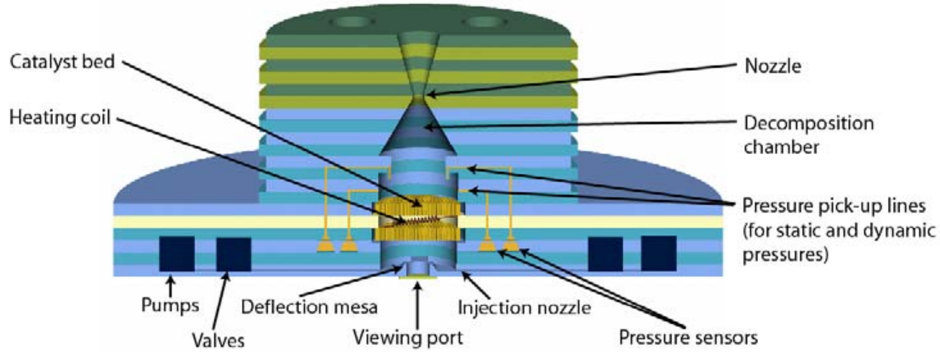
- MEMS Monopropellant thruster for NASA ST-x mission:
  - Thrust: 10-500 μN
  - Impulse Bit: 1-1000 μN-s
  - Specific Impulse targets:
    - 130 seconds (Hydrogen Peroxide)
    - 200 seconds (Hydrazine)
- Si with glass cover, inc. Nozzle, plenum, chamber and injector
- Monopropellants:
  - Hydrogen Peroxide, H_2O_2
  - Hydrazine, N_2H_4

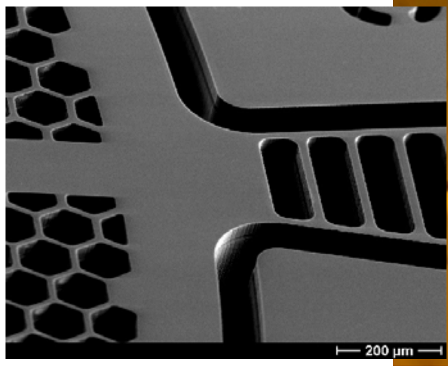


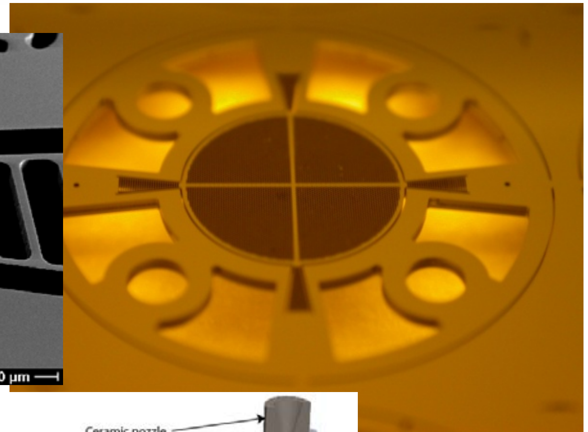


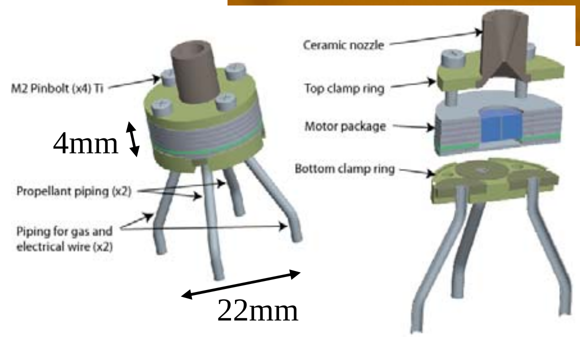
Design process

- How did we get to current design?
  - Flat plate (traditional MEMS) v. vertically integrated architecture
    - Pressure tolerance
  - Various propellant options considered
    - Green priority to allow low cost testing
  - Hybrid motors also
    - No growth path
  - Cooling v. heating
  - Nozzle options
  - Ceramic v. Si chamber
  - Pumping of propellants rejected to unsuitability of MEMS pumps
    - Drove design to hybrid of MEMS cat. Chamber and conventional plumbing









