The thermal vacuum test of BEESAT-1

FUNDAMENTALS OF SYSTEM VERIFICATION

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1. THE VERIFICATION PROCESS

Verification process

Verification assures that the space system meets its specified requirements, posed in agreement with the required project life cycle. The supplier verifies the product.
[ECSS-E-10-02A]

View of the Alphasat satellite, after tests in the Intespace's anechoic test chamber, Toulouse, France, 15 March 2013
[photo: ESA, S. Corvaja, 2013]

Verification objectives

a) design qualification

b) to ensure that the product agrees with the qualified design and is free from workmanship defects and is acceptable for use

c) confirmation that the space system and staff (including tools, procedures and resources) are able to fulfil the mission requirements

d) to confirm performance parameters of the space product in or after particular steps of the project life cycle, e.g. pre-launch, in-orbit, post-landing.

Verification process cycle

1) Identification and classification of all requirements to be verified
2) Determine verification criteria (methods, level, stages) and models against identical requirements
3) Planning for verification activities
4) Inclusion of customer into verification activities
5) Determination of verification documentation
6) Performance of verification tasks and verification control
7) Completion of verification control and evidence verification close-out
8) Appraisal through the customer and final approval

Central issues to the verification process

What?	-	Project requirements
Where?	-	Verification devices, resources
How?	-	Verification methods, model- and test philosophy
When?	-	verification stages and mile stones

What? → Where? → How? → When?

Phases of the verification

The verification process is accomplished in sequential verification stages according to the life cycle existence of a space project. The classical verification stages are according to ECSS-E-10-02A (1998):

- qualification
- acceptance
- pre-launch
- in-orbit
- post-landing

There are about 40 people involved in Sentinel-1A's month-long thermal–vacuum testing programme at Thales Alenia Space in Rome, Italy.[photo:Thales Alenia Space]

2. PHASES OF VERIFICATION

Qualification

- The objective is to demonstrate **that the design fulfils all requirements including margins.**
- The qualification object must completely correspond to the „full flight design“ and the flight standard (e.g. QM, FM, PFM).
- The verification through tests at the Q-models and test excitations, which are clearly higher and take longer than the acceptance excitations.

Acceptance

- The objective is to demonstrate **that the product is free of workmanship defects and integration errors** and is ready for subsequent operational use.
- The verification takes place through tests with excitations, which are a little higher than the given and/or the expecting loads.

Pre-launch

- The verification objective of the pre-launch stage shall be to verify that the product is properly configured for launch and early operations.
- The record takes place through tests and analysis.

In-orbit

- The verification objective lies in the certification **that the product** is suitable **for the applications in real space conditions,** which cannot be fully duplicated or simulated on the ground.
- The certification takes place through in-orbit-test in supplement of ground tests.

Post-landing

- The verification objective of the post-landing stage shall be to verify **elected functions and the product status after a mission** and consequences of possible in-orbit anomalies.

Methods of verification

The verification is accomplished by one or several of the following methods (ECSS-E-10-02A (1998):

- analysis
- review-of-design
- inspection
- test

One of Hylas-1's twin solar arrays during deployment tests at ISRO Bangalore [photo: ISRO]

3. METHODS OF VERIFICATION

Analysis

= method which entails performing **a theoretical or empirical evaluation by accepted techniques.**

Such analysis techniques are:

- systematic analysis
- statistic analysis
- qualitative analysis
- modelling and simulation
- verification by similarity
  (with another already verified product)

At the analysis it is to be observed:

a) The analytic method must be already validated.

b) The analysis should be used in support of test and vice versa.

c) The tests for the support of the analysis must be implemented at a representative model.

d) The verification analysis may be based on the design analysis.

e) All boundary conditions, acceptance and test data are to be defined clearly.

f) The analysis should always contain the nominal case and the boundary case (worst case).

g) The analysis can be accomplished also according to defined similarity criterias of a product A with an already verified product B, if it is proved by the analysis that A deviates only in insignificant parameters from B.

Review-of-Design

A verification method using validation of previous records or evidence of validated design documents, when approved design reports, technical descriptions and engineering drawings unambiguously show that the requirement is met.

A validated process is a production process which is subject to the **complete and documented inspection in each partial step**, so that the product can be accepted without inspection.

Inspection

The inspection is a verification method, which is characterized by the visual determination **of physical characteristics** of an object to be verified. The inspection is to

- determine the agreement of the examined hardware or software with the appropriate documentation. (e.g. test reports, protocols etc.)
- be accomplished together with quality assurance measures during the process of integration and fabrication,
- and/or can be accomplished in supplement of the validation (Review-of -Design).

Test

The test is a verification method of requirements by **measurement of product properties or – functions under different** simulated **site conditions.**

The test can include the demonstration of qualitative operating properties and requirements.

A distinction is drawn between the following types of test:

a) development test
b) analysis validation test
c) qualification test
d) acceptance test

a) Development test

Objectives: investigation of new developments, demonstration of the **suitability of new design concepts**

Implementation: test of development model and/or breadboards concerning certain characteristics

Application: only new developments

b) Analysis validation test

Objectives: winning of data to **validation or improvement of the mathematical models**.

