THE ISOCAM STRATEGY FOR IN-FLIGHT CALIBRATION

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ABSTRACT

Many factors combined in order to form the ISOCAM in-flight calibration strategy : (a) the history of the mission development and the evolution of the ground segment design; (b) the approach to planning and organising the work of the Instrument Dedicated Team (IDT) and the tools available to do the work; (c) the preparation of the in-flight calibration command sequences, including the approach to pre-flight testing and simulation of the sequences (distinct from the mainline instrument ground calibration and characterisation); (d) the distribution in time of the calibration observations and any need for special calibration periods; (e) serendipitous calibration: including calibrations extracted from routine science observations or achieved opportunistically through benefiting from regularly scheduled spacecraft or orbital maintenance periods; (f) the amount of time we really needed to accomplish a good calibration vs. the time we had. Could we have performed ALL calibration in-flight? (g) the choice of which Uplink System to use and when (CUS or AOTs); (h) the value and role of formal procedures vs. personal checklists, training and experience; (i) the usage and value of different categories of documentation and the avoidance of extraneous documentation and useless effort; (j) how did the calibrators interface with the rest of the system. These issues will be discussed as a prelude to the more detailed presentations on specific aspects of the calibration which will follow during the course of the meeting.

Key words: ISO – Calibration, ISOCAM, System Design, Testing, Documentation

1. INTRODUCTION

Notwithstanding the option to include an acknowledgements section at the end of this paper, it has to be said here that this material is presented on behalf of the ISOCAM group at Saclay, the ISOCAM group at Orsay, the former CAM Instrument Dedicated Team (CIDT) at ESA, VilSpa, and the former CAM Instrument Support Team (CIST), whose committed efforts, sustained over years, made ISOCAM the success that it has been (and continues to be).

Other talks in these Proceedings give details of specific aspects of CAM calibration. In this paper I would like to address the in-flight calibration strategy in the broadest sense. The approach, overall, to CAM in-flight calibration, including :

- pre- and in-flight planning and preparation
- main tools employed
- validation (testing, simulation) of calibration sequences
- kinds of observations, time spent, time needed
- looking at the data
- procedures & documentation
- lessons learned for the future.

As will be seen, the ISOCAM in-flight calibration was extensively and carefully prepared. At the same time, we learned a lot as the work progressed and, in the nature of the task, we invented much as we went along, which, up to a point, is OK!

2. CALIBRATION IN OVERALL SYSTEM DESIGN

2.1. THE EARLY YEARS

2.1.1. IOCRD

By launch minus 8 years key elements of the systems and infrastructure needed for the eventual in-flight calibration work were already in development. Various aspects of instrument ground testing, verification and evaluation were underway. In this period work began to define the set of calibrations to be performed in-flight. Anticipating later highly productive approaches, the definition of the In-orbit Calibration Requirements was an ongoing, iterative and collaborative effort involving close co-operation between ESA calibration scientists and the various instrument development teams' experts. These worked together to define actual in-flight Calibration observations, drawing deeply upon experience from ongoing ground-based characterisation. This led to a highly practical document - the In-orbit Calibration Requirements Document (IOCRD) - which merged requirements with planned implementation details. This document evolved up to launch and became the basis for the bulk of the ISOCAM in-flight calibration and engineering test work. The ISOCAM in-flight calibration, both in Performance Verification and Routine Phases, was directly driven by this document. During the years of operations the IOCRD was stripped of implementation information to bring it into line with the formal definition of a requirements document. For this reason, anyone wishing to consult and obtain maximum benefit from the ISO IOCRD for ISOCAM is advised to consult the earlier, useful, pre-launch version referenced in this paper.

2.1.2. System Engineering Design: "a view from the end"

Up to a very few years before launch the Ground Segment was poorly elaborated in the ISO System Engineering Design. Although the development of many key systems progressed steadily through the decade preceding launch, ground-segment development work started with a limited view of what the final system should look like: i.e. with a limited "view from the end". The efforts to arrive at a comprehensive system design making adequate provision for the many aspects of operations (e.g. a flexible commanding system for calibration and engineering tests, adequate calibration sequences, mission planning, S/W development and maintenance, quality and configuration control etc.) cost vital time in the period around launch minus 3 to 1.5 years, and placed the ground-segment development teams under enormous and sustained pressure.

