IMPRS Lectures on SPACE INSTRUMENTATION

4 – 7 December 2006
MPS , Lindau :

Space Instrument Development

Hermann HARTWIG , MPS

After winning the proposal selection

it usually takes about 8 years for a major instrument up to launch .

Examples :

SOHO (ESA solar cornerstone mission)

instrument selection : 1988 ⇨ launch : Dec 1995

ROSETTA (ESA planetary cornerstone mission)

instrument selection : 1995 ⇨ launch : Mar 2004

W H Y ?

Commercial off-the-shelf (COTS) instruments usually will not work for space because they

- are too heavy
- will not survive the launch loads
- will stop functioning under space conditions:

space is a very hostile environment !

A closer look at :

- mass : why it is important

SOHO :	scientific instruments accumulated	= 610 kg
	spacecraft mass at launch	= 1850 kg
	launcher mass	= 237 500 kg
	launch cost ATLAS II AS	= 72 000 000 €
	specific launch cost for instrument :	118 000 €/kg
ROSETTA:	scientific instruments accumulated	= 186 kg
	spacecraft mass at launch	= 2900 kg
	launcher mass	= 760 000 kg
	launch cost ARIANE 5	= 100 000 000 €
	specific launch cost for instrument :	537 634 €/kg
	[for comparison : price of gold (Au) :	17 500 €/kg]

A closer look at :

- **launch loads :** why they are important

  for smaller experiments the Design Loads can be as high as 60 x gravity (60g)

  for larger experiments (> 50 kg) still 25 x gravity

  Design must have : low mass ; high strength !

- **hostile space environment**
  - high vacuum
  - zero-g
  - radiation (electromagnetic & energetic particles)
  - very low temperatures

examples for unusual effects in space environment :

- high vacuum cleans metallic surfaces ⇨ cold welding of moving part
  design shall avoid metal-to-metal contacts !
- usual liquid lubricants evaporate in vacuum ⇨ bearings seize
  use vacuum-compatible dry lubrication films !
- energetic particles passing through semiconductor devices create charge clouds ⇨ bit flips in memory cells
  implement hardware error correction scheme into design !

  or –worse- create conductive channels in insulating layers between power conductors ⇨ self-sustaining short circuit (latch-up effect)
  implement latch-up protection circuits into design !
- high vacuum : no convective cooling for electronics ⇨ electronics overheat
- zero gravity : standard heatpipes don‘t work ⇨ “
  careful design of conductive/radiative heat transfer !
- high vacuum : outgassing of organic materials; EUV “cracking“ of molecular deposits on cold surfaces (detectors, optics) ⇨ carbon black blinding
  careful material selection ; cleanliness control program !

For all these reasons

- space instruments are custom-designed one-of-a-kind items
- building these unique instruments follows a universal pattern :
  - staged development with milestone peer reviews
  - succession of models with increasing complexity and level of detail

Instrument Development Cycle : overview

- Preliminary Design (Phase A), ends with:
  - Preliminary Design Review (PDR)
  - hardware delivery : STM Structural / Thermal Model
- Detailed Design (Phase B) , ends with:
  - Critical Design Review (CDR)
  - hardware delivery : EM Electrical or Engineering Model
- Flight Hardware Manufacturing (Phase C)
- Assembly/Integration/Verification - AIV (Phase D) ,
  - optional with mid-term Test Readiness Review (TRR); ends with :
  - Flight Acceptance or Pre-Shipment Review (FAR / PSR)
  - hardware delivery : FM (Flight Model(s))

A : Preliminary Design Phase :

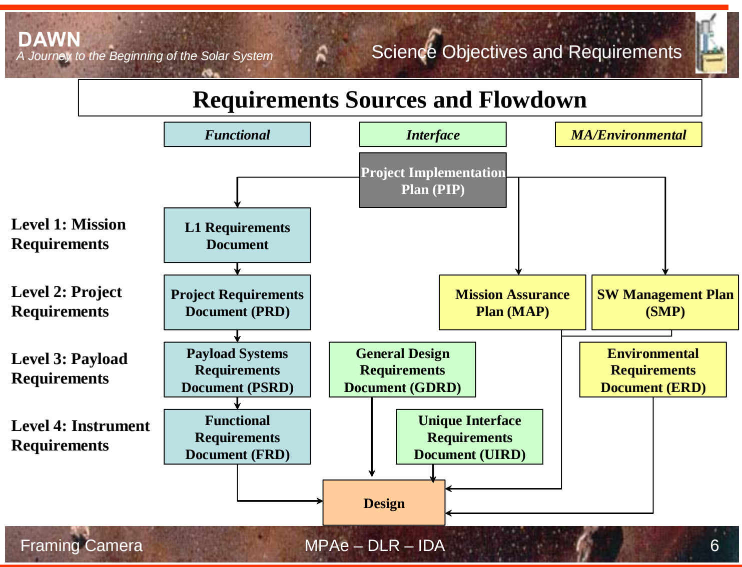
- establish requirement flowdown : from mission requirements to payload requirements to instrument functional requirements to instrument specification
- allocate mass and power budgets to subsystems
- define mechanical and electrical interfaces between subsystems