Implementation: model test in the flight standard with low test excitations and shortened effect duration

Application: determination of the natural frequency and the resonance modes for validating the FEM model determination of temperatures and limit values for validating the mathematical thermal model etc.

c) Qualifications test

Objectives: demonstration and **validation of the flight suitability of the design and/or the construction** for the required launch and space environment

Implementation: test of an individual model in the flight standard with increased test excitations and higher short effect durations

Application: each new developed hardware

d) Acceptance test

Objectives: validation that the **flight model** fulfils all requirements and is **free from workmanship defects**

Implementation: flight model test with test excitations similar like expected loads, but shorter time

Application: each flight model (instrument, satellite), critical mechanisms, components, structures, etc.

Typical qualification test levels and test duration

Table 1: Qualification test levels and durations

Test	Levels		Duration	
	Equipment	Space element	Equipment	Space element
Shock	+6 dB [a]	N/A	3 shocks in both directions of 3 axes	3 activations of explosive firing
Acoustic	+4 dB [a]	+3 dB	2 min [b]	2 min [b]
Vibration	Random/Sine: +4 dB	Random/Sine: +3 dB	Random: 2,5 min per axis [b] Sine: 2 octave/min 1 sweep up and down (5 Hz–100 Hz)	Random: 2 min per axis [b] Sine: 2 octave/min (5 Hz–100 Hz) (notching, if necessary)
Thermal cycling	10 °C extension of maximum and minimum predicted temperatures [a]	10 °C extension of maximum and minimum predicted temperatures [c]	8 cycles	8 cycles
Thermal vacuum	10 °C extension of maximum and minimum predicted temperatures [a]	10 °C extension of maximum and minimum predicted temperatures [c]	8 cycles if combined with thermal cycling, 1 cycle if thermal cycling is performed	8 cycles if combined with thermal cycling, 1 cycle if thermal cycling is performed
EMC	+6 dB EMC safety margin		depending on operating modes	
Static/acceleration	1,25	1,25	100 s + 50 s per mission	Sufficient to record test data
Pressure	1,5 (proof), 2 (burst)	1,5	5 min (3 cycles for valves) only for proof	5 min (3 cycles)
Life	N/A (margins only for accelerated tests)		4 times operating life	

[a] If the equipment qualification is carried out for multi-project utilization standard spectra or temperature limits can be used.

[b] Duration is dependent on the number of missions.

[c] Suitable distribution of the flight delta temperature for equipment is used, i.e. temperature limit is reached as soon as one unit in a selected area is at the hot and cold temperature reached during the unit qualification thermal testing.

[ECSS-E-10-02A (1998)]

Typical acceptance test levels and test duration

Table 2: Acceptance test levels and durations

Test	Levels		Duration	
	Equipment	Space element	Equipment	Space element
Shock	Maximum expected shock spectrum	N/A	1 shock in both directions of 3 axes + dwell and burst tests	1 activation of explosive firing
Acoustic	Envelope of maximum expected acoustic spectrum		2 min	1 min
Vibration	Random: Envelope of maximum and minimum expected spectrum [a]	Random: Envelope of maximum and minimum expected spectrum [a]	Random: 2 min per axis	Random: 1 min per axis
Thermal cycling	5 °C extension of maximum and minimum predicted temperatures [b]	Flight temperature [c]	4 cycles	4 cycles
Thermal vacuum	5 °C extension of maximum and minimum predicted temperatures [b]	Flight temperature [c]	4 cycles if combined with thermal cycling, 1 cycle if thermal cycling is performed	4 cycles if combined with thermal cycling, 1 cycle if thermal cycling is performed
Pressure	1,5	1	5 min (only one cycle)	Sufficient to establish leakage

[a] For random acceptance test spectrum see 4.8.1.3 d.
For the equipment, the minimum spectrum is the acceptance vibration test (AVT) spectrum having no relation with the expected mission and derived from experience on several projects.

[b] If the equipment acceptance is carried out for multi-project utilization standard spectra or temperature limits can be used.

[c] A suitable distribution of the flight delta temperature for equipment is used, i.e. temperature limit is reached as soon as one unit in a selected area is at the hot and cold temperature reached during the unit acceptance thermal testing.

