STUDY GROUP

QUALITY OF SPACE PROGRAMS

Progress Report - October 2003

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1. INTRODUCTION

For all applications, business and systems, related to Space programs, Quality is mandatory and is a key factor for the technical as well as the economical performances. The differences of applications (launchers, manned space-flight, sciences, telecommunications, Earth observation, planetary exploration, etc.) and the differences in technical culture and background of the leading countries (USA, Russia, Europe) have generally led to different approaches in terms of standards and processes for Quality. At a time where international co-operation is quite usual for the institutional programs and globalization is the key word for the commercial business, it is considered of prime importance to aim at common standards and approaches for Quality in Space Programs. Starting from the early 90's, the International Academy of Astronautics has focused one session of the Safety, Rescue and Quality Symposium on that issue.

The post Cold War period of the 90's has also seen some major changes regarding the global approach of the institutional Space Programs. The political trend to reduce the budgets raised the cost as a major issue and led to some major changes in the US, with the DoD New Acquisition Policy implemented in 1994, and the NASA "Better Faster Cheaper" motto. Other countries such as Europe, Russia and Japan, reduced also their efforts.

In 1997 the Turin Round Table [3] initiated the discussion about "The Challenge of maintaining Quality and Safety in Space Programs with reduced budgets". This was the opportunity of introducing and discussing key topics or issues, which have been later developed in the IAA Quality sessions, or confirmed by the main events of the following years. These were :

- Categories of programs : institutional versus commercial, operational versus experimental, Small versus Big, National versus international;
- Problematic of risk acceptance : how to define reasonable targets for quality level in accordance with an accepted risk ?
- How to manage the risk on a "daily basis" : through new management rules and/or organization ?
- First challenge : do well, in time, within the cost;
- Importance of Phases A & B and continuity with Phases C/D/E
- The case of the institutional programs : roles of Agencies and Industry;
- What is the applicability of usual management rules to international programs ?

In 2001, the Academy has set up a Study Group which mandate was to "Make recommendations to improve the Quality, Reliability, Efficiency, and Safety of space programs, taking into account the overall environment in which they operate : economical constraints, harsh environments, space weather, long life, no maintenance, autonomy, international co-operation, norms and standards, certification."

The mandate and the spectrum of the Study Group being quite wide, the methodology during the first two years of its activity has been to rely on :

- the papers presented in the frame of the Quality sessions of the IAC,
- a systematic survey of the failures, accident and inquiry boards related to Quality issues,

in order to identify the key trends of the problem and to restrict the focus for further work.

2. HIGHLIGHTS OF QUALITY IAA SESSIONS

The first session of the IAA Safety, Rescue and Quality Symposium, has focused mainly on two topics, the impact of cost reduction, and the international frame of some space programs :

- 1996 : New Trends in Safety and Quality in Space Programs
- 1997 : New Concepts in Safety, Rescue and Quality in Space Programs
- 1998 : Quality and Safety Issues for Space Programs in a Cost Constraining Environment
- 1999 : The challenge of quality and safety for international programs
- 2000 : Joint Session on Standardization of Quality and Safety Specifications and Verification and Certification Processes for ISS
- 2001 : Risk versus cost : why did "Faster, Better, Cheaper" fail and how solve the issue ?

A first synthesis was given during the Houston IAC in 2002 [17], which is largely reflected in the present report.

A lot of topics were addressed during these sessions. Globally the general trend was reflecting a tremendous evolution in terms of Quality and Risk Management. The budget pressure led decision-makers and managers to emphasize cost reduction and to balance risks with costs. This was also relying on the belief that the Space business was becoming mature with the development of commercial business, and that risk management methodologies as well as international standards would allow to achieve the good level of Quality, thanks to modern practices.

Regarding the initial focus of the Study Group, mainly five themes are to be emphasized, to sum up the findings from these sessions :

· Interest of Norms and Standards :

The relationship between ISO 9000 standard and the Space activities has been addressed in References 6 and 7 : the key message is that the Space sector has had a late interest for ISO, since it had developed its own Quality methodologies very early. Now most Space Agencies as well as Industries are ISO 9000 certified. In complement to ISO, Space Quality Standards have been developed in USA (AS9000 SAE Aerospace Basic Quality System) and in Europe (RG Aero 00040 and ECSS [8]), and are a starting point to develop an International Aerospace Quality System Standard in the frame of ISO.

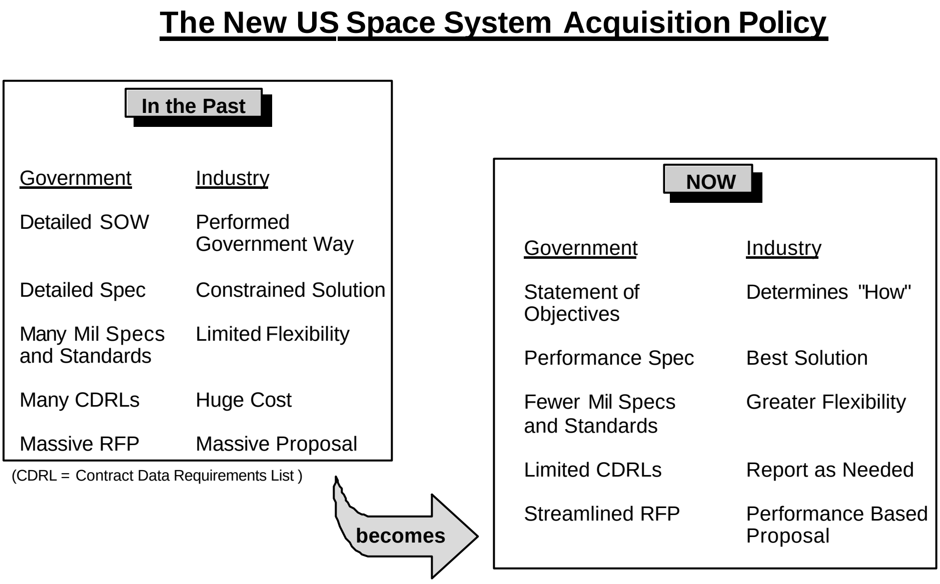
· Cost reduction, new way of contracting :

