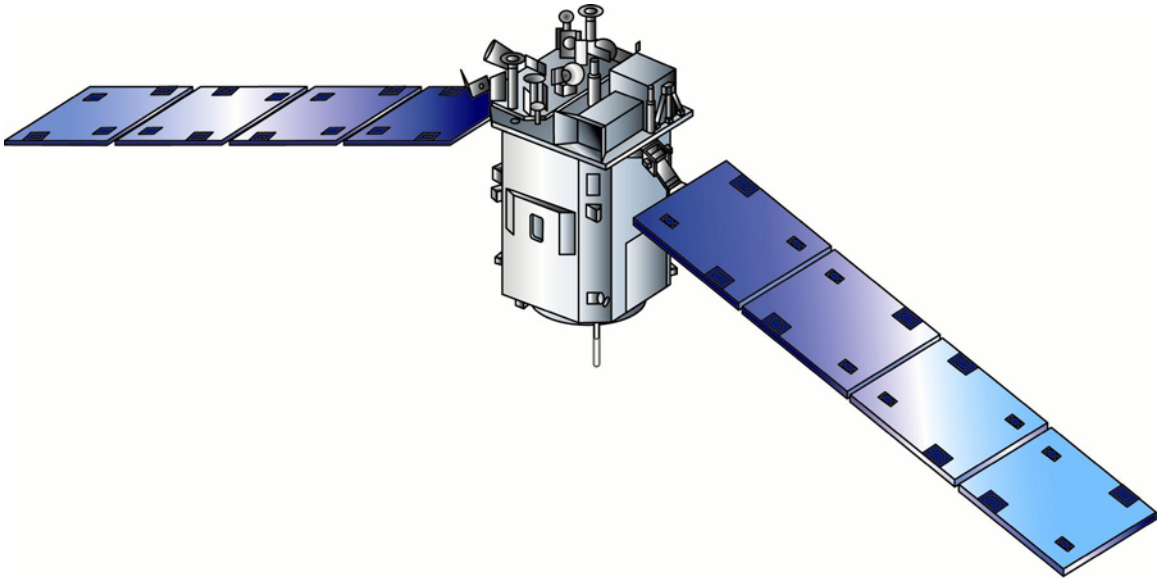
National Aeronautics and Space Administration (NASA)

Thermosphere Ionosphere Mesosphere Energetics and Dynamics Project (TIMED)

Case Story & Lessons Learned



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and
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EXECUTIVE SUMMARY

The TIMED mission was originally conceived around 1990 as a very ambitious multi-spacecraft mission. It eventually was launched on December 7, 2001 as a more modest but very capable mission using a single spacecraft. The program was caught in all the dramatic changes that NASA went through in this time period. At one point it came close to termination. The development can be characterized in three distinct phases.

It started in 1990 as a Goddard space Flight Center (GSFC) study mission. Under the direction of a new Administrator in 1992, there was a significant push to reduce mission size and cost while still maintaining a multi-spacecraft mission. The cost targets were a fraction of the original estimates. Eventually the GSFC Director decided the constraints and requirements were not compatible and the mission was not appropriate for GSFC. Thus in 1993 GSFC backed out and the Headquarters program office was without a TIMED developer. There are a number of program lessons that can be drawn from this phase including the need to recognize ground rule changes and react to them in a timely manner.

NASA Headquarters then asked the Johns Hopkins University Applied Physics Laboratory (JHU/APL) to study and implement a low cost mission. On the recommendation of an Ad Hoc Science Panel the mission was now descoped. It included only one spacecraft with four instruments. The APL Project Office reported directly to one person in the Headquarters program office who was the single point of contact. During this phase the first significant funding became available leading to a new start in FY97. One lesson learned early in this phase was that a better alignment was necessary between the resources and mission requirements hence the downsizing as APL got the mission. At this time the Administrator decreed that program management for all programs was to be moved from Headquarters to the Centers. GSFC was awarded program management responsibility, i.e., GSFC was inserted between Headquarters and APL.

The last phase, starting in late 1996 included the development and launch of TIMED under both GSFC and APL. The relationship between the APL Project Office and the GSFC Mission Office was a difficult one. There were many reasons for this including the legacy of the program changes of the previous years. As a result there are many lessons that can be drawn from this phase including the need for clear lines of authority and reporting in the program. There were also some subsystem process issues within APL that contributed to some post-launch anomalies. These were examined by a Mishap Investigation Board.