[ECSS-E-10-02A (1998)]

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Sequence of the test types

Development tests	To confirm the new developed design concept
↓	
Qualification tests	To confirm the detailed design for the flight models construction
↓	
Acceptance tests	To verify flight models manufacturing process

4. LEVELS OF VERIFICATION

Verification levels

~ correspond to the hardware nomenclature:

Piece parts: individual parts like e.g. circuits, screws, cables, case, plugs, materials

Component: complete functional unit, like e.g. power control unit, star camera, battery

Subsystem: all of the piece parts and components, which comprise a functional subsystem, e.g. thermal control system, power supply etc

System: complete spacecraft, consisting of several subsystems and instruments

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Verification level and prevailing methods

Piece Parts	validation, inspection
Component	validation, inspection, partial test,
Subsystem	analysis, test, inspection, review
System	analysis, test, inspection, review

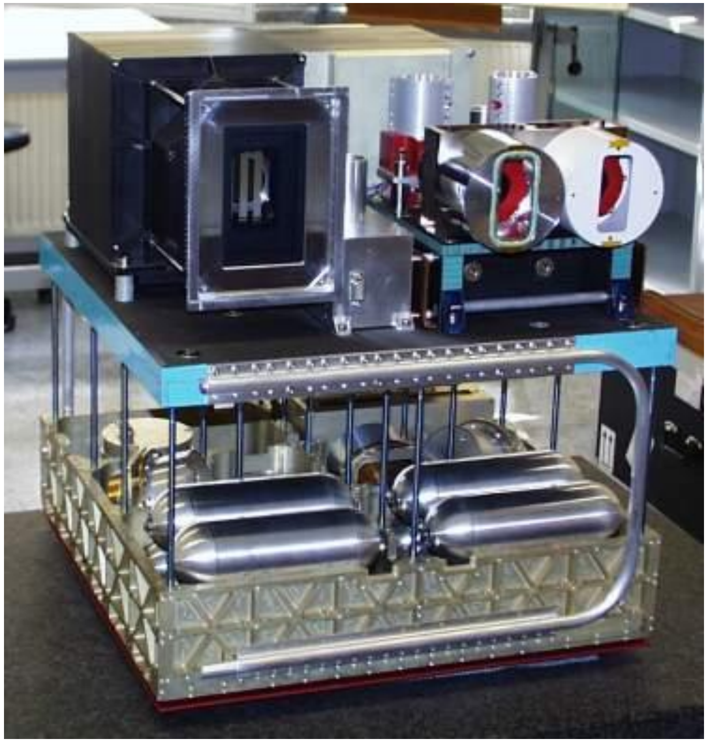
5. MODELS FOR VERIFICATION

Models for verification: Mock Up (MU)

Purpose:
- interface optimization and validation
- validation of integration process
- accommodation control
- architecture analysis
- human factor evaluation
- assessment of operation procedures

Representation:
- geometrical configuration, layouts, interfaces

Application:
- accommodation analysis
- manufacturing and assembly analysis
- parabolic flight



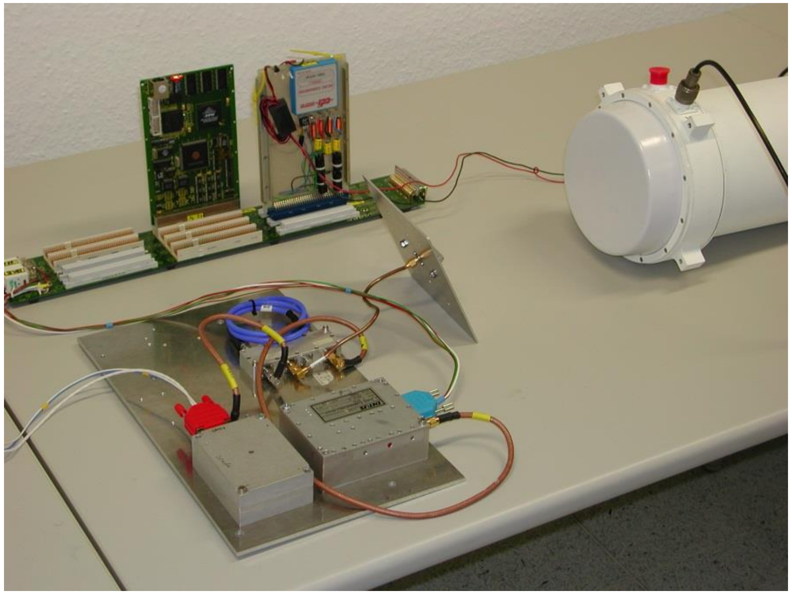
BIRD Mock up to STM validation and accommodation analysis [Photo: DLR]

Development Model (DM)

Purpose:	- development support
	- confirmation of the design feasibility
Representation:	- the selected to be tested functions, e.g. mechanical, electrical, thermal or other functions (controls, controllers, software etc.),
	- size, shape and interfaces do not have to be representative necessarily.
Application:	- development tests
	- all verification levels
Designations:	breadboard, breassboard, control bench

Suitcase Model

Purpose:	hardware simulation of the communication subsystem compatibility tests with all ground stations interface tests failure mode analysis
Representation:	complete functionality of the flight model size, shape and interfaces are representative.
Application:	compatibility tests with all ground stations all qualification tests on component level and on system level
Designations:	suitcase model, breass board, RF bench



Suitcase model of the BIRD satellite and S-band antenna feed of the ground station [photo: DLR]

Structural Model (SM)

Objective:	- structure qualification - FEM validation
Representation:	- flight standard regarding the structural parameters - structure dummies
Application:	- qualification test

Thermal Model (TM)