A lot of papers and discussions, around the US New Acquisition Policy and the so-called "Faster, Better, Cheaper" approach, addressed in fact the global question of reducing the cost of Space programs, both in development and in production, while keeping the requested level of Quality. Different aspects were considered.

Whitehair [1] explained the intent of the New Acquisition Policy, which was "to place the responsibility for the integrity of the systems on the private contractor by reducing specifications, documentation and government oversight", leading to a new way of doing business. But he also expressed concerns regarding this policy, mainly as a consequence of the switch from oversight to insight and the transfer of responsibility to private sector :

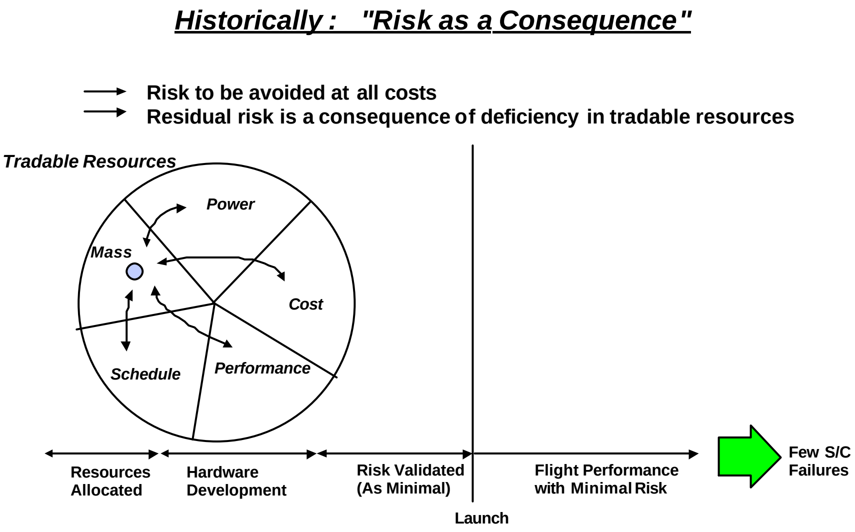
- high cost of program recovery if untried policy is applied without scrutiny but later proves to be faulty
- transfer of product liability to the private sector
- increase in insurance premiums
- undiagnosed failures because of lack of oversight
- cost overruns late in a program
- degradation of customer insight into cause of failure

Some of these concerns were premonitory at the light of the recent CAIB and DoD/USAF Reports (see §4).

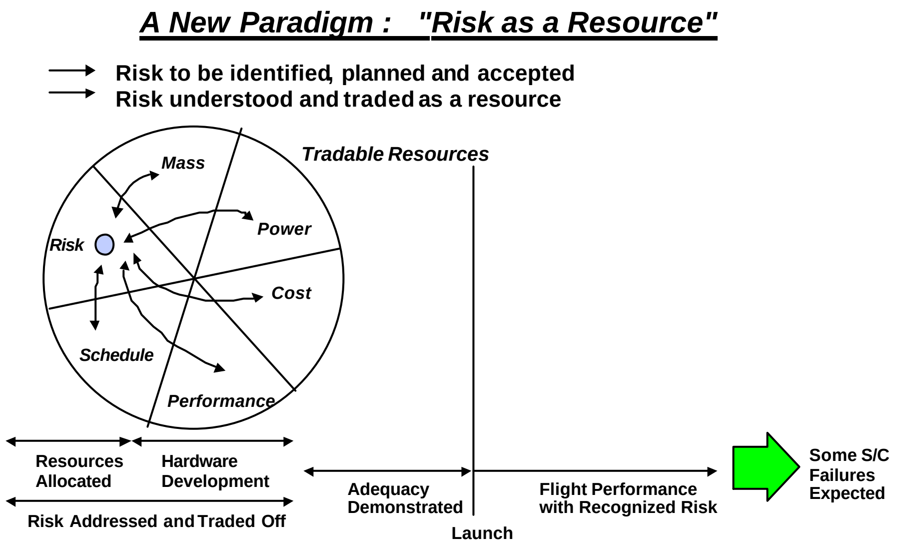


Lacau [2] expressed also some concerns as early as 1996, regarding "Better, Faster, Cheaper" clearly stating that Mission Success should the first priority, from which economical efficiency would be achieved.

In the frame of the NASA "Better, Faster, Cheaper" approach, Greenfield [4] explained the difficulty to switch from a culture of "Risk as a consequence" (or Risk avoidance) and rule-based risk management, to a culture of "Risk as a resource" (or Risk



acceptance) and knowledge-based risk management.



Peercy [13] showed how the flight experience accumulated from similar programs has allowed to improve the System Safety Process for the Shuttle operations, thus reducing the number of flight anomalies, while implementing the contract with USA and associated cost reductions.