Despite the programmatic difficulties early and the post-launch anomalies the mission is working and has met its minimum success criteria. Had the lessons learned in retrospect been recognized earlier, the TIMED development would have been smoother.

INTRODUCTION

The purpose of this case study on TIMED is to help NASA managers, engineers, and scientists understand what happened during the implementation of the TIMED Project in order to be able to apply the lessons learned in future programs and projects. The study focuses on lessons learned, both successes and failures, but it is not a detailed history. There are no detailed traces of the Level 1 requirements or traces of the Program Operating Plan (POP) histories. The information was gathered mainly from discussions with some of the principals involved with the development of TIMED, and from reference material. The TIMED history is a long one, from roughly 1990 through 2001, and included a lot of changes and reorganizations. The people involved remember it in different ways so the inputs, though generally consistent, are sometimes at odds. A lot of the lessons learned on TIMED are already being implemented on other programs such as the Solar Terrestrial Probes (STP) and Living With a Star (LWS) programs. Also, it is unlikely the events and changes that took place during the TIMED development will be repeated soon. Nevertheless, there are still lessons worth noting and applying in the future.

TIMED was launched on December 7, 2001. At one time or another it was the exclusive development responsibility of a GSFC project office, an APL project office and finally an APL project office and GSFC mission office. In this report the TIMED development will be considered in the three phases it seemed to follow in its long development. The first one, from approximately 1990 to 1993, included the startup through the original project at the Goddard Space Flight Center (GSFC) until the disbanding of that project. The second one, from 1994 to 1996, includes the start of the APL study until GSFC gets reengaged. The third phase includes the APL/GSFC cooperation through post-launch, i.e., from 1997 through 2001. The lessons learned from each phase will be considered in that phase. Each lesson learned is identified as either one for Project-level or Program-level consideration.

TIMELINE

During the development of TIMED, from 1990 through 2001, NASA experienced dramatic internal changes in the way it did business. Understandably, TIMED was affected by these changes. In one respect one can read the Agency changes by looking at the TIMED development history. Therefore it is useful to consider a summary of the timeline of the development period.

TIMED Timeline

Prior to 1990	Various mission studies including one at the Advanced Missions Analysis Office (AMAO) at GSFC
Spring 1990	ITM Coupler the first priority in the Space Physics planning meeting. First Roadmap. Twenty five science requirements not prioritized.

December 1990	Science Definition Team established. GSFC selected to study TIMED with the understanding that it would develop the mission.
April 1991	Planning meeting report published. There should be 6 spacecraft in the approximately $1B category. Seen as the Space Physics "Great Observatory".
Summer 1991	OSS Woods Hole strategy session. Space Physics comes out with a more modest mission goal in the $300M to $400M range. Division Director decides TIMED is to be the first of these missions. Interested in starting STP.
1992	Started TIMED with a full Project Office at GSFC. Three spacecraft including one dipper. Range: $300M to $400M. Not yet a new start.
April 1992	AO released for the instruments. Science Definition team did a requirements priority before the AO went out.
Spring 1992	New NASA Administrator. He starts the push for smaller missions.
1992	1992 to 1994 GSFC TIMED Project works mission in phase B. First costs go up to $400M to $450M and then HQ pressures Project to reduce to $300M, $250M and even to $150M and lower. This is based on lack of funding and the new Agency push toward smaller missions.
July 1992	Delta NAR still has two spacecraft around $330M.
Fall 1992	Reviewed AO proposals. Requirements reduced from the 25 general ones of the early planning meetings to 9 prioritized ones and then to two (Temperature, density, wind structure of the MLTI and energy balance).
June 1993	Selected nine instruments. TIMED Science Working Group (SWG) established. Dipper spacecraft eliminated for cost reasons.
1993	Continued pressure to bring mission costs down to fractions of initial estimates. GSFC Director not interested in some of the new radical proposals being made. Team disbanded at GSFC. With GSFC out HQ no longer has a TIMED developer. At about the same time the SWG concludes you can't build the mission to meet the original science requirements at the new target costs.
Spring 1994	Ad Hoc Science Review Panel convened. Report issued in June recommends one spacecraft with four instruments.
May 1994	HQ decides to go to APL after GSFC gives up TIMED.