In this period there was an excessive emphasis on formal aspects of planning, involving too deeply the very experts who were needed to do the work. For a period, system complexity grew, schedule pressure steadily increased, and available (for practical work) manpower shrank. In periods of retrenchment in system design or planning, management must avoid drawing specialist manpower into bureaucratic exercises at the expense of the ongoing hands-on work. The separation of the roles should be respected.

However, overall the efforts to bring the system into line bore fruit. And after a campaign of extensive instrument, subsystem and end-to-end simulations in the months and years before launch the ISO system and operational teams "hit the ground running" when the spacecraft was launched. Broadly speaking, operations ran smoothly from the word 'Go!'.

2.2. Key elements in a successful approach

2.2.1. IDTs - Instrument Dedicated Teams

In the period from launch minus 2 to launch minus 1.5 years joint ESA/PI development teams - Instrument Dedicated Teams (IDTs) - were set up. These were constituted from PI team and ESA specialist manpower, and all team members were co–located a substantial fraction of the time pre-launch, and full-time at VilSpa from launch minus 6 months. The IDTs provided the focussed, practical, environment necessary for the development work to progress, and from their inception preparations for instrument in-flight operations accelerated due to hugely increased efficiency and reduction of administrative overhead.

2.2.2. The Calibration Uplink System (CUS)

In this period the Calibration Uplink System (Ref. Munoz in this proceedings) became available to the calibration scientists for the flexible definition of those calibration and engineering test sequences which could not be adequately addressed using the general user tools for observation definition - the Astronomical Observation Templates (AOTs).

The question has been raised as to why it was not better to schedule ALL calibrations with the standard AOTs used for the bulk of science observations. In fact. for ISOCAM (and probably to a great extent in general) the CUS and AOTs used the same elemental commands and sequences (mnemonics and Instrument Control Sequences (ICSs)) to control the instrument. But whereas modified AOTs could only be generated and evaluated after a necessarily long and highly structured definition, modification, testing and approval process involving most of the Science Operations Team sub-groups, alternative strategies and instrument configurations could be generated within 24 hours or less with the CUS, and as necessary evaluated on the simulator prior to uplink.

The CUS and the AOTs were not so much independent systems for command uplink, but rather, different user interfaces to the set of instrument control sequences and the instrument parameter database, with the CUS giving flexible access and the AOTs not.

For this reason the CUS became the system of choice for the bulk of the ISOCAM in-flight calibrations early in the mission, with usage shifting somewhat towards the AOTs later in the mission.

3. IN-FLIGHT EVOLUTION OF THE CALIBRATION PLAN

An ISO pre-launch planning document SAI/94-335/Dc/JN/JC ISO Science Operations Centre Routine Phase Operations Plan, Issue 1.0, 06/11/1994 stated "... Calibration Requirements and the Calibration Plan are under strict configuration control." Thankfully, this grim scenario never came to pass for ISOCAM in the Routine Phase.

Of course, as should be apparent from the preceding section, planning and preparation for in-flight calibration begins many years before launch, and is a careful and painstaking process involving incorporation of ground-test experience, repeated expert consultations, and detailed and careful testing and simulation. However, by its nature, the Calibration Plan is dynamic and flexible and must remain under the control of relevant experts. These experts should, of course, maintain full configuration and traceability within the command sequences developed for calibration, but a change of calibration strategy, or a change of a test sequence, should not require approval of a central Configuration Control Board (CCB) in the way that cyclically maintained core operations software does.

Certainly, across the different phases of the mission the degree of flexibility changes. At launch, a baseline schedule exists, and rightly so, for every hour of the Spacecraft Commissioning (SC) and Performance Verification (PV) Phases. During the Commissioning Phase this plan is followed with, necessarily, least flexibility, as the spacecraft's in-flight behaviour is initially evaluated. In ESA, this Phase is under the control of the Project Team who have had responsibility for the development of the spacecraft. This is not a calibration phase, though observations having value for calibration may be performed in the period. This phase is addressed in Section 6.1 below.

During PV Phase the planned schedule may evolve rapidly, and largely at the discretion of the instrument experts. What was done is most directly documented in the data. The tools – the core observational templates and parameter tables – were under configuration control: an impressive term which essentially means keeping very careful track of every change you make.

During Routine Phase CIDT adjusted its calibration plans month by month, mainly through monthly meetings of the calibration and instrument people. Every half year experts from CAM sites gathered and reviewed progress. This approach was flexible, highly effective, and suited to evolving instrument understanding, and is a strategy which relies on judgement, skill and experience on the part of the people involved.