Objective:	- qualification of the thermal design - Validation of the thermal mathematical model
Representation:	- flight standard regarding thermal parameters - thermal dummies
Application:	- subsystem level (thermal control system) - partial system level - qualification tests

Structural Thermal Model (STM)

Objective:

- SM & TM objectives

Representation:

SM & TM representatives

- structure/thermal model

Application:

- system level
- qualification test

BIRD STM on PSLV-C3-upper stage for vibro tests [Photo: ISRO]

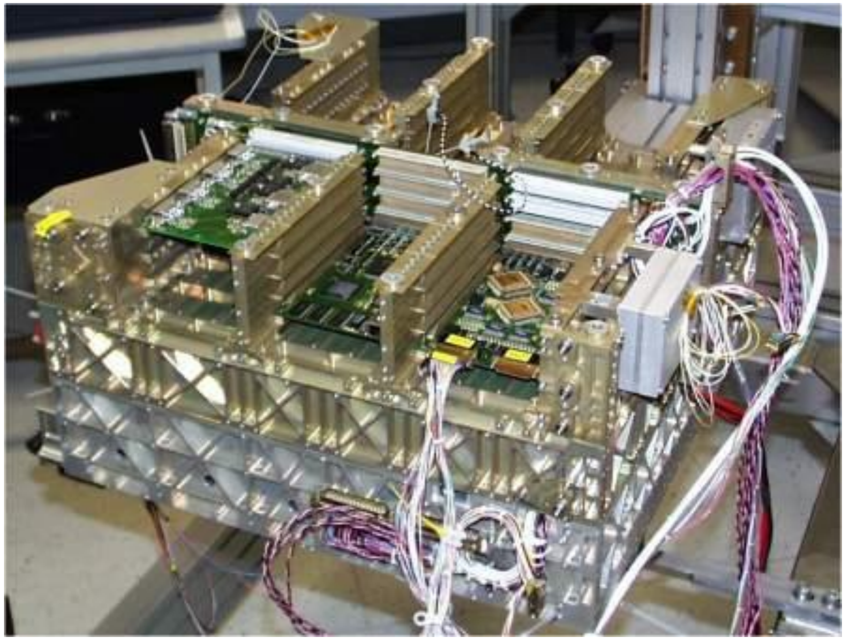
Engineering Model (EM)

Objective:
- functional qualification of the fault tolerance
- demonstration & parameter drift control

Representation:

- flight representative in form fit function
- flight model design without redundancy and hi-rel parts

Application:
- all levels
- partial functional qualification tests



BIRD EM after removing of the STM [Photo: DLR]

Qualification Model (QM)

Objective: - design qualification
Representation: - full flight design and flight standard
Application: - components level
- subsystem level
- qualification tests

Engineering Qualification Model (EQM)

Objective: - functional qualification of the design & I/F
- EMC certification
Representation: - full flight design
- MIL or commerce. parts from the manufacturer of the high.-rel parts
Application: - all levels
- functional qualification tests

Flight Model (FM)

Objective:	- flight application
Representation:	- full flight design & flight standard
Application:	- all levels
	- acceptance tests

Flight Spare Model (FS)

Objective:	- flight spare for flight application
Representation:	- full flight design & flight standard
Application:	- ground checks
	- acceptance test

Protoflight Model (PFM)

Objective:
- flight application and
- qualification of the design

Representation:
- full flight design & flight standard

Application:
- all levels
- prototype qualification test

BIRD (P) FM at the fitting of the MLI [Photo: DLR]

6. MODEL PHILOSOPHIES

Model philosophies

- model philosophy must be configured to product requirements
- a distinction is drawn between 3 different philosophies for satellites:

- Prototype Model Philosophy
- Protoflight Model Philosophy
- Hybrid Model Philosophy