The example of concrete processes applied to Ariane 4 [5, 15] production showed that a "classical" programs, which was not considered a Faster, Better, Cheaper one, succeeded to reduce production lifecycle (Faster), increase Quality (better) and reduce the costs (Cheaper), using robust and well known management methods for productivity improvement.

· <u>International frame</u> :

The Shuttle/Mir program management was analyzed in Reference 9 : responsibility sharing, management of RSC Energya and NASA documentation, definition of an Integrated Safety Documentation, implementation of Joint Safety Assurance Working Group. The lessons learned from this cooperative program are applied to the ISS program. The complete session in 2000 addressed the issues associated to the ISS international program. An other example of international cooperation was given by the CBERS program [11,18] , a remote sensing satellite jointly developed by China and Brazil. The paper explained how the activities were divided and managed, and the encountered difficulties, with an interesting return of experience for further cooperation.

· <u>Importance of sound Risk Management</u> :

Through the past sessions, the importance of clever risk management approaches has been emphasized. As already noted above, it was the core of Greenfield paper in 1997, with this concept of "Risk as a resource" [4] . Newman [10] presented the Process Based Mission Assurance (PBMA), applied to new performance based contracts between Agencies and Industry. The backbone of the PBMA, which uses 10 basic assurance process elements, is risk management thinking. It aims at life cycle risk management, focusing on processes which "make it safe, make it work, and manage risk". In 2001, Greenfield [16] presented one of the recommendations from the NIAT 2000 report "Enhancing Mission Success" [25] : "Understanding and controlling risk – Improve risk identification, assessment and management". The paper raised the importance of developing clear "success criteria" and of understanding what is an acceptable risk, as well as using proper risk management tools and techniques (fault tree analysis, FMEA). This topic of Risk Management methodologies has been also the continuous focus of session 2 of the IAA Safety, Quality and Rescue Symposium, during the past years.

· Space Weather :

More recently some specific sessions have also been devoted to the importance of the Space Environment regarding Quality, mainly through three topics :

- modeling : present models have to be improved, regarding the understanding of the physical mechanisms, and the representation of the various zones of Space. The increase of satellites lifetime, now the same order of magnitude as a solar cycle, requests this better modeling.
- Technologies validation through ground or flight testing : in flight testing is necessary to analyze the real environment of a spacecraft, including its own influence on the space environment (e.g. ISS)
- Space Weather : there is more and more interest to acquire means to forecast the space environment evolutions, especially regarding the occurrence of solar peak events.

· Lessons learned and Knowledge Management :

Last but not least, a lot of papers addressed the need for knowledge management and the use of lessons learned, as a key to prevent bad quality performances. The manned space-flight case, with Shuttle and Shuttle / Mir experience, was largely discussed by Peercy [9, 12, 13] , and the CBERS example has already been cited here above [11] . In its paper addressing the large hi-tech projects and highlighting the modeling and simulation as means to master complexity, Belleval [14] concluded on the importance of a long term strategy of competence (instead of "hire-and-fire"), and of knowledge management. It should be also noted that GAO in 2002 considered the proper use of the Lessons Learned existing process in NASA a key issue for the revitalization of human capital[19].

3. THE KEY EVENTS BETWEEN 1997 AND 2002

The 1997-2001 period has seen an impressive record of failures or problems, demonstrating that Space activities were still facing Quality problems, and were far from being a “business as usual” : as stated in Reference 33, “Space is unforgiving : thousands of good decisions can be undone by a simple engineering flaw or workmanship error, and these flaws and errors can result in catastrophe”.

A list of the main events is given in Appendix. A lot of them are concerning “dynamic phases“ (launches, re-entry, aero-braking, orbital maneuvers, docking) where a mishap is difficult to be recovered, and leads to mission abort. The most spectacular and costly events of the period occurred in 1998 and 1999, with the failures of the launchers Titan, Atlas, Delta and Proton and the mishaps of Mars missions. The situation slightly improved in 2000 and 2001, but the period ended with the failure of Ariane 5 ECA maiden flight in December 2002.

In the same time, the number of anomalies for GEO Telecommunications satellites has dramatically increased since 1998, some of them being fatal for the mission as shown in Appendix.

From the series of reports issued after the major 98-99 failures in launchers and Mars missions (Report on Project Management in NASA [27], NASA FBC Task Final Report [28], DoD Assessment of Space Launch Failure [29], Space Launch Vehicles Broad Area Review [30]) a list of organic reasons for these failures were identified, as summarized in Table 1 extracted from a GAO report [20]. The most repetitive reasons are Insufficient Risk Assessment and Planning, Poor Team Communication, Inadequate Review Process and Inadequate System Engineering. These reports issued recommendations which were implemented by DoD for the management of USAF launches, and which led to a list of themes for NASA to “Enhance Mission Success“ [25] :

- Developing and Supporting Exceptional People and Teams,
- Delivering Advanced Technology,
- Understanding and Controlling Risk,
- Ensuring Formulation Rigor and Implementation Discipline,
- Improving Communication.

The problems encountered in the commercial business of GEO Telecommunications satellites are mainly due to computer failures, attitude control loss, and solar generators loss or performance degradation.

The increase of the number of anomalies has been found to come from the following reasons [31] :

- Significant increase in the number of on-orbit satellites,
- Significant increase in the technical complexity of satellites, illustrated by an average power level for GEO commercial satellites which has been multiplied by 3 between 1996 and 2001,
- Shortening of manufacturing cycle, by 20 to 30%, with less rigorous analysis, test and evaluation on satellite prior to delivery.