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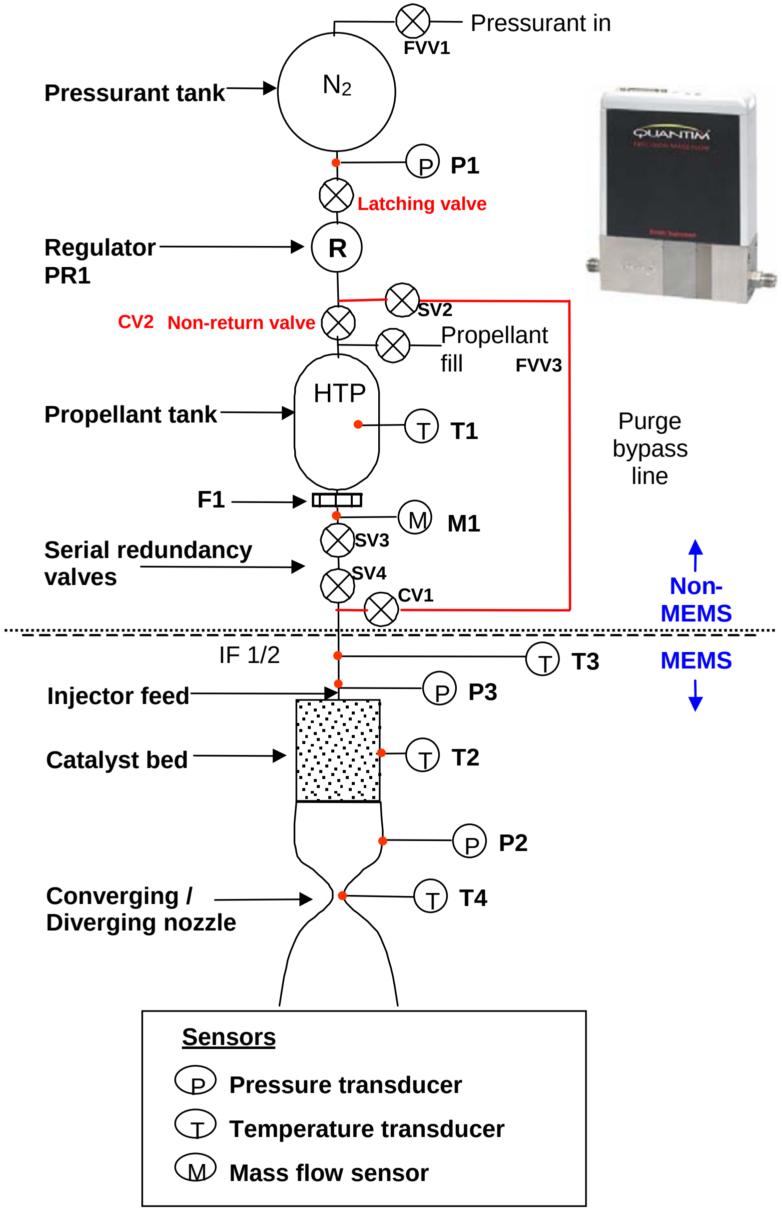
Pumps & propellant feed

- TPF (Turbo-Pump-Fed) benefit in this system.
  - Turbopumps do not provide a greatly marked benefit due to the mass of commercialy available micropumps
  - A high flow / high ΔP MEMs micro pump would be beneficial
  - Low efficiency of rotary turbopumps do not help
  - Overall, we lean to a pressurised/blowdown system



Critical assessment

Performance – challenges

- Leakage in vertically integrated design
- Catalyst bed performance
  - Difficult to test in a representative fashion
  - Further catalyst development needed: Durability
- The hydrogen peroxide storage issue
  - OK for short (6mo.) missions
  - Evolved O2 and diluted H2O2 concentration for longer missions
  - Initial support from BNSC to develop low cost HTP storage tank with permeable liner
  - ESA Green propellants programme
- Performance figures
  - 375°C for 100s achieved – once only: *c*, Isp and Thrust not measured*
  - 400°C achieved with silver gauze – larger effective surface area (rougher)

Is MEMS the best way forward?