  (e.g. form factors for PCBs, connector types and arrangement etc)
- determine dimensions, volumes, shapes ;
- write specifications / RFQ for subsystems, that will be subcontracted to industry
- assemble STM (form, fit, no functions) = mass and thermal “dummy“

- ⇨ Preliminary Design Review ; STM delivery

example:

requirement flowdown diagram for DAWN Framing Camera



B : Detailed Design Phase :

- define / select materials and processes
- design parts , select components
- write basic operational code / software
- generate mathematical models for:
  - structural analysis (Finite Element Model)
  - thermal analysis

  validate models and pass on to S/C contractor (to be included into their global model)
- perform Failure Modes, Effects and Criticality Analysis (FMECA)
- assemble EM (no form, no fit, but all functions; components not space rated); verify functionality and interfaces (power / command & telemetry)

- ⇨ Critical Design Review ; EM delivery

Example :

design reviews :

Agenda for the

Critical Design Review

Framing Camera DAWN mission

DAWN
Framing Camera (FC)
Critical Design Review - CDR
May 18 & 19, 2004

MPAe, Katlenburg-Lindau, Germany

Tuesday May 18, 2004

09:00 Welcome and Introduction – H. U. Keller
09:10 Goal of the Meeting – D. Norris
09:20 DAWN Project Status – C. Russell
09:30 Overview FC – Science Objectives and Requirements - H. U. Keller
09:50 FC Team Organigram and Top Level Workpackages – H. Sierks
10:00 Instrument Concept and Implementation – H. Hartwig
10:15 **Coffee Break**

Camera Head
10:30 Optical Design – H. Mosebach/K-T
10:45 Lens System, Filters, Baffle and related Analysis – H. Mosebach/K-T
11:00 CCD and Front End Electronics – S. Mottola
11:20 Front Door Mechanism and Fail Safe Mechanism - H. Hartwig
11:30 Filter Wheel Mechanism – H. Hartwig

11:45 Discussion
12:00 **Lunch Break**

Electronics Box
13:00 Electrical Interfaces Block Diagram & Grounding Concept – I. Hajja
13:10 Data Processing Unit and Mass Memory – H. Michalik/IDA
13:30 Power Converter Unit – R. Enge
13:45 Mechanism Controller Unit – W. Kuehne
14:00 Housekeeping Data Acquisition – I. Hajja

14:15 FC Heater Concept - H. Sierks

Resources
14:30 Power Breakdown – H. Sierks
14:40 Mass Breakdown – H. Hartwig
14:50 MICD & Accommodation – H. Hartwig

15:00 **Coffee Break**

Instrument Modelling
15:15 Structural Design – H. Hartwig
15:30 Thermal Design – H. Hartwig with H. P. Schmidt/DLR

Software
16:00 Low Level Software - H. Michalik/IDA
16:10 Operation Software – H. Michalik/IDA

16:30 EGSE Configuration and Software – H. Michalik/IDA
16:45 EM demonstration run in room 51-40

Wednesday May 19, 2004

09:00 Model Philosophy and Schedule – H. Sierks
09:20 Qualification Approach and Environmental Test Matrix – H. Sierks
09:30 QA Approach and Status – M. Richards
09:45 Operations Plans – P. Gutierrez
10:00 Calibration Plans – K. Schneider
10:15 **Coffee Break**
10:30 FC Data Processing Approach – R. Jaumann
10:50 Risk Mitigation Plan – H. Sierks
11:00 Review of PDR RFAs – H. Sierks
11:30 Discussion
12:00 **Lunch Break**
13:30 Board Summary, Action Items, and Wrap-up
17:00 Adjourn

Splinter Meetings as required.

Board Members:

Dave Norris (Chairman)
Fred Vescelus
John Schloe
F. Gliem
K. Wilhelm

Attendees List:

UCLA
Chris Russell
Steve Joy

JPL
Ed Miller
Betina Pavri
Khanara Ehlers
Paul Hesse
Carol Polanskey
Jerry Dalton