Summer 1994	APL TIMED Project studies one spacecraft using minimum HQ funding and some APL internal money. Oversight from HQ is one Program Manager who is the point of contact. Funding to APL is through a Navy contract.
October 1994	HQ descopes instruments from nine to four as recommended by the Ad Hoc Science Review Panel. Systems Requirements Review (SRR) held by APL
December 1994	Conceptual Design Review at APL.
February 1995	Initiate pre-phase B instrument design. Initiate mission-wide technology insertion assessment at APL
May 1996	Conduct Technology Insertion Review at APL.
June 1996	APL receives first real money, $10M, starts phase B.
1996	Administrator edicts that Program Management should not be done by HQ. This forces a change in the direct program management oversight of APL by HQ.
August 1996	Letter from Office of Space Science (OSS) Associate Administrator (AA) to GSFC (new Director) assigning GSFC program responsibility for TIMED. Agency is still seeking “light touch” management of outside organizations.
Fall 1996	GSFC establishes a small (3 FTE) TIMED Mission Office in the Flight Projects Directorate and a Program Manager in the Space Science Program Office (Code 180). TIMED shows up in the budget (FY97) for the first time as a new start.
February 1997	PDR and NAR.
April 1997	Presentation to the NASA PMC for permission to go ahead. TIMED was approved but STP was not. The LRD was set at January 2000. APL now in phase C/D.
June 1997	APL/GSFC letter contract signed. Launch Readiness Date (LRD) of January 2000.
November 1997	TIMED Program Implementation Plan developed by Code 180 and signed by HQ and GSFC. Total budget of $129.3M for phase C/D. It showed a GSFC Mission Office and APL Project Office with the Program Office at GSFC (Code 180). Still only 3 FTE in GSFC Mission Office.
December	CDR

1997	
February 1998	Level I Requirements Document signed by OSS.
March 1998	PCA signed for $129.3M for phase C/D and LRD of May 2000.
May 1998	Concept of Operations Review
July 1998	Independent Annual Review
1999	STP becomes a program. TIMED is placed under the STP Program. Much more infrastructure is now available to support the TIMED Mission Office.
October 1999	Pre-Environmental Review. First information that Jason couldn't make the May 2000 LRD. At least six launch date revision notices issued after May 2000.
February 2000	Post-Environmental Review
June 2000	Mission Operations Review
October 2000	HQ Red Team review. Minimum mission success criteria defined.
November 2000	Flight Operations Review. Definition of Mission Success Criteria.
February 2001	Delta Red Team Review
May 2001	Delta Flight Operations Review and Pre-Ship Review.
July 2001	Mission Readiness Assessment; West Virginia team review of flight software.
August 2001	Mission Readiness Review
December 7, 2001	TIMED/Jason launch. TIMED had four anomalies in GNC system but recovered.
January 22, 2002	TIMED declared operational. Phase E commences.
February 11, 2002	TIMED Mishap Investigation Board (MIB) appointed to investigate the anomalies.
April 22, 2002	TIMED meets minimum mission success criteria.

PHASE ONE: 1990 to 1993

TIMED started in the "old NASA". Spacecraft were becoming increasingly larger and the missions were taking longer to develop compared to the earlier years of the Agency. Studies to explore the Mesosphere-Lower Thermosphere-Ionosphere (MLTI) were taking place in the 1980's. A Space Physics planning meeting in 1990 envisioned a large number of spacecraft, at least six, and instruments, fifteen, in the set of MLTI missions. This set would be equivalent to a "Great Observatory" for Space Physics. There were 25 unprioritized science requirements. It was expected to cost approximately $1B. The first of these was to be the ITM (Ionosphere-Thermosphere-Mesosphere) Coupler which would later become TIMED. The planning meeting report was published in April 1991. At an Office of Space Science (OSS) strategy meeting at Woods Hole in the summer of

1991 the Space Physics goal became more modest, i.e., a couple of spacecraft in the $300M to $400M range. The Space Physics Division Director decided that TIMED would be the first of these missions.