This recent upturn in anomalies has prompted the satellite manufacturers to implement stringent quality control processes and standards : “We will significantly increase our emphasis on product and enterprise-wide quality.” (R. Brinkley, President Boeing Satellite Systems, February 2002).

Reasons for failure	Major Program Reviews			Major Mishap Revie			
	Broad Area Review	Lockheed Martin Independent Assessmen t Team	Faster Better Cheaper Task Force	WIRE	Mars Climate Orbiter	Mars Polar Lander	Lewis
Cost and Schedule Constraints	●			●			●
Insufficient Risk Assessment and Planning		●	●		●	●	●
Underestimation of Complexity and Technology Maturity	●		●				●
Insufficient Testing			●	●	●		●
Poor Team Communication	●	●	●	●	●	●	●
Inattention to Quality and Safety	●	●	●		●		
Inadequate Review Process	●	●	●	●	●	●	●
Design Errors	●			●	●	●	
Inadequate System Engineering	●	●	●	●	●	●	●

Inadequate or Under Trained Staff	•	•			•	•	

Table 1 - Reasons for Spacecraft Failures (source Ref 20)

Beyond these "operational" events, we can also mention some "programmatic" events which did not result in mission failures or abort, but are considered relevant to the topic of Quality of Space programs.

The ISS program is facing a well-known escalation of costs, which is mainly due to improper management, and is therefore a Quality problem. But it has also shown some difficulties related to safety approach in international programs. In 2000 a GAO Report has raised the issue of "Russian compliance with safety requirements" [24] . Some non-compliance with NASA ISS safety requirements were noted for the Zarya and Service Module (later named Zvezda) : orbital debris shielding, inability to operate after losing cabin pressure, lack of verification for design and service life of windows, and excessive noise levels. Some of these non-compliances were due to different design approaches, and "technical disagreements with Russian engineers". Better visibility, technical justifications and some design upgrades allowed NASA to accept these non-compliances. However this example shows how it can be difficult to mix different technical cultures and safety approaches.

Some problems encountered by the Shuttle program (wiring flaws in 1999), which were caused by human errors and improper quality control, have led to analyze the impact of NASA workforce reduction following the implementation of the USA contract (from 3000 in FY95 down to 1800 in FY99). The consequence of that reduction and also of the retirement of highly experienced people was said to be shortages of required personnel to maintain adequate oversight of the contractor [21]. The revitalization of Shuttle workforce became a priority and is still carefully monitored [19, 21]. Downsizing plans were terminated in December 99, and efforts were initiated to hire new staff to safely support the Shuttle's planned flight rate. NASA was giving emphasis to human capital management, for instance through an improvement of its Lessons Learned Process [20]. The Columbia catastrophe has unfortunately shown that these measures were not sufficient or arriving too late to improve the situation.

In its action to open the way towards future Reusable Launch Vehicles, NASA entered new contractual mechanisms of "cooperative agreements" with the X34, X33 programs. The termination of both programs in 2001, because of significant cost increases raised questions about the cause for this failure. The assessment by GAO [26] was that "NASA did not develop realistic cost estimates, timely acquisition and risk management plans, and adequate and realistic performance goals". Risk assessment and mitigation plan are considered even more important in a contractual scheme were risks are shared between Industry and Agencies.

All these reports and assessments were in fact strong warnings, announcing the complete change of tendency in Quality approaches, which could result from the Columbia catastrophe early 2003, and from DoD/USAF new awareness of the limits of the 1994 New Acquisition Policy for Space systems.

4. 2002-2003 : A DRAMATIC YEAR

In early 2002, the cost overruns of SBIRS High program has re-opened the debate of the relationship between Industry and Government Agencies in Space Programs. Through the application of the 1994 US New Acquisition Policy, both NASA and DoD implemented Total System Performance Responsibility contracts (TSPR), where the contractor takes responsibility to be the total system contractor. DoD now feels space developments too much challenging for such an approach, and USAF identified system engineering problems at contractor level. The capability of the Agencies to exercise better contract oversight had been a key recommendation expressed by GAO, from 1997 [19, 22].

As a result of the concerns of DoD about "significant problems in many critical National Security Space Programs resulting in significant cost growth and schedule delays", a Defense Scientific Board / Air Force Scientific Advisory Board Joint Task Force on Acquisition of National Security Space Programs was settled in August 2002 and delivered its report in May 2003 [33].

In a dramatic conjunction of events, the Columbia catastrophe on February 1st, 2003, resulted in the implementation of the Columbia Accident Investigation Board which delivered its conclusion in August 2003, after a thorough analysis of the physical causes of the accident, but also of the root organizational and cultural causes [32].

We consider that these two reports could be a very important milestone, regarding the way Quality will be addressed in the future for Space programs. Therefore, a summary of some key points is given hereafter.

<u>Budget Sizing and Cost Pressure</u> :

Both reports are identifying the cost constraints implemented through the New Acquisition Policy and the Better, Faster, Cheaper approach, as the most influential factor in Quality decrease.

The CAIB report has raised the culture of "doing too much with too little", meaning to keep the same ambitions with less money. This aspect had already been reported in the frame of various Task Forces before (e.g. Advisory Committee on the Future of the US Space Program in 1990, known as the Augustine Committee).

CAIB diagnosis is that "the major root cause of the Columbia accident is the NASA management crusade for efficiency which shaped the environment in which Shuttle managers worked".