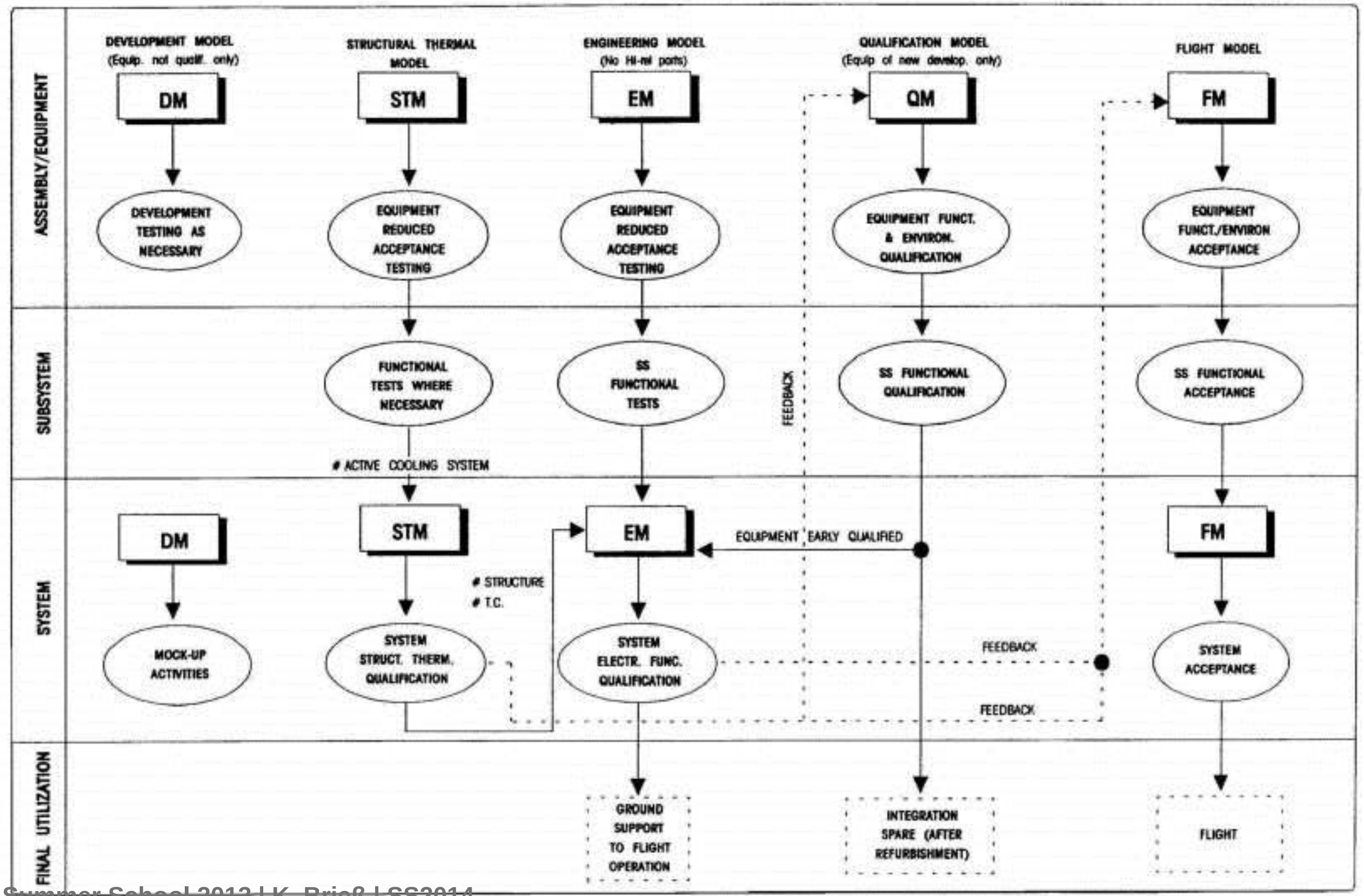
Prototype model philosophy

- extensive model development up to the FM
- minimization of the risk
- for new and or complex systems
- for deep space missions

- Advantages:
- low risk
- parallel activities at different models
- closing of the qualification activities before final approval
- usage possibility of QM or EQM as integration flight spare