At any time we had a clear set of overall goals in mind. We had an outline medium-term plan and priorities. We had a firmed-up short term plan (coded Calibration Observations (COs)).

At the start of the Routine Phase calibration was concentrated in a weekly revolution holding 4 hours of calibration per instrument. Calibration people were sceptical that it would be possible to work with such an isolated block. Yet, for CAM, we ended up mainly opting for monthly calibration revolutions. Precise target selection was done weekly or monthly, for weekly or monthly calibrations.

4. ISOCAM CALIBRATION TOOLS

Some of the principal tools used in the ISOCAM calibration work were :

- CAM Astronomical Observation Templates (AOTs)
- Calibration Uplink System (CUS)
- Real-time and Quick-look Assessment S/W
- ISOCAM Interactive Analysis (CIA) S/W
- Configuration Control (Vax CMS for CIDT)
- a wide range of highly useful personal tools
  - instrument performance simulator
  - target visibility tools, field rotation corrections, saturation checking tool
  - "book-keeping" and tracking tools (e.g. execution status of calibration observations etc.)
- the WEB arrived just in time for operations, supporting :
  - event histories per revolution
  - data-product status tracking tools

and many others.

5. PREPARATION OF IN-FLIGHT SEQUENCES

ALL CUS based SC and PV calibration observations were tested during instrument ground tests: during both Flight Spare (FS) and Flight Model (FM) tests. A subset was re-checked - along with AOTs - during VilSpa SOC pre-flight simulations. Hundreds of hours of tests were clocked-up

These simulations were largely engineering tests, not calibration, but they ensured secure, reliable command sequences from the start of the mission. They also ensured complete familiarity of CIDT personnel with systems and working procedures.

The formal SOC training exercise involving external contractors and lectures, as it was applied to IDTs arriving at VilSpa, was money and time not well spent. IDT personnel felt (and were) more expert than the trainers. They themselves were able to more effectively train any less experienced colleagues. The courses were good in themselves and well-intentioned, but were targeted on complete novices. Future training for operations must be better adapted to the personnel to be trained. Courses should be commissioned where needed: Not because their absence leaves an un-pretty gap in the flow chart.

6. PERFORMED CALIBRATIONS

6.1. Spacecraft Commissioning Phase : Revs. 0 - 21

The Spacecraft Commissioning Phase (SCP) was planned in every detail before launch, and all sequences to be executed were tested on the simulator.

ISOCAM was prime instrument for at least some of the time on revolutions 7, 11, 13, 14, 15, 16 and 21, beginning with basic instrument checkout on revolution 7, and was operated in parallel mode on revolutions 12, 13, 14, 18, 19 and 20. CAM activities in SCP are summarised in Table 1.

Table 1. CAM observations in SCP.

Rev. no.	Usage
0 to 3	LEOP S/C checkout (Sci. Instruments off)
4+	mix of S/C and Sci. Instruments tests
7	ISOCAM checkout - key ground sequences
11	Tests of deactivation calibrations
	CAM First-Light on M51
12	ISOCAM in parallel mode for the first time
13	Jitter buffer tests
14	Focal Plane Geometry
15	Tests of SSO Tracking
16	Refinement of pointing offsets
	Responsive transients
18 to 20	CAM in parallel mode
21	Further refinement of pointing offsets

In agreement with the Project, core SCP activities were augmented by additional already-simulated measurements put into gaps in the SCP timeline. These included :

- the ISOCAM (and ISO) first-light image on Rev.11
- early responsive transients tests

as mentioned in the table.

CIDT appreciated the fine judgement of the Project representative (P. Estaria) in maintaining due rigour for critical operations while supporting a carefully considered flexibility to optimise the output of SCP.

6.2. Performance Verification Phase : Revs. 22 - 77

The PV Phase lasted 56 revolutions, with roughly 1 in 4 given to each instrument. The CAM PV Phase was planned in every detail before launch, and all sequences to be executed were tested on the simulator, having previously been tested on the instrument Flight Spare and Flight Model during ground tests involving the CAM instrument team and the CIDT. However, PV observations were adjusted from one CAM calibration revolution to the next (a 4 day cycle) during PV Phase, to adapt to growing knowledge of the actual conditions in flight. Calibration observations almost always used the fully validated sequences described above. Modified sequences (unless the modifications were trivial) were tested on the simulator before execution. This required rapid turn–around of re–planned revolutions in collaboration with the Mission Planning team. This had been well simulated during the pre-launch end-to-end tests and went smoothly. The success of such a high-pressure operational cycle sustained for 56 days (following on the SCP and pre-launch tension) owed a great deal to the dedication and willingness of all participants to "go the extra (or several extra) mile(s)". The performance of the ISO operational teams in this period should be a matter of pride for all involved!