DoD/USAF Report identifies two basic reasons for cost growth and schedule delays :

- Cost has replaced mission success as the primary driver in managing space development programs
- Unrealistic estimates lead to unrealistic budgets and unexecutable programs : this is also the result of "life or death" competition at industry level, and "price to win" approaches instead of realistic estimates

DoD/USAF position is that "Cost performance goals can be achieved only by managing quality and doing it right the first time : Mission Success is the priority".

Schedule pressure :

The CAIB notes that an undue pressure on "arbitrary" schedule milestones is focusing the program management on that single parameter, instead of properly addressing the complexity of programs driven by multiple criteria (cost, performance, schedule, safety, …). The ISS Node 2 launch date planned on February 19, 2004, to achieve the ISS "US Core Complete" , had became an emblematic objective for the NASA Top Management, … and therefore for all Shuttle and ISS employees.

CAIB clearly addresses the Management responsibility in that issue : "safety sometimes compete with schedules, so the effects of schedule pressure in an organization must be carefully monitored".

Lessons learned :

CAIB has found "Echoes of Challenger in Columbia accident" :

- inadequate concern over deviations from expected performance
- silent safety program
- schedule pressure

As a remark, it should be noted that some echoes of Ariane 5 501 maiden flight failure, could be seen in Ariane 5 ECA 517 maiden flight failure (process of validation and qualification reviews).

For CAIB the history of foam debris events shows that "NASA is not functioning as a learning organization".

This weakness in Lessons Learned Management process had been already addressed in previous GAO reports [19, 20].

In a similar way, the DoD/USAF report notes that "Industry has failed to implemented proven management and engineering practices on some programs"

Limits and dangers of ISO 9000/9001 :

One of the key tools presented in New Acquisition Policy and Better, Faster, Cheaper approach, was the ISO 9000/9001 standard : the ISO 9000/9001 certification of the Space industry was considered as Quality guarantee for the institutional customer, allowing him to reduce its own Quality workforce.

While recognizing the interest of the ISO 9000/9001 certification, the CAIB raises its limits :

"ISO 9000/9001 expresses strong principles, which are more applicable to manufacturing and repetitive-procedure industries, such as running a major airline, than to a research-and –development program",

and even considered the danger of relying too much on it :

"Aiming to align NASA inspection regime with ISO 9000/9001 protocol, commonly used in industrial environments, the Human Space Flight Program shifted from a comprehensive "oversight" inspection process to a more limited "insight"process, cutting mandatory inspection points by more than half".

Danger of reduced oversight :

CAIB stresses again, as did Rogers Commission after the Challenger accident, "the lack of independent safety oversight at NASA", which in fact was a result of the cost cutting and workforce reduction.

The DoD/USAF report says : "Government capabilities to lead and manage the space acquisition process have seriously eroded : this is the consequence of TSPR contracts and replacement of traditional government "oversight" by "insight"".

Therefore, one of the key principles of the US New Acquisition Policy is now clearly questioned.

Importance of Organizational culture :

Following the definition of CAIB, "Organizational culture refers to the basic values, norms, beliefs, and practices that characterize the functioning of a particular institution. At the most basic level, organizational culture defines the assumptions that employees make as they carry out their work; it defines “the way we do things here”. An organization’s culture is a powerful force that persists through reorganizations and the departure of key personnel.”

The weight of the cultural patterns is so high that it leads to miss some clear warnings, such as the ones from previous Shuttle safety boards from 2000.

CAIB notes that “The organizational causes of the accident are rooted in the Space Shuttle Program’s history and culture… Cultural traits and organizational practices detrimental to safety and reliability include :

- reliance on past success as a substitute for sound engineering practices
- organizational barriers which prevented effective communication of critical safety information
- lack of integrated management across program elements
- evolution of an informal chain of command and decision-making processes that operated outside the organization’s rules”

The above mentioned “can do” or “do too much for too little” attitudes are also referring to culture.

This short review is far from being exhaustive, considering the richness of CAIB and DoD/USAF reports. However the selection of findings and recommendations clearly shows that, beyond the technical excellence, the risk management methodologies, and the Quality standards, the key issue is cultural and organizational. To illustrate that, the following CAIB statement is rather clear :

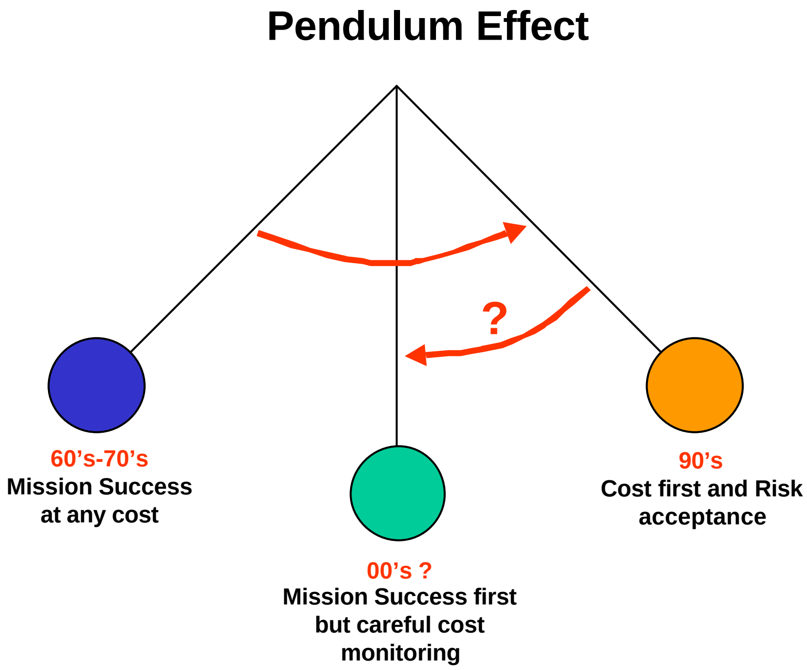
“Unlike return-to-flight recommendations, the Board’s management and cultural recommendations will take longer to implement, and the responses must be fine-tuned and adjusted during implementation. The question of how to follow up on NASA’s implementation of these more subtle, but equally important recommendations remains unanswered. The Board is aware that response to these recommendations will be difficult to initiate, and they will encounter some degree of institutional resistance. Nevertheless, in the Board’s view, **they are so critical to safer operation of the Shuttle fleet that they must be carried out completely**”.