- Vertically integrated architecture does not lend itself well to mass production
  - Due to requirement to stack numerous layers together
- Conventional feed system does not enable benefits of microthruster to be realised
  - Additional development required (pumps, valves, tanks)
- Was the H_2O_2 propellant the best choice?
  - Alternatives were (less mature) ADN, HNF, HAN, or catalysed N2O.
- Is this competitive
  - Probably not yet – potential is there

Cost:

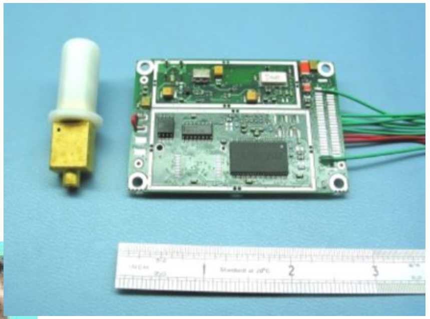
- 600kEuro to date
- Parallel programme (Mechatronic)
- 120kEuro CCN to
  - Refine, model and mfr. Integrated assembly
  - Test, analyse, validate model
  - Reanalyse market and plan further development
- CCN takes us to TRL4
- Estimate further 600-1000kEuro to raise to TRL6

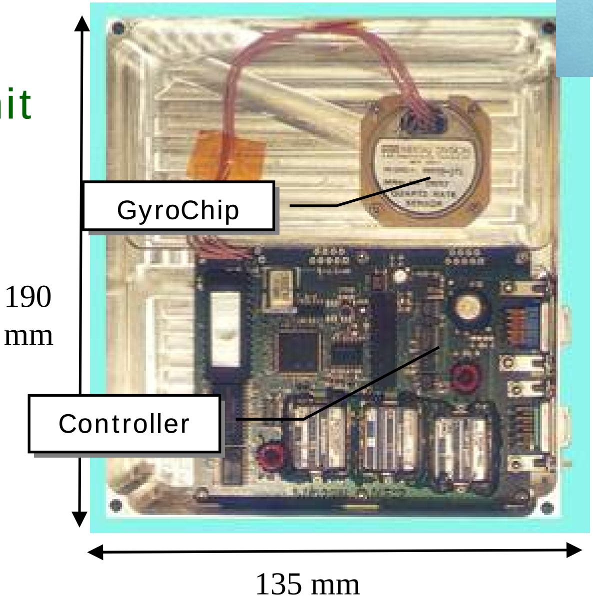
MEMS INERTIAL SENSING

Miniature AODCS at SSTL

- Attitude
  - Precise attitude system
  - Attitude propagation
  - Fast open loop manoeuvres
  - Single or multiple axis system
  - Compatible with low cost
- Heritage
  - UoSAT-12 (QRS-11)
  - BILSAT (SIRRS-01)
  - 6 more QRS-11 on GSTB-V2/A
- Details
  - Based on SSTL interface unit
  - CAN interface
  - Raw 28V supply
- Specifications
  - ±50°/s range
  - 0.02°/s resolution
  - 0.002°/s drift
  - >60Hz Bandwidth

- GPS
  - SGR-05U (Cost:)
  - Compact, COTS based surface mount PCB
    - Limited by antenna size.
    - Limited drive to reduce size further
  - 20g, 0.5W
  - Multiple antenna for orientation





UoSAT-12 gyro and controller

Why (MEMS) gyros?