Table 2. CAM observations in PV Phase.

By Rev.56 milestone CIDT could report:

- CAM sensitivity nominal
- ISO PSF (nominal)
- radiation effects as predicted
- endorsed 40 min. extension of science window
- dark current behaviour characterised
- flat-field quality problems (wheel jitter) found
- responsive transient effects nominal
- v.good pointing repeatability
- generally : good agreement with expectations

Calibration deliveries status at end-PV Phase:

- CALG: Off-line Pipeline calibration files
- CALU: Uplink System (AOT logic) cal. files
- CALQ: RTA/QLA $^{(1)}$ calibration files

Special (manual) operations conducted during PV:

- improving handling of CAM saturations
- studied behaviour of CAM's wheel jitter
- extending operations towards e^--belt. A 40 minute extension resulted
- From Rev.27 on parallel-mode used whenever possible during other instruments' PV Revs. (except LWS)

(1) RTA/QLA = Real-Time/Quick-Look Assessment S/W

For PV Phase 75 CUS Calibration Observation Batches (COBs) were built including 1400 Calibration Observations (COs). Only a subset of these COs were actually scheduled.

6.3. Routine Phase : Revs. 78 - 875

The Routine Phase calibration observations were not systematically built before launch. The requirements, and specific configurations recommended, were detailed in the IOCRD. But the IDT needed and used great freedom to adapt the calibration details throughout Routine Phase.

It is useful to record how the Routine Phase calibration time was divided among the 4 ISO instruments. This is shown in Table 3 below.

Table 3. Division of calibration time among instruments $^{(\mathbf{a})}$

Time description	CAM	LWS	PHT	SWS	hours (4 instrs.)
OTT	24.5	24.9	25.2	25.4	$1669^{(\mathbf{b})}$
TDT	24.0	25.2	25.6	25.2	$1799^{(\mathbf{c})}$

(a) After 113 regular calibration revolutions (RP$^{(\mathbf{d})}$ only).
(b) Total OTT (On Target Time) = (Observation time - overheads)
(c) Total TDT (Target Dedicated Time) = Observation time including overheads. Represents 97.8% of total calibration time.
(d) RP = Routine Phase

In total, for CAM, 200 CUS calibration procedures (COBs) were prepared during the Routine Phase, containing 3500 calibration observations (COs). 300 AOT–based CAM calibration batches were executed, each one containing several COs, so that in the end the CUS and AOT interfaces to the command sequences were used about equally.

Table 4. Usage of ISOCAM calibration time overall.

Parameter	Hours	% of total
Total Photometry	138.5	21
PSF	94.0	14
Zodi flats	54.5	8
AOT Verification in PV	52.0	8
Darks	47.5	7
Straylight	42.0	6
CVF	38.0	6
Polarisation	22.0	3
ICD flats	16.5	2.5
Faint Sources	20.0	3
Linearity tests in PV	14.5	2
Sub-Total	539.0	82
Other[1]	121.5	18
Total On Target Time used[2]	660.5	100

[1] SCP calibrations, transients (10 hours), cross- calibration, astrometry, extended, sources, red sources, CAM SW flat-fields, vignetting etc.

[2] 66% of this was done in Routine Phase

In retrospect, many calibration results were eventually extracted from science measurements and CAM parallel mode. Could ISOCAM have managed with less calibration time?? Possibly 10 or 20% less. But not less than that. And such judgements made in hindsight tell little about what was actually realisable at the time. In general, the allocation was well scoped.

6.4. Special CAM calibration modes

A range of systematic checks were programmed into otherwise scientifically unusable periods of the orbit :
During instrument activation as the S/C emerged from the radiation belts Internal Calibration Device (ICD) curing and sensitivity/Flat-Field checks were made. Also dark signal measurements were made. During ground-station hand-over at roughly the mid-point of each revolution further dark signal measurements were recorded. For several revolutions CAM parallel mode was specially configured to study revolution-long trends (for example - in the dark signal).