A traditional project office was opened at Goddard in 1992 to study TIMED in anticipation of a new start development. The project office came over, fully formed, to TIMED after dissolution of a Space Station project they were on. The study included two high altitude spacecraft plus a dipper that would dip into the lower regions of the atmosphere. Based on the requirements as understood, the mission costs actually increased to as much as $450M during the study. In April of 1992 an Announcement of Opportunity (AO) was released for the instruments. The Science Definition team had reduced and prioritized the large number of requirements generated in the 1990 planning meeting for this AO. In July of 1992 a Delta Non-Advocate Review (NAR) was looking at two spacecraft and a cost estimate of $330M

Had there been no other changes, a new start might have been expected in a couple of years possibly in the $300M range with other similar size missions. However, a new Administrator came to NASA in 1992. His vision was to have many more, smaller missions with shorter development times. This vision and pressure on the Agency budget because of other problems worked against a TIMED new start in its present form. Responding to these pressures the Headquarters program office pressured the Goddard project office to reduce costs to $300M, $250M, $150M, and even to $100M. In the meantime the instrument proposals were reviewed in the fall of 1992 and nine instruments were selected by June of 1993 when a Science Working Group (SWG) was also established. The original 25 requirements had been reduced to nine and then to two (Temperature, density, wind structure of the MLTI, and energy balance).

By June of 1993 the dipper spacecraft was gone because of cost constraints. The pressure to reduce the costs while maintaining multiple spacecraft, now two, continued through 1993 with frustration at both the program office at Headquarters and the GSFC project. One of the concepts even included five microsats on Pegasus class launch vehicles. However, with a factor of three or four reduction the budget could not support the requirements of the full mission. At about the same time the SWG concluded the mission couldn’t be done with the original requirements within the cost constraints. At a meeting in 1993 between the Space Physics Division Director and the GSFC Director the latter, responding to the cost pressures on the project, indicated GSFC was not interested in developing small spacecraft under these constraints. He also did not see GSFC in the development of the very small spacecraft being considered. Essentially GSFC turned down TIMED as it was then envisioned. The project team was disbanded and TIMED went back to being studied in the Advanced Missions Analysis Office (AMAO) at GSFC. At this point the Headquarters program office no longer had a TIMED developer. Thus what started as a grandiose vision only three years earlier was now at a standstill.

PHASE ONE LESSONS LEARNED

Some general lessons can be drawn from this phase of the TIMED story from the experiences of both the Headquarters program office and GSFC.

1. It is necessary to recognize and respond to ground rule changes in a timely manner. (Program)
There were sea changes in the Agency in these years in the way the Administrator was moving the Agency. Neither Headquarters nor GSFC recognized the changes in a timely manner, or they believed they would not endure. A dramatic change had been made in the ground rules but on TIMED the attempt was made to continue looking at multiple space missions at one quarter to one third the original cost estimates. The mismatch between mission requirements and the budget resource was too great but neither the program office nor GSFC moved off the original path. It is not too surprising that large organizations respond to dramatic changes slowly. The lesson learned here is to be sensitive to ground rule changes for what they are, i.e., dramatic changes in direction. They need to be verified as a first step, i.e., are you sure this is what we want to do? Upon verification the new direction needs to be consistent with the new ground rule; in this case the redefinition of a modest, single spacecraft mission for approximately $100M.

Convention of the TIMED Ad Hoc Panel in 1994 was a key step in saving TIMED. The challenge, in the words of the panel, "…was to find to find the core subset of measurements that could provide, at least, the zeroth order definition of the state of the MLTI region within available resources." In other words, to strip down requirements to do a viable mission within the cost constraints. The reality had finally sunk in. This resulted in the final form in which TIMED flew, i.e., a single spacecraft with four instruments. However, this was done after the GSFC/Headquarters break. Had this been done earlier, it is likely the GSFC/Headquarters break wouldn't have happened.

2. Control expectations (Program/Project).
As the Agency changed there was an attempt to fit many of the original expectations into the shrinking budget resource. Eventually the requirements and the number of instruments were reduced but not without some science team resistance. The final descope from nine to four instruments required a new peer review science panel (TIMED Ad Hoc Panel) to make the recommendations. The program office needs to continually control the expectations of the science community during the definition and development of any program. Even under normal circumstances there are changes to the science from definition through development. In times of great change it is even more important to control expectations. It is counter productive to argue that "you can't do the science for that small amount of money." A successful mission was eventually launched under the smaller budget even though it was not as extensive as the original vision. It is possible to do good science even if it is not all the science you want to do.