Orbital
Mike Violet

MPAe

Example :

structural mathematical model

Finite Element Analysis

Framing Camera on the DAWN mission

Finite Element Analysis : Modelling

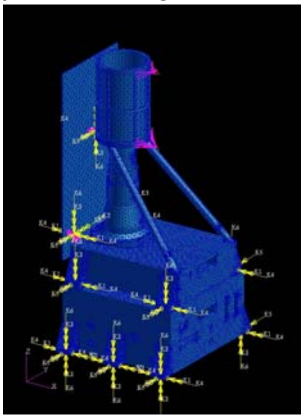
model anlyzed with :
- MSC NASTRAN

pre-/post-processing with :
- MSC PATRAN

element type used :
- TET10(3D)

element size :
- 4mm global edge length,
- smaller in critical areas

model size :
- 153 715 elements
- 288 605 nodes
- 78 spring elements
- 22 multi-point constraints

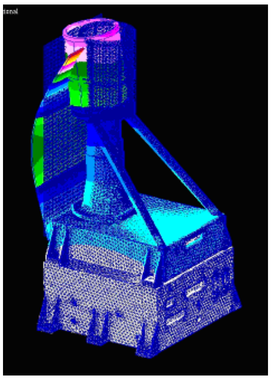


Example:

Finite Element Analysis cont'd:

Finite Element Analysis : Dynamics : 3rd Eigenmode

Mode Nr.	Frequency in [Hz]	Remarks
1	353.48	bending of mainly the radiator but also the baffle around y-axis
2	377.18	swinging of tubus/baffle in y-direction (and bending around x-axis)
3	414.42	swinging of tubus/baffle in x-direction (and bending around y-axis)
4	447.40	bending of the radiator around z-axis
5	670.00	longitudinal vibration of the structure in z-direction
6	737.16	bending of the baffle around y-axis
7	813.82	local vibrations
8	937.80	2nd mode for swinging of tubus/baffle in y-direction
9	990.14	longitudinal vibrations in z-direction
10	1049.16	bending of radiator around y-axis



Example :

thermal mathematical model

Finite Difference Analysis

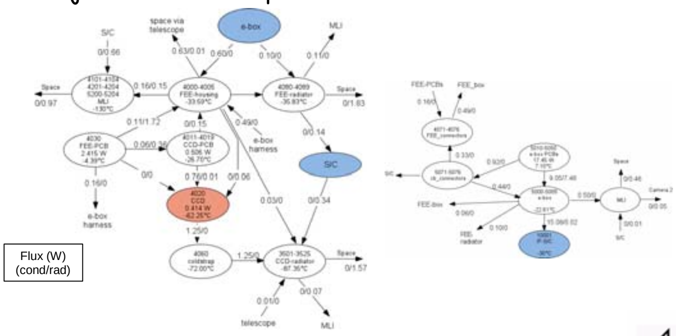
(ESATAN/ESARAD)

Framing Camera on the DAWN mission

Dawn Framing Camera Thermal Control Subsystem

Steady State Analysis - Operations (continued)

- Results : cold case heat fluxes from CCD and adjacent nodes to space



H.P. Schmidt, DLR, Institute of Space Simulation - DAWN FC CDR, 2004-05-18 & 19 16 DLR

C / D :Assembly / Integration / Verification :

- **Controlled and documented flight parts production & procurement; population of Printed Circuit Boards; in Clean Room ; ESD protected etc**
- **Testing at subsystem and system level:**
  - **Functional tests , including S/C interface verification (with S/C simulator)**
  - **Performance Tests / Calibration**
  - **Environmental tests :**
    - **Vibration**
    - **Pyro-Shock**
    - **Thermal-Vacuum / Thermal- Balance**
    - **Mechanism Lifetime**
    - **Electro-Magnetic Compatibility (EMC)**
  - **Physical properties**
    - **Interface Metrology**
    - **Mass**
    - **Center of Gravity**
    - **Moments of Inertia**

Vibration testing :

simulates launch loads (structural and acoustic)

power of ARIANE-5 at launch = 30 million h-p ; acoustic pressure level ~145 dB !

Test :

on electrodynamic shaker systems: giant “loudspeaker“ coil drive , w/o membrane

sine test : swept single frequency ; control = peak acceleration

random test: wide-band random “noise“ spectrum; control = power spectral density profile

SIR-2 Sine qualification levels (TBC by ISRO)
for O-Box ; on ASS panel extension

frequency	in-plane (X and Y)	frequency	out-of-plane (Z)
5 Hz to 20 Hz	9.3 mm(0-p)	5 Hz to 18 Hz	11.5 mm(0-p)
20 Hz to 70 Hz	15 g const.	18 Hz to 50 Hz	30 g const.
70 Hz to 100 Hz	8 g const.	50 Hz to 70 Hz	20 g const.
		70 Hz to 100 Hz	15 g const.
sweep rate	2 oct/min		2 oct/min

SIR-2 Random qualification levels (TBC by ISRO)
for O-Box ; on ASS panel extension

frequency	in-plane p.s.d. (X and Y axis)	out-of-plane p.s.d. (Z axis)
20 Hz to 100 Hz	+ 3 dB/octave	+ 3 dB/octave
100 Hz to 700 Hz	0.1 g^2/Hz	0.3 g^2/Hz
700 Hz to 2000 Hz	- 3 dB/octave	- 6 dB/octave
RMS level	11.8	18.2 g