These modes were of enormous value in characterising long term trends, as demonstrated in the paper of Gallais 2003 in these proceedings. They used fixed command sequences called Permanent Command Sequences and drove up the number of PCSs past initial (per instrument) design limits.
Not surprisingly many calibrations also came serendipitously from science data.

7. ACHIEVED RELIABILITY OF CALIBRATIONS

The outright failure rate for CAM calibrations due to human error was less than 3%. Failure rate due to all causes was less than 4%). A few observations deviated from the intended configuration but still fell within the calibratable parameter space. For comparison, the failure rate for general science AOT observations was less than 4% for all causes. [But note that this figure takes no account of observations which may have yielded no science due to being badly adapted to their science goals. Such a scientific evaluation of success/failure is not attempted here.]
The commonest causes of rejection of calibration deliveries by the Mission Planning (MP) team were :

- source not visible
- deviations from labelling conventions relied upon by the MP system.

The commonest causes for human-induced failures for scheduled calibration observations were :

- misjudgements of source brightness for the instrument configuration
- instrument configurations not stitched together correctly, causing a stable misconfiguration lasting until the next reset (this could be hours)
- very, very, rarely the observing sequence file (called the POF or Planned Observation file) was rejected on the Spacecraft Control Centre (SCC - ESOC) side due to an illegal instrument parameter value getting past CUS and Mission Planning Phase 1 (MPP1) system checks. Such occurrences represented combined human-error and bugs in the system and would generate Software Problem Reports (SPRs) and change requests.

Half of all human error cases were caught by the Mission Planning team between CIDT delivery and scheduling. This highlighted the fact that, while one should not deviate from secure procedures, the flexibility to loop-back and re-enter secure procedures in response to identified (minor-)contingencies is a good thing.

8. ERROR AVOIDANCE STRATEGIES

We generated routine calibrations from stable, well tested, but adjustable core sequences. The transparency and ease of usage of the CUS (Munoz 2003 & Sec.2.2.2) played a central role in error avoidance. As did complete IDT familiarity with instrument specific CUS elements under IDT control. The stable core of the CUS (the compiler, in a sense) was under central configuration control by the software maintenance team.

Ideally, there should be a single system for instrument command uplink, but one giving sufficient flexibility to experts. The CUS was flexible and highly (expert-)user friendly. The generation of calibration observations, and the modification of the "language elements" of the CUS (Instrument Command Sequences (ICSs) and "Verbs" (parameterised groups of command sequences for more complex operations) were at IDT discretion. In CIDT all new command sequences were verified by eye-balling them, by running test code that recognised anomalous configurations and by simulation (if deemed necessary). It isn't necessary to simulate every change of a filter wheel position. The CUS, the logic, MPPI/2 were very good error detectors

All changes to the logic of the Astronomical Observation Templates used for general science observations were tested on the spacecraft simulator.

For calibration deliveries to the mission planning system CIDT implemented check-list validation by two or more IDT experts acting together. Immediate updating of IDT checklists followed any error. The capacity to exit and re-enter central team procedures for re-delivery of bad observations before scheduling saved many observations. A crucial factor in reducing error incidents was the daily personal interaction among IDTs, Calibration Liaison personnel, and Mission Planning staff. Fundamental changes in calibration sequences were tested on the simulator before uplink.

9. LOOKING AT THE DATA

CIDT screened the log files for each revolution for error messages and every error was followed-up using the Real-time Analysis and Quick Look Assessment software. If these were insufficient to resolve the error message deeper investigation was done with CAM Interactive Analysis (CIA) (Ott 2003a). Final products of the automatic processing pipeline (OLP - Ott 2003b) were not much used in calibration work. They were however looked at as part of the product quality checking process.

Based upon its systematic checking of all revolutions for instrument problems, CIDT maintained a “Failed and Questionable Observations Report (FaQOR)” giving typically a one paragraph (but sometimes much more detailed) analysis of each error message or anomaly investigated. Over the life of the mission this grew to include well over 1000 problem assessments. These became a major source of quality information for CAM observations, and have been made part of the support documentation available to ISO Data Archive (IDA) users.

During operations, CIDT did not have the resources to look at the results of all Calibration observations. Maybe 30% could be screened in quasi-real-time (i.e. before the next calibration revolution).

In general, the idea of having fixed procedures to derive calibration files for the Off-line Processing (OLP) pipeline was never a reality. The real situation saw too much evolution in calibration understanding. OLP calibration files were updated over months at periodic upgrades of the OLP and the then-current best reductions were applied at experts’ discretion. The production of optimised calibration files proved to be a highly interactive task requiring extensive instrument expertise and judgement.