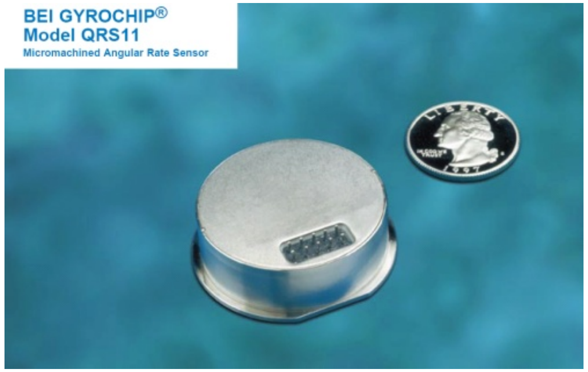
- UoSAT-12
  - Technology testing in anticipation of high resolution imaging missions
- BILSAT
  - Agility requirement requested by customer for high resolution and hyperspectral imaging
- GSTB-V2/A
  - Detumbling
  - Low performance sufficient
  - Low cost paramount, BOL useage only

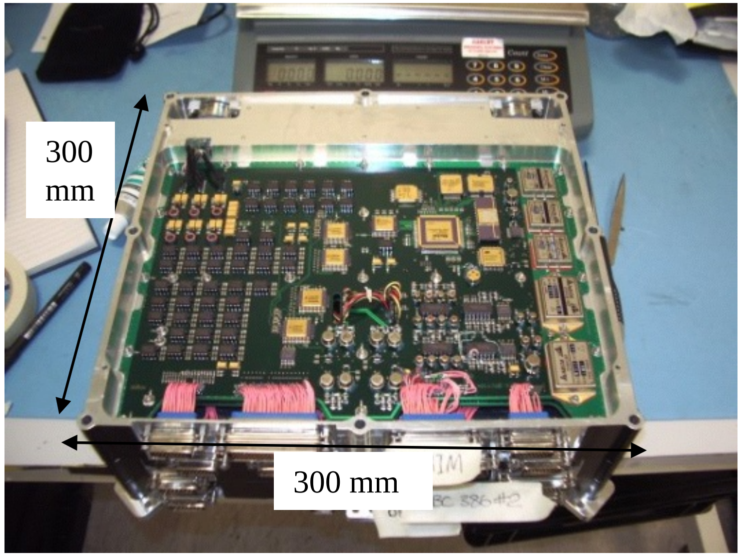
GSTB	Spec.	Actual
Rate Noise	0.005 deg/s	
Max. bias	<0.25deg/s	
Initial drift	<216 $deg/hr^{3/2}$	
Steady bias drift	<20 $deg/hr^{3/2}$	
Range	±10 deg/s	> ±50 deg/s
Mass	< 400g (6)	<240g
Power	2.4W for 3	<1.2
Lifetime	27 mth MEO	TBD