5. IS IT A REAL TURNING POINT ?

During the 60's and 70's, the political will of the to big Powers racing for the leadership in Space, USA and USSR, was so high that the budgets were at the level of the ambitions of these countries. The success of the missions was the key driver, for National Security reasons in military space during this Cold War period, and as the proof of leadership in civil space through the achievement of emblematic "firsts". This first period was really characterized by "mission success at any cost".

Initiated after the end of the Moon exploration, the second period emphasized more and more the high costs of the space programs, and the progressive emergence of a commercial business created the feeling that the space business was becoming mature, that the governments could decrease their budgets and transfer responsibilities to the private sector. In the 90's this evolution resulted in the USA in the DoD New Acquisition Policy and the NASA Better, Faster, Cheaper motto, but the same trends appeared in Europe and other countries. The cost became the main driver, and risk became something to be accepted and mastered, in order to reduce the costs. Theoretically, all the methods, tools and management approaches were supposed to be implemented, to allow a balanced cost/risk approach. But, as demonstrated in the CAIB and DoD/USAF reports, the technical and organizational culture was in fact still influenced by the previous period, but with less money, ending finally in higher risks.

The USA being today the leading power in Space, we can expect that the future trend in Quality approach will quite influenced by the concrete consequences of both Columbia accident, and DoD/USAF new approach for acquisition of National Security Space programs. Our expectation is that there will be a switch to **mission success as the first priority**, not only for Safety in the case of the manned missions, but also for cost and delay good control. Will it mean that we will come back to the approach of the 60's ? Probably not, since the budget constraints will still remain. Therefore the key challenge of Quality will be really to achieve the good balance between Mission Success objective, and cost spending to achieve that objective.



6. PROPOSAL FOR A STATEMENT AND FURTHER STEPS

- <u>The statement</u>

The main challenge of the Quality in Space business is not a classical problem of methodologies, standards and tools. Risk assessment, hazard and failure modes analyses, ISO9000, ECSS, and MIL standards, lessons learned and knowledge management processes, all these approaches are theoretically and conceptually mastered, … but their real implementation and their applicability to the Space business is questionable.

The issue is more a question of organizational culture, of general approach of program funding, of awareness of the lack of maturity of the Space business, and of prioritization of key drivers for program management (proper balance between cost and risks).

Securing the Space business is requesting a cultural change regarding Quality approach : it is not possible to come back to the 60's-70's Cold War and pioneering era, where cost was not an issue and performance and mission success were the only drivers, and it is not reasonable to continue following the 90's momentum where cost reduction was the single driver.

The key challenge of Quality for Space programs will be to restore Mission Success as the primary driver, but to use modern methods allowing to achieve that goal for less money than in the 60's.

- <u>Further Steps</u>

It is proposed to focus the future work of the Study Group on global management and cultural issues, using all the expertise of the Academy. The following topics could be addressed, from the point of view of their impact on the Quality of Space Programs :

- customers / industry roles, responsibilities and relationship
- organizational culture : models, how to change a culture, …
- workforce management
- lessons learned management

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APPENDIX

Record of Main Failures and other Quality Relevant Events

1997 Main Events

Date	Spacecraft	Event	Description
10/01	Telstar 401	loss of satellite	Electronics short-circuited due to Sun electromagnetic radiation surge 4 days ear
17/01	Delta 2-7925 - GPS 28	launch failure	Destruction after 21s, due to SRB anomaly.
04/03	Progress M33	maneuver abort	Failure to re-dock to Mir after undocking on 6/02/97.
23/02	Mir	explosion and fire	Explosion of a solid-fuel oxygen generating candle in Kvant 1, causing a fire.
08/04	Columbia STS 83	mission abort	Mission abort (originally planned 16-day) due to fuel cell problems.
20/05	Zenit 2 - Tselina 2	launch failure	Explosion seconds after launch from Baikonur.
25/06	Progress M34	orbital collision	Collision with Spektr during a manual re-docking maneuver. Pressure loss.
30/06	ADEOS 1 (Midori)	loss of satellite	Contact lost after a power loss over a week.
03/07	Mir	attitude control loss	Gyrodynes failure, causing loss of attitude.
09/07	Iridium	loss of satellites	From a cluster of five, n°21 achieved a too low orbit, and n°20 failed in orbit.
16/07	Mir	attitude control loss	Cosmonaut inadvertently disconnects power/computer cable, resulting in the statio on the Sun. Systems restored within 24 hours.
14/08	Soyuz TM 5	rough landing	Landing rockets failed to fire on touchdown.
18/08	Mir	problem during docking	Mir computer system crash during re-docking of Progress M35. Docking comple
23/08	Athena 1 - Lewis	loss of satellite	Lewis found to be tumbling after successful launch. Re-entered September 28.
14/09	Proton K - 6 iridium	launch partial failure	Iridium 27 placed in too low orbit and failed. The other 5 are good.
28/09	PSLV - IRS 1D	launch failure	Malfunction of 4th stage and injection into a 308x822 orbit instead of a 820 circul
02/11	VLS - SCD 2A	launch failure	Destruction after 65 s of the first VLS, due to failure of one of the four strap on
24/12	Proton K - AsiaSat 3	launch failure	Failure of 4th stage after 1s of its second burn. Satellite later achieved GEO, thro maneuvers with moon swing by.