10. EFFICIENT DOCUMENTATION

It has been reported that the ISO Project library holds 79000 documents. A subset of document titles dealing with the ISO Science Operations Centre (SOC) follows :

- ISO Science Mission Implementation Plan
- ISO Mission Operations Management Plan
- ISO Science Operations Centre Front-end Operations Plan
- Science Operations Centre/Spacecraft Control Centre Operational Interactions
- ISO Scientific Performance Verification Operations Plan
- ISO Science Operations Centre Routine Phase Operations Plan
- SOC Facility Operations Handbook (SFOH)
- ISO Flight Operations Handbook (IFOP)
- Calibration Activities at the ISO Ground Segment
- ISO Calibration Work Plan.

Were they all really essential to describe what a few teams did here ?? Reading them reveals a lot of duplication. With a better System Design overview it should be possible to say what has to be said with fewer documents. Sit the authors around a table : they’ll manage to say the same things in fewer documents! When policy makers speak of cost savings through streamlining of management, one of the first things to review will be the efficacy of the documentation tree.

There are a few notorious examples in the history of ISO of documents that were given far more importance, and possibly consumed more resources, than the truly important work they sought to describe. This is not getting the balance right.

BAD documents suffer from one or more of the following :

- they delay work on already understood tasks
- they reverse-engineer the descriptions of already completed, well established, or underway tasks
- they serve only to tell management in detail how the experts do their job (If you hire well - you don’t need to know. If you hire badly - it won”t help anyway.)
- they unproductively absorb needed expert manpower in the above
- they rigidise non-safety critical activities
- they (try to) proceduralise operations lacking an inherent algorithm
- the effort to write the document is a noticeable fraction of the effort it describes
- they serve mainly to make the document tree pretty and management feel warm and fuzzy.

GOOD documents enjoy one or more of the following :

- they briefly point the way to necessary work
- they make specific practical information conveniently available
- experts keep them on their desk and consult them regularly
- they don’t try to proceduralise things that cannot be reduced to an algorithm
- they securely regulate safety critical operations e.g. how not to damage the instruments
- they trigger important activity where none was pending
- the effort to write the document is only a small fraction of the effort it describes.

11. LESSONS LEARNED

The pre-flight design conception of the Calibration ISO Ground Segment (e.g. ISO-SSD-9105B Issue 1.0, 01 September 1992, “Calibration Activities at the ISO Ground Segment”) had mixed success in predicting the shape of things to come.

11.1. Things we got right

It was fundamental to the ISO in-orbit calibration philosophy that the ground based test results were, in general, not assumed to constitute an essential component of the working calibration of the instruments in flight. The pre-flight estimate of the amount of time that would be needed for calibration (about 4 hours per week, proved remarkably accurate, though the pre-flight scepticism of the instrument people that calibrations could be performed in a contiguous block proved ill-founded. In practice we found that:

- ground-based sensitivity per filter and CVF λ-calibration were used in the calibration files for some time after launch, but in the end virtually all CAM parameters were derivable in-flight
- calibration observations didn’t need to be (and could not practically be) interleaved with the science observations
- dedicated weekly/monthly calibration periods worked fine

– an average of 4 hours per week calibration (18% of science time - essentially the same as for all instruments) was enough
– one needs flexibility and ease of adaptation in the commanding system. The CUS was heavily used.

11.2. Things to change

On the other hand, some of the design choices made with respect to the CAM Astronomical Observation Templates (AOTs) in the years before launch were a little off target. Little use was made in practice of calibration options internal to CAM AOTs, such as intra-observation dark-current measurements, or Internal Calibration Device (ICD) flux calibration/Flat-field measurements. Apart from short term, observation-induced, transients the instrument was remarkably stable over the mission lifetime. Performing dedicated calibrations within an observation only destabilised the detector and caused more harm than good. The notion of having strictly configured S/W algorithms for the derivation of Calibration Files proved to have no relevance to real experience. In practice, calibration understanding leading to the generation of a calibration file grew over time and through hard-won experience interacting with the data. In such a continuously evolving context the application of configuration control to the derivation algorithms was impractical. Of course the resulting Calibration File releases were under configuration control.