- Disadvantages:
- high costs

Prototype model philosophy

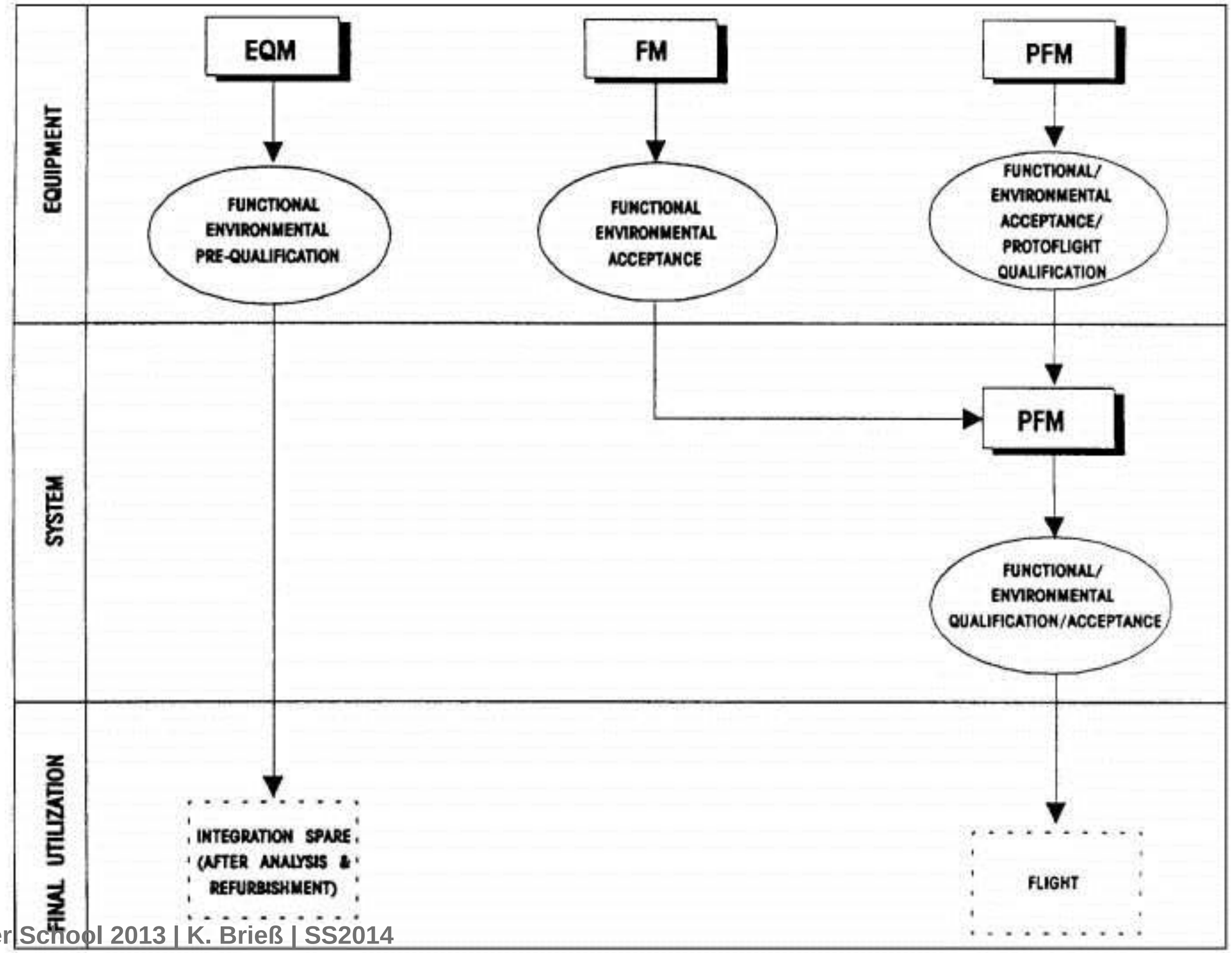


[ECSS-E-10-02A (1998)]

Protoflight model philosophy

- design qualification without critical assemblies
- minimization of model costs
- The pure „protoflight approach “ is based on a single model (protoflight model), which flies after the protoflight qualification and acceptance test campaign.
- for systems with few critical technologies
- extensive use of qualified hardware
- Compromise between costs and risk
- Advantages:
- low costs
- Disadvantages:
- increased risk
- serial activity flow on the same model
- contextual qualification and acceptance tests
- no integration spares

Protoflight model philosophy



[ECSS-E-10-02A (1998)]

Hybrid model philosophy

- compromise between Prototype and Protoflight approach
- minimum compromise between costs and risk
- parallel activities at different models possible
- EQM as flight spare would be nice
- use of commercial components, but also MIL or High-Rel components, if it is applicable from cost point of view
- configured to individual mission requirements