1998 Main Events

Date	Spacecraft	Event	Description
22/01	Shavit - Ofeq 4	launch failure	Launcher malfunction during 2nd stage burn.
21/02	H2 - Kakehashi	launch failure	Premature shutdown of 2nd stage leading to much lower than planned orbit.
mid May	Echostar 4	solar generator failure	One solar generator failed to deploy correctly. Consequence is a more than 50% channel capability, and a 4-year reduction of operational life.
19/05	Galaxy IV	computer failure	Failure of the 2 on-board computers. Total loss of the satellite.
15/06	Tsyklon - 6 Strela 3	launch failure	3rd stage early cut off and failed to adjust the final orbit (elliptical instead of circu a drift of the satellites with the previous cluster of Strela 3 launched in 1997
12/08	Titan 4 - Mercury ELINT	launch failure	Power interrupt pitched the launcher into the sea after 40s (1.4 B$ loss). Reason wiring harness, which was later found in other Titan during investigation.
27/08	Delta 3 - Galaxy 10	launch failure	Destruction at 75s, when guidance failure caused erratic flight. Reason was an i modeling of flight control dynamics in the on-board software.
08/09	Delta 7925 - Iridium	orbit injection failure	One Iridium (n°79) of a cluster of five achieved a lower than planned orbit.
09/09	Zenit 2 - 12 Globalstar	launch failure	Destruction after a computer error causing premature 2nd stage engine shutdowr

1999 Main Events

Date	Spacecraft	Event	Description
09/04	Titan4 - DSP 19	launch failure	Failure in IUS separation of lower stage and upper stage (600 M$ loss). Reason tape misapplication, which prevented good separation. Indications were present i
27/04	Athena 2 - Ikonos 1	launch failure	Fairing failed to separate after 4 min.
30/04	Titan 4 - Milstar 2	launch failure	Failure of Centaur burn sequence, due to computer software error (1.1 B$ loss) manual data entry error in flight software.
05/05	Delta 3 - Orion 3	launch failure	RL10B nozzle extender failed and upper engine burned for only 1s (230 M$ loss poor manufacturing process and improper quality oversight.
05/07	Proton M - Raduga	launch failure	2nd stage engine malfunction and explosion.
23/07	Columbia	propulsion problem	2 of 3 main engine controllers failed and a leaking hydrogen coolant line raised o temperatures on one main engine close to redlines.
Summer	Space Shuttle	fleet grounded	Detection of wiring problems, leading to general grounding of Shuttle fleet during inspection and correction. Concerns were expressed about Quality Control.
September		LM Report	Lockheed Martin Independent Assessment Team on Mission Success.
23/09	Mars Climate Orbiter	loss of spacecraft	Burnt in Mars atmosphere. Cutbacks in tracking, combined with incorrect values imbedded deep in flight software were to blame.
27/10	Proton K - Express A1	launch failure	Failed early in 2nd stage burn.
November		BAR Report	Space Launch Vehicles Broad Area Review : examine launch failures and mal recommendations for changes in practices, procedures and operations to enhanc
15/11	H-2 - MTSAT	launch failure	Failure in 1st stage propulsion systems.
03/12	Mars Polar Lander	loss of spacecraft	Failure during landing sequence at point of separation of lander and penetrators. pointed to shortcomings in project management and pre-flight testing.
11/12	VLS - SACI-2	launch failure	2nd stage failed to ignite (2nd flight test of VLS).
21/12	Galaxy XI	solar generator failure	Launch of the first of 6 satellites based on Boeing BSS702 platform (launched b 99 and May 01), which suffer large power losses due to the degradation of solar (XM1, XM2, Galaxy XI, PAS-1R, Anik 1F, Thuraya).

2000 Main Events

Date	Spacecraft	Event	Description
January	Shuttle	ASAP Report	Aerospace Safety Advisory Panel report addresses the issue of Shuttle workfor been reduced for cost savings and need to be revitalized with more people and ac experienced engineers.
		NASA Shuttle Maintenance Review	The review emphasizes attention to details in processing tasks and work specific on human factor aspects and workforce improvement.
10/02	M-V - Astro E	launch failure	First stage failure. Vibrations led the ceramic heat shield in the nozzle to break.
February		NASA FBC Task Final Report	Report on Assessment of NASA's "Faster, Better, Cheaper" practices.
February		DoD Assessment of Space Launch Failures	Report on the causes of 98-99 space launch failures and the actions required to access to space.
12/03	Zenit Sea Launch - ICO F1	launch failure	2nd stage premature shutdown due to a valve software command mistake.
March		MCO Report	Report on Project Management in NASA, by the Mars Climate Orbiter Mishap I Board
March		GAO Report	Space Station : Russian Compliance with Safety Requirements.
23/08	Delta 3 - DM-F3	launch not complete	Achieved lower than planned orbit, after last stage firing until fuel depletion.
27/08	Solidaridad 1	computer failure	Failure of back up on board computer (1st was lost in April 1999). Total loss of t
28/09	Galaxy VIII-i	propulsion failure	Loss of the ionic propulsion system. Reduction of operational life by 10 years.
04/11	Insat 2B	attitude control loss	Failure of attitude control system. Loss of the mission (no pointing).
20/11	Cosmos 3-M - QuickBird 1	launch failure	2nd stage failed to restart and terminal stage and satellite re-entered atmosphere
22/11	Galaxy VII	computer failure	Failure of 2nd on board computer (1st was lost in 1998). Total loss of the satellite.
27/12	Tsyklon 3 - Strela/Gonets	launch failure	3rd stage failed and launcher crashed.
December		NIAT Report	Report from the NASA Integrated Action Team : Enhancing Mission Success :