11.3. List of lessons

So, how would one characterise the main lessons that we learned:

- L1: Keep it simple, and if something is simple, be glad, and don't make it into a big deal.
- L2: Minimise duplication of documents. Minimise issues of documents.
- L3: Only proceduralise processes with a well defined inherent algorithm.
- L4: Have an early general overview of system design. Look backwards from where you aim to finish.
- L5: Start as soon as possible to build actual, real cases - not models of cases. (E.g. compare early and late IOCRD versions)
- L6: Test the full system as soon as possible. The earlier the better.
- L7: Being flexible is not bad. Only being reckless is.
- L8: Instrument commanding should begin in inherently flexible systems. Specific command sequences and complexes can be frozen at any time to provide restricted interfaces for general users.
- L9: Test well. Simulate. Test. Test. Test.
- L10: Spare no effort to catch end eliminate errors. Keep procedures open to looping and re-entry as far as possible, to maximise opportunities to catch and repair errors.
- L11: Use Quick-look tools and automatic diagnostics to trap problems. Keep a record of every problem observation and what you learned - however small the problem. You'll be glad at the end when you have a comprehensive quality record that is vastly more difficult to build after the mission.
- L12: Minimise time spent thinking about the work in the abstract:
  – minimise effort on workpackages & writing Plans for the writing of documents and S/W
  – When the work that has to be done is clearly in front of you - just DO IT! Don't write books about it.
  – don't overplan. If something is inherently volatile, changing rapidly over time, detailed plans waste time. (Exceptions are: SC or PV Phases. They may change with launch date, yet the actual schedules are built from precise elements and these have to be fully prepared in advance. Note - I say schedules - these are more concrete than Plans.)
- L13: Many calibration results come from science data.
- L14: Why co-location works:
  – if implementers and users are far apart requirements are poorly understood
  – even small, feasible, highly-beneficial changes and fixes may be reflexively rejected on largely formal grounds ("It's not in the Requirements Document")
  – with intelligent, face-to-face, constructive, discussion change-requests can be much more practically handled
  – the Configuration Control Board (CCB) hears all sides and decides
  – the key is common sense and judgement. Know when to be formal and when to be flexible
  – as in all relationships - Communicate! Listen! Don't formalise communications. Talk! Formalise DECISIONS as necessary.
- L15: Build one Team at all costs, even if not geographically.

12. CONCLUSIONS

By launch minus eight years key elements needed for ISOCAM in-flight calibration were already in development. The In-orbit Calibration Requirements Document (IOCRD) focussed expert thinking from an early stage. However, as late as launch minus three years the ISO System Engineering Design took very limited account of the Ground Segment. We lacked a view of what the final system should look like. The development teams were put under enormous and sustained pressure, exacerbated by excessive involvement of experts in formal aspects of planning. Management must avoid drawing specialist manpower into bureaucratic exercises.

The formation of the CAM Instrument Dedicated Team (CIDT) freed manpower for the real work. CIDT, a merged and co-located ESA/PI team drew together expertise from both sides. Communication was immediate. Everyone was pulling together. After moving to VilSpa everyone (the whole SOC) was on one site - another leap in communication. We could walk between offices and discuss face-to-face. System development became vastly easier.

Pre-flight testing was extensive, running systematically through FS and FM ground tests and SOC pre-flight simulations. Future training for operations must be better adapted to the personnel to be trained.

A flexible commanding system (CUS) was essential. By its nature, the Calibration Plan is dynamic and flexible and must remain under expert control. Periodic meetings of experts should review progress.
ISOCAM usage of monthly calibration revolutions amounting to about 18% of CAM science time was well scoped. Dedicated calibrations within an observation only destabilised the detectors. Systematic checks, programmed into scientifically unusable periods were of enormous value in trend monitoring.

Simplicity is a virtue. We proceduralised only those processes with a well defined inherent algorithm, and relied on the use of checklists for critical operations. Throughout the mission overall, the outright failure rate for CAM calibrations due to human error was less than 3%.

As far as possible, quality checking of data should be sustained systematically throughout the mission from start to finish. A human screening element is particularly valuable. Retrospective QA performed at the end of the mission is a vast task. CIDT maintained a "Failed and Questionable Observations Report (FaQOR)" which grew to include well over 1000 problem assessments.

It is enormously important, for overall effectiveness and output, to forge one Team at all costs.

ACKNOWLEDGEMENTS

See the Introduction of this paper, and the Foreword, the Introduction, and the Legacy Discussion introductory remarks of this Proceedings, where tribute is paid to one's esteemed colleagues.

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