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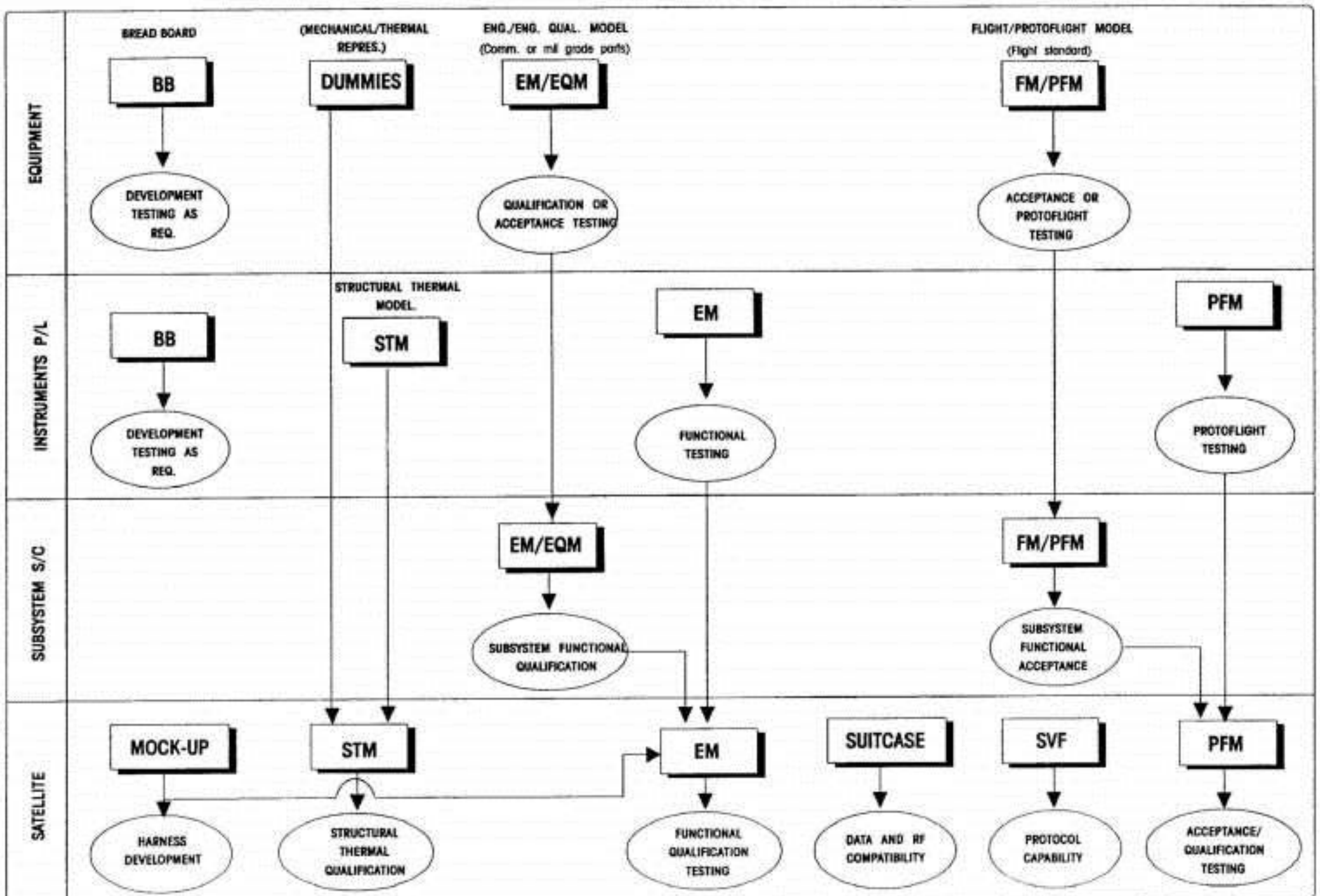
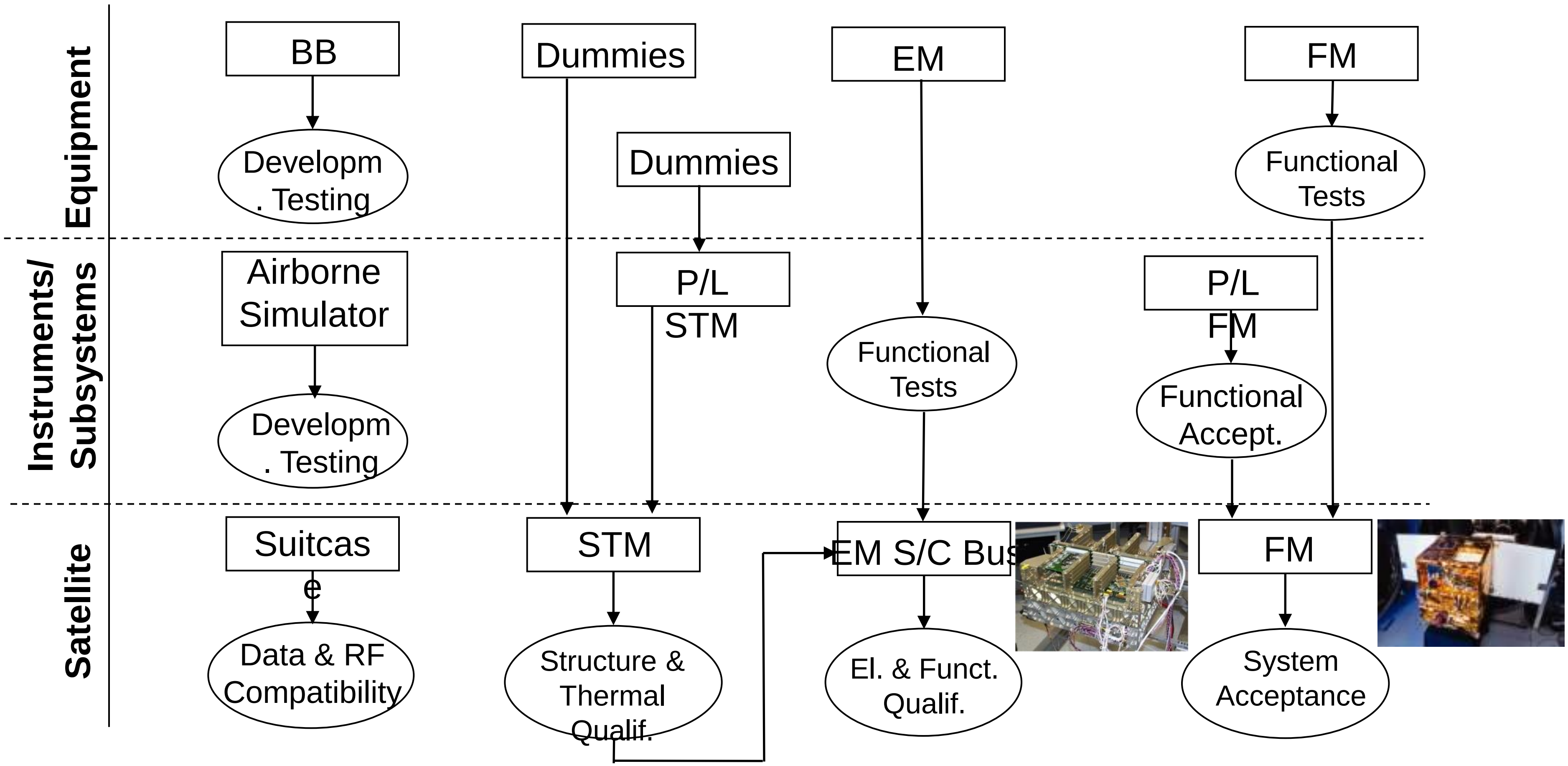
Hybrid model philosophy



