
**IMPRS Lectures on
SPACE INSTRUMENTATION
4 – 7 December 2006
MPS , Lindau :**

Space Instrument Development

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H. Hartwig

#1

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

WHY ?



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#2

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]
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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))

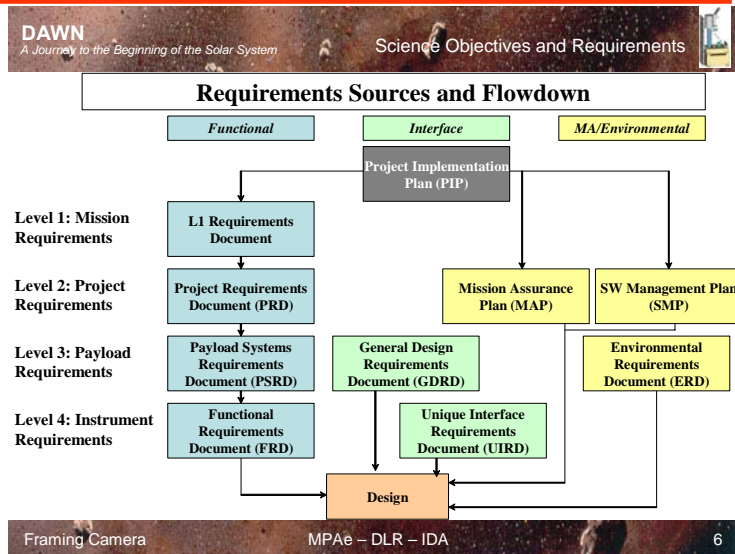


A : Preliminary Design Phase :

- **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**



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#11

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, Karlstburg-Lindau, Germany

Tuesday May 18, 2004

- 09:00 Welcome and Introductions - H. U. Keller
- 09:10 Goal of the Meeting - D. Storm
- 09:20 DAWN Project Status - C. Russell
- 09:30 Overview FC - Science Objectives and Requirements - H. U. Keller
- 09:50 FC Team Organization and Top Level Workpackages - M. Szeles
- 10:00 Instrument Concept and Implementation - H. Hartwig
- 10:15 Coffee Break
- 10:20 Camera Head
- 10:30 Optical Design - H. Miesbach I/T
- 10:40 Lens System, Filter, Baffle and Thermal Analysis - H. Miesbach I/T
- 11:00 CCD and Front End Electronics - S. Monda
- 11:20 Front Door Mechanism and Full Inlet Mechanism - H. Hartwig
- 11:30 Filter Wheel Mechanism - H. Hartwig
- 11:45 Discussion
- 12:00 Lunch Break
- 13:00 Electronics Box
- 13:10 Electrical Interfaces, Block Diagram & Grounding Concept - I. Hage
- 13:20 Data Processing Unit and Main Memory - H. Miesbach I/TA
- 13:30 Power Conversion Unit - E. Engel
- 13:40 Mechanism Control Unit - M. Kutzke
- 14:00 Housekeeping Data Acquisition - I. Hage
- 14:15 FC Science Concept - H. Szeles
- 14:20 Review
- 14:30 Power Breakdown - M. Szeles
- 14:40 Main Breakdown - H. Hartwig
- 14:50 MPAe P. Accommodation - H. Hartwig
- 15:00 Coffee Break
- 15:05 Instrument Modeling
- 15:15 Structural Design - H. Hartwig
- 15:30 Thermal Design - H. Hartwig with M. P. Schmidt-DLR
- 16:00 Software
- 16:10 Low Level Software - H. Miesbach I/TA
- 16:20 Operation Software - H. Miesbach I/TA
- 16:30 ECSE Configuration and Software - H. Miesbach I/TA
- 16:45 EM documentation via to review 03-49

Wednesday May 19, 2004

- 09:00 Model Philosophy and Schedule - H. Szeles
 - 09:10 Qualification Approach and Environmental Test Matrix - H. Szeles
 - 09:20 QA Approach and Status - M. Fickardt
 - 09:45 Operational Plans - P. Gutierrez
 - 10:00 Calibration Plans - E. Schneider
 - 10:15 Coffee Break
 - 10:30 FC Data Processing Approach - E. Jozanovic
 - 10:50 Risk Mitigation Plan - M. Szeles
 - 11:00 Review of PDR, EFA - H. Szeles
 - 11:30 Discussion
 - 12:00 Lunch Break
 - 13:30 Board Summary, Action Items, and Wrap-up
 - 17:00 Adjourn
- Splitter Meeting as required.*
- Board Members:**
- Dave Jozanovic (Chairman)
 - Fred Vandenbos
 - Saba Schaefer
 - P. Gilson
 - K. Wilhelm
- Attendees List:**
- UCLA
 - Chris Brandt
 - Steve Jay
 - DFP
 - Ed Schaefer
 - Bertina Pivotti
 - Blairney Egan
 - Paul Hesse
 - Carl Pfeiffersky
 - Jerry Dahms
 - Osbert
 - Mika Vaisala
 - MPAe