Example : **ROSETTA Lander STM** on shaker at IABG, Munich

measurement accelerometer wiring

Thermal Vacuum / Thermal Balance Test :

tests thermal behaviour in special test chambers under space conditions

(high vacuum ; cold space ; solar illumination / planetary thermal emission)

passive protective systems:

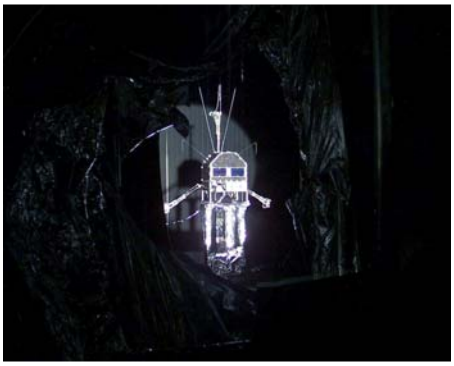
- Multi-Layer Insulation (MLI) ;
- thermal radiators / absorbers
- second-surface mirrors (reject heat against solar irradiation)

active protective systems :

- heaters (electrical or radoactive)
- coolers (Stirling)
- capillary heat pipes (zero-g)

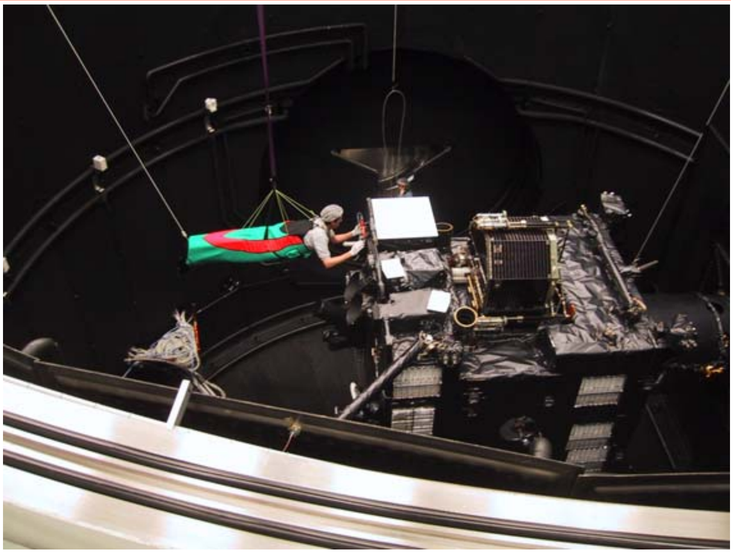
Thermal-Vacuum / Thermal-Balance Test of ROSETTA Lander

at IABG, Munich



I M P R S **Space Instrument Development** Lindau, 7 Dec 2006

ROSETTA
flight spacecraft
inside Large
Space Simulator
test chamber
at ESTEC, NL



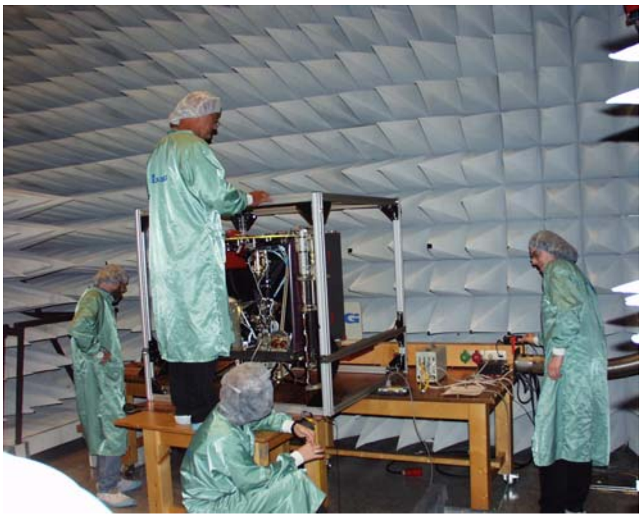
H. Hartwig #21

I M P R S **Space Instrument Development** Lindau, 7 Dec 2006

EMC testing of ROSETTA Lander at IABG, Munich:

radiated & conducted emission,

radiated & conducted susceptibility



H. Hartwig #22

SUMMARY & General Recommendations :

- Keep track of requirement flowdown !
- Assemble (and maintain!) a good technical team !
- Start design with resource margins (25% min.) !
- Take design reviews serious – they help you !
- Nurse back-up solutions along with the main development !
- Keep documentation up-to-date !
- Test – test – test !!! (but don‘t overstress the Flight Unit !)
- Hold post-delivery “Lessons Learned“ review with your team !