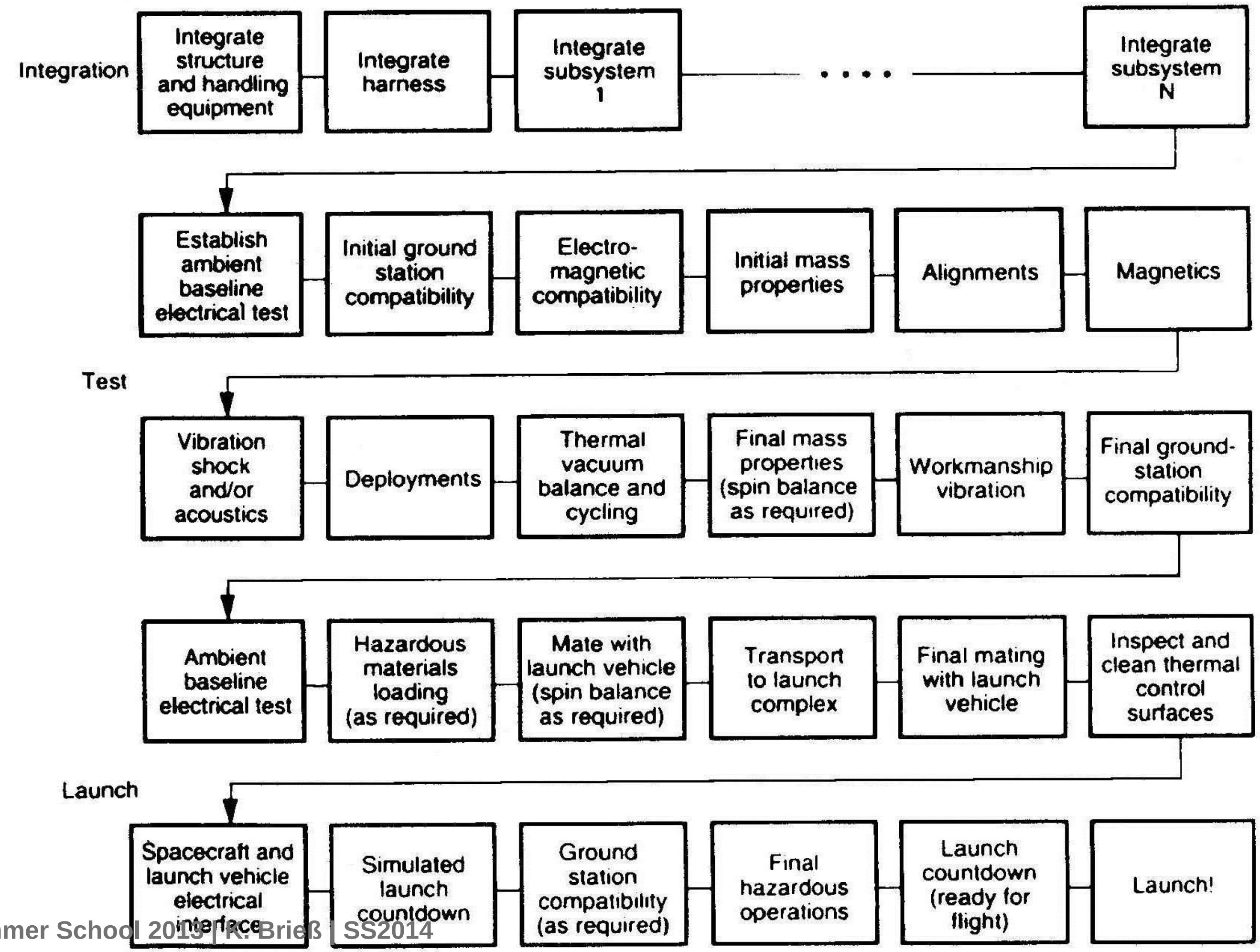
[ECSS-E-10-02A (1998)]

Example: hybrid $2^{1}/_{2}$ model philosophy BIRD



7. TYPICAL INTEGRATION AND TEST SEQUENCE

Typical Integration and Test Sequence



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9. Literature

ECSS-E-10-02A	ECSS-E-10-02A Space engineering . Verification. - 1998
ECSS-E-10-03A	ECSS-E-10-03A Space engineering . Testing. – 2002
Pis94	Pisacane, Moore, Fundamentals of Space Systems, 2005
Ber04	Berlin, Peter, Satellite Platform Design, Kiruna, 2004
For03	Fortescue, P., Stark, J., Swinerd, G., Spacecraft System Engineering, Chichester, 2003
Lar99	Larson, Wiley, Wertz, James, Space Mission Analysis and Design, Dordrecht, 1999