MEMS Gyros selected

- BILSAT: BAe SIRRS-01

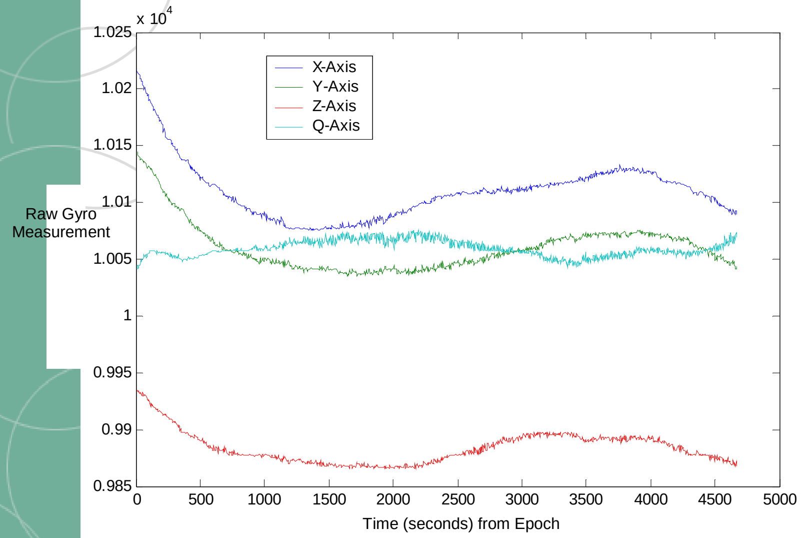
- GSTB: Systron Donner QRS-11



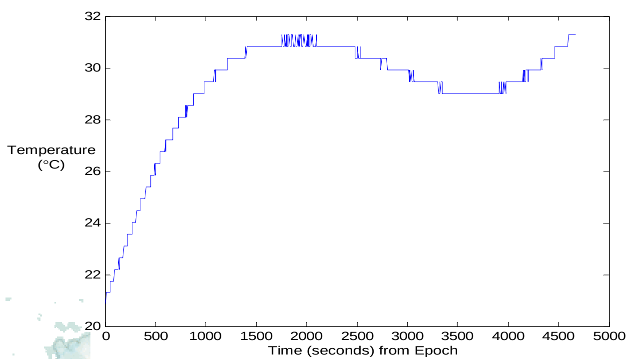


BILSAT flight data

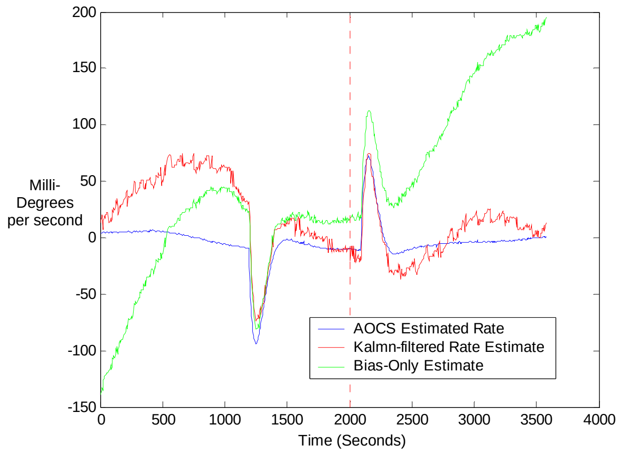
- Initial comissioning

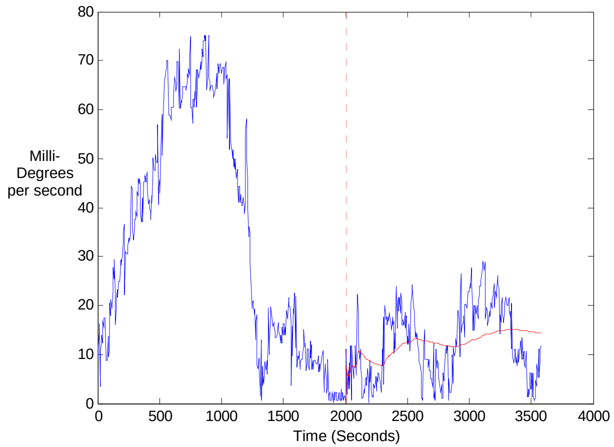


Raw output dependant on temperature variation



- Following temperature & bias compensation (Kalman filtering)