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Example :

structural mathematical model

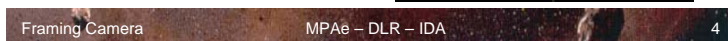
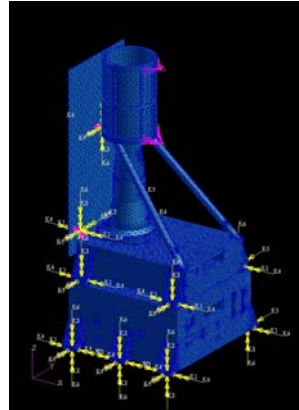
Finite Element Analysis

Framing Camera on the DAWN mission



Finite Element Analysis : Modelling

model analyzed 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



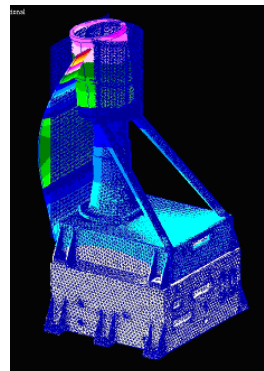
Example:

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	2 nd 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

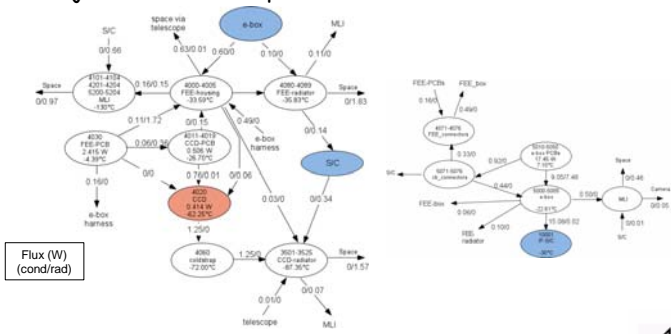


Dawn Framing Camera

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



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



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

measurement accelerometer wiring



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#18

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 :

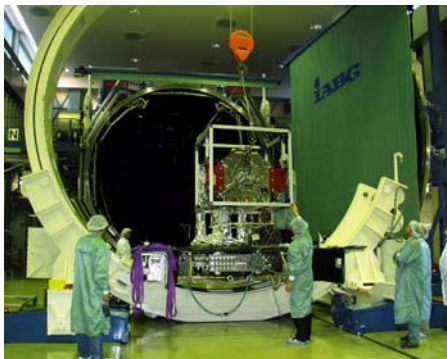
heaters (electrical or radioactive)

coolers (Stirling)

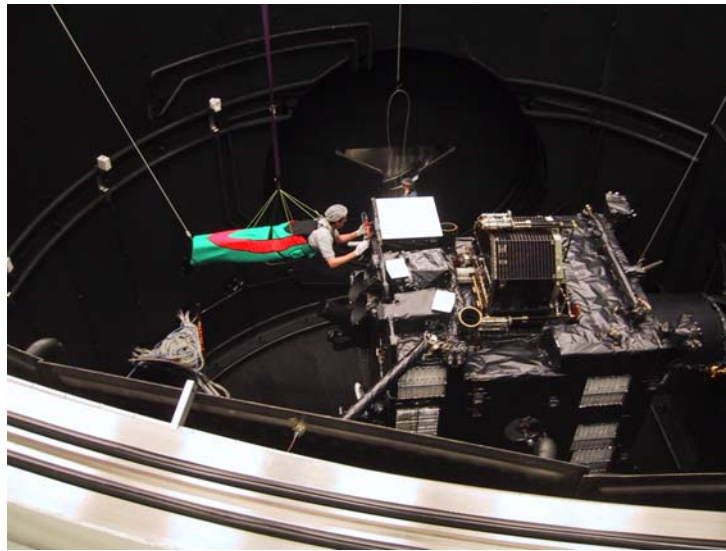
capillary heat pipes (zero-g)



Thermal-Vacuum / Thermal-Balance Test of ROSETTA Lander
at IABG, Munich



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



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#21

EMC testing of
ROSETTA Lander
at IABG, Munich:
radiated & conducted
emission,
radiated & conducted
susceptibility



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#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 !**
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