			the Future.

2001 Main Events

Date	Spacecraft	Event	Description
January		GAO Report	Report on NASA Major Management Challenges and Program Risks.
18/04	GSLV - GSAT 1	launch not completed	3rd stage cut off 12 s earlier than planned. Too low injection orbit prevented GSA orbit by its own means (too short in propellant).
11/06	Express 1	attitude control loss	Attitude control system failure leads to satellite deactivation.
12/07	Ariane 5 - Artemis / Bsat 2b	launch failure	Target GTO orbit not achieved due to upper stage failure to reach full thrust and off.
20/07	Volna - Solar Sail Test	orbital injection failure	The payload failed to separate from the final stage.
21/07	Taurus - Orbview 4	launch failure	Problem after 1st stage separation caused rocket to go off trajectory. The rocket failed to achieve a sustainable orbit.
06/09	PAS 7	Partial loss of power	Sort-circuit cells after eclipse, leading to 25% loss on solar array power
28/11	Progress M1-7	docking failure	Failure of soft docking due to a rubber seal left on docking ring by previous Prog cleared during EVA and further hard docking of Progress M1-7 completed on D
07/12	Arabsat 3A	Solar array failure	Failure on one Solar Array Drive, leading to partial power loss and 8 channels fa

2002 Main Events

Date	Spacecraft	Event	Description
January		GAO Report	Report on NASA : Better Mechanisms Needed for Sharing Lessons Learned.
04/02	ISS	goes out of control	Attitude control lost during 6 h. After Zvezda computers developed communicati failed to transfer data to US gyros, the GNC US computer stopped stabilizing the was in danger of losing electrical power, but crew was able to manually point U
04/02	H2-A - DASH	orbital injection failure	DASH re-entry demonstrator failed to separate from upper adapter. The main p was successfully orbited.
04/05	Direct TV-3	Computer failure	On-board computer failure. The satellite is de-orbited
08/03	TDRS 9	orbit transfer failure	Problem in pressurization of one of the satellite's propellant tanks. On-going slov achieve GEO orbit.
April	SBIRS High	Program restructuring	Cost overruns, poor management. DoD questions application of TSPR (Total Sy Responsibility) to Space Systems.
04/05	Direct TV-3	Computer failure	On-board computer failure. The satellite is de-orbited
July	Shuttle	Shuttle fleet grounded	Grounding for several weeks after finding cracks in LH2 lines. Problem fixed by
20/07	Italsat 2	Early end of life	The satellite is de-orbited after 6 y instead of nominal 10 y, due to attitude contro
15/08	CONTOUR	liberation maneuver failure	Probable break up of spacecraft at firing of STAR 30BP solid propellant motor f Earth orbit.
15/09	KT-1	Launch failure	Failure of first attempt of a new all-solid-propellant Chinese launcher.
15/10	Soyuz	Launch failure	Contamination in hydrogen peroxide line leads to explosion of strap-on booster 2 Crash near the pad.
25/11	Proton K/DM	Launch failure	Block DM upper stage failed to ignite for the second burn. Satellite left in parkin insurance loss (275 M$) leads to question the "bug is better" approach for comm satellites).
11/12	Ariane 5 ECA	Maiden flight failure	Vulcain 2 nozzle structural problem leading to loss of control.

2003 Main Events

Date	Spacecraft	Event	Description
January	Astra 1G	Power problems	SES receives 57 M$ from insurance for partial loss of power due to solar arrays
01/02	Shuttle	Destruction during re-entry	Columbia disintegrates during re-entry leading to loss of the 7-crew members. Ca leading edge, after debris from LOX/LH2 thermal protection knocked the left wi launch.
07/02	Thaicom 3	Solar array failure	Possibly similar cause as Arabsat 3A (Solar Array Drive)
20/02	Nimiq 2	Power supply failure	Failure of power supply subsystem just after orbit transfer
May		DoD/USAF Report	Report of the Defense Scientific Board / Air Force Scientific Advisory Board Jo Acquisition of National Security Space Programs
05/05	MSAT 2	Solar array failure	Same platform as MSAT 1 which had a similar failure in 1996
July	PAS 6B and Galaxy 4R	Loss of electric propulsion	These two Boeing 601 HP platforms have lost their xenon ion propulsion system reduction of their lifetime down to 4.5 years
22/08	VLS	Explosion on pad	Unexpected burn of one solid propellant booster, leading to the explosion of the l pad, during launch preparation operations. 21 people killed.
August	Shuttle	CAIB Report	Report from the Columbia Accident Investigation Board
19/09	Telstar 4	Short circuit	A short circuit in the primary bus has led to the loss of the satellite