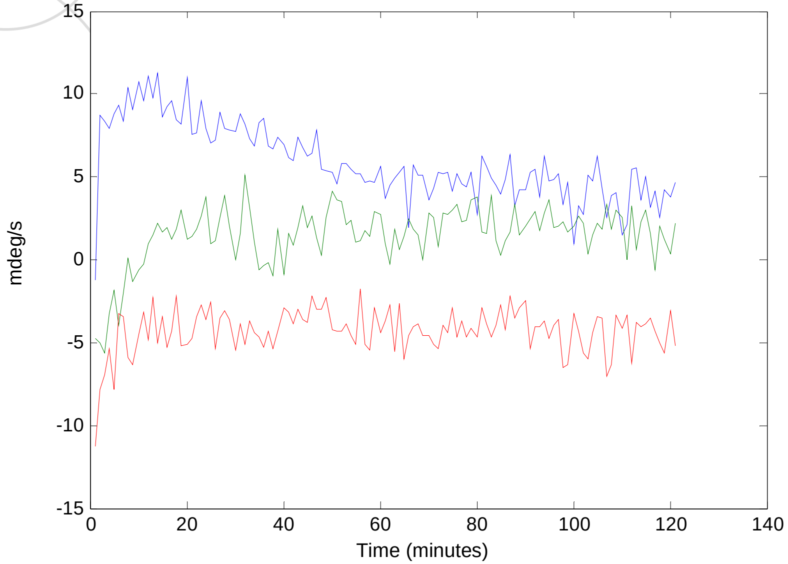




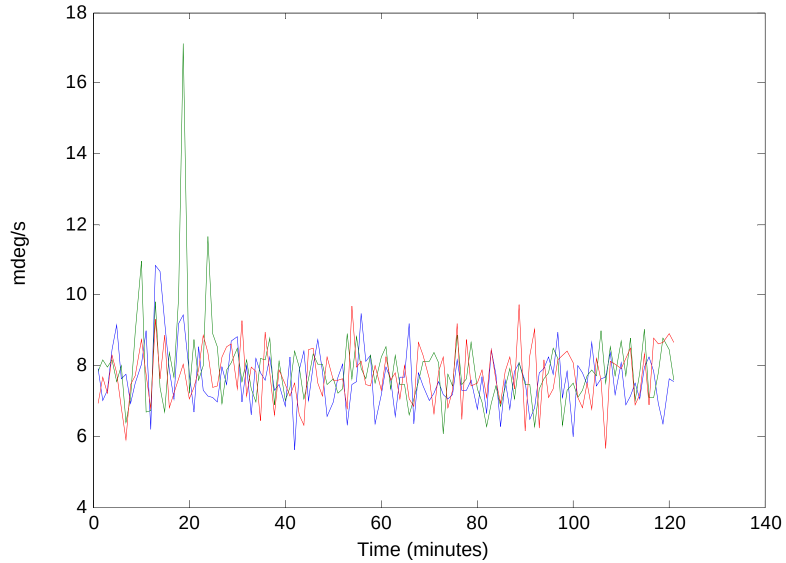
X, Y, Z axes: estimated rates using gyro outputs and temperature valid for ≥10 mins. before errors start to increase rapidly. Star Tracker updating required.

GSTB-V2/A Test Results

- Post-Thermal calibration rates and Errors



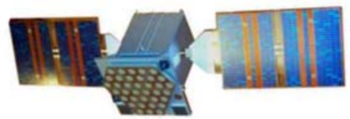
Attitude rate

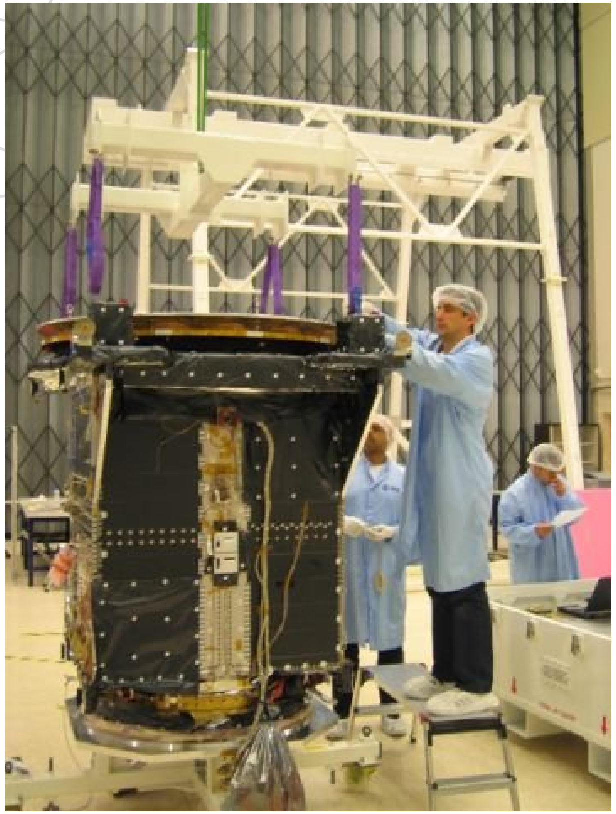


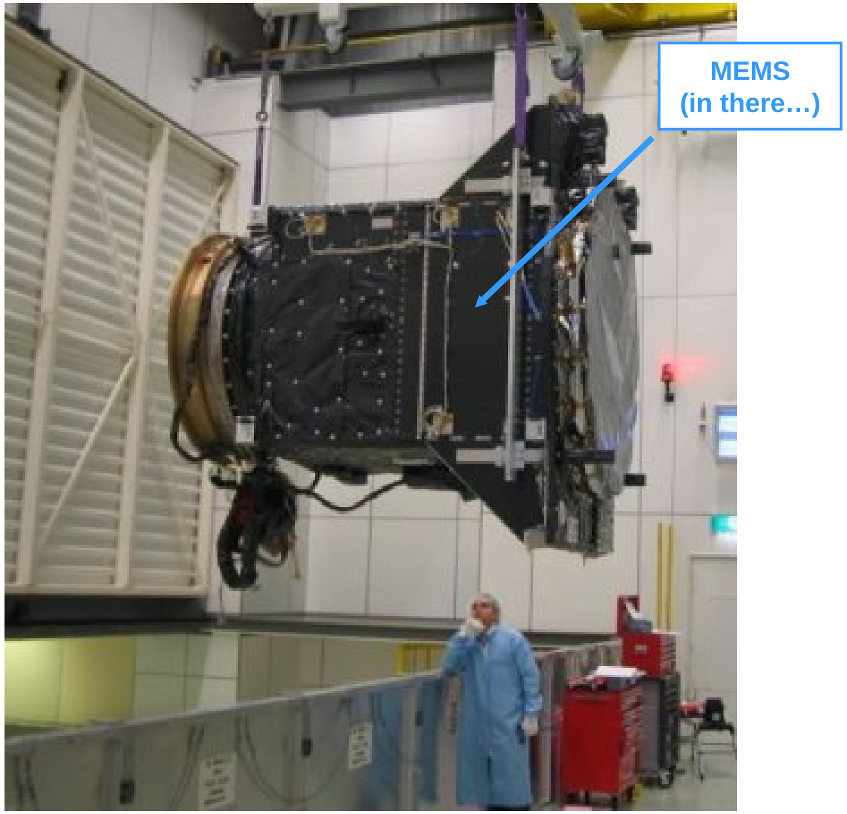
RMS Errors

GSTB-V2/A: See for yourself!

- GSTB-V2/A is currently in ESTEC Test Facility!







- Mass is certainly NOT a driver for choosing MEMS gyros

Future activities

- What is the future of MEMS ADCS at SSTL / SSC?
  - Conventional route
    - Magnetometer based for coarse /safe mode
    - Sun sensors
    - Star trackers
  - Integrated Route
    - Integrated Gyros with Star Trackers (UniNav type)
    - Added functionalities on Star Tracker
  - Performance Issues
    - MEMS gyros so far not usable for precise ADCS
    - However SSTL is considering AST+MEMS gyros baseline for Hi Res Next generation missions
- ASTC's miniaturised magnetic attitude control system
  - Minimum integration (CAN)
- Sun sensors e.g. from DTU, TNO
  - On a case by case basis

Traditional Route:
Steadily shrinking but little change in absolute cost.
Not that competitive at module (subsystem) level

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Summary

- In "production" missions, SSTL operates an ad-hoc, opportunistic, mission-based miniaturisation and use of MEMS in AOCS
- In "other" missions though, SSTL can propose flight demonstrations (see paper 03/10 from ESA 5th MNT Round Table)

- Miniaturised propulsion used successfully on SNAP
  - Augmented versions on DMC
- MEMS Gyros used successfully on UoSAT-12, BILSAT
- MEMS gyros (others) to be used on GSTB-V2 in 2 months' time

- MEMS gyros use in Hi Res pointing in R&D
- Kick motor in R&D, critical assessment continuing
- SSTL considering AST/Gyros integration

- Possibilities to test MEMS AOCS components on-board SSTL S/C