3. Center buy-in and cooperation is necessary (Program).
Although both the program office and GSFC did not recognize the ground rule change (or hoped it would go away), GSFC also originally did not buy in to the change in direction for GSFC regarding the new emphasis on smaller, more rapidly developed missions. GSFC was structured for the older way of doing business. However, like any good organization it could adapt to the goals of the parent organization. However, there was a philosophic difference between the Administrator and the GSFC Director on the goals of GSFC and the Agency. Although this was resolved within a couple of years and Goddard changed and thrived, the initial resistance did contribute to the original disbanding of TIMED. Although each Center has unique capabilities to contribute to the NASA mission it is still necessary for that Center to buy-into the Agency goals. Of course this includes a mutual understanding by the Center and Agency on how the Center can best contribute.

4. Basic mission requirements must be set early, prioritized, and maintained (Program/Project).
The original planning included multiple requirements (25), multiple spacecraft (3) and many instruments (15). As the pressure mounted to do the mission for closer to $100M rather than $300M, all these, i.e., requirements, spacecraft, and instruments, eventually were reduced. However, it was not done without extreme difficulty, including a new peer review science panel to recommend the final four instruments, and a GSFC/Headquarters break on squeezing all the requirements into a smaller box. Had the original requirements been prioritized early it might have been possible to recognize early that good science could be done with one spacecraft and fewer instruments by concentrating on the top few requirements. While not as desirable from the science community point of view, it is part of the program office responsibility in controlling expectations.

PHASE TWO: 1994 to 1996

No longer having a TIMED developer after GSFC backed out, the headquarters' program office decided to go to the Johns Hopkins University Applied Physics Laboratory (JHU/APL). The agreement was that TIMED would have the same management arrangement as was then in place for NEAR, i.e., a single point of contact at Headquarters. APL has experience in small scientific missions. In June of 1994 APL established a project to study TIMED. It was now a single spacecraft with nine instruments. This was clearly a different concept from the one that left GSFC where multiple spacecraft were studied. At first APL used some internal money to start the study. Earlier in the year, spring, consideration was being given to descope the number of instruments. The Science Working Group itself could not agree on this so a special science panel, with secret membership, was established to make recommendations. This panel, the TIMED Ad Hoc Science Review Panel, reported in June recommending a single spacecraft with four instruments. In October 1994 the program office descoped the number of instruments from nine to four.

The Systems Requirements Review (SRR) and Conceptual Design Review were held at APL in October 1994 and December 1994 after which Headquarters started providing some study money. From December 1994 to June 1996 APL was provided with about

$1.5M of study money. These funds were used to support early instrument design and technology insertion assessment. The funding was through an existing Navy contract. During this extended phase A study there was a single point of contact from Headquarters with APL. This person provided what oversight there was of TIMED at APL. There are different views on the effectiveness of this management approach. The Headquarters program manager and the APL project team thought it worked well. The Space Physics Division Director, however, was uncomfortable with only a single point of contact and minimal oversight. This approach was never tested fully on TIMED before it was overtaken by other events that changed the way business was done.

APL as well as NASA was also undergoing change at this time to enhance its technical base. (This was true in other parts of the aerospace industry as well.) One of the new APL developments was the Integrated Electronics Module (IEM) which would integrate the electronics for a number of subsystems and significantly reduce mass. APL decided to develop IEM flight units and other new technologies for TIMED. As part of the development, APL decided to incorporate an IEM Engineering Test Unit (ETU). Other new development challenges for TIMED include the addition of a spacebourne Global Positioning System (GPS), autonomous operations, and a sophisticated ground system development. By the time of the PDR in1997 the spacecraft design was very different from the one started in 1994 as a result of the new technology insertion. These new developments, done in parallel with a spaceflight mission development, put a strain on the TIMED budget.

In June 1996 APL received $10M and started a more serious phase B study. TIMED showed up in the FY97 budget for the first time as a new start. In the same year, 1996, the Administrator made another change. He directed that program management was no longer to be done from Headquarters but was to be delegated to the Centers. Simultaneously, he was pushing for recognition that many organizations besides NASA were capable of developing missions and should be allowed to do so with only a “light touch” management from NASA. These organizations were to have total responsibility for the mission including its’ success. In August 1996 a letter from the Office of Space Science Associate Administrator to the new GSFC Director assigned program management responsibility for TIMED to GSFC. GSFC assigned a program manager in the Space Science Program Office (Code 180), and established a small Mission Office (not Project Office) in the Flight Projects Directorate. There were less than three full-time-equivalents (FTE) in the Mission Office. The intention was to keep the light touch management approach.

Note: There had been some unsubstantiated claims that APL had used political influence to move TIMED from GSFC to APL. There doesn’t seem to be much evidence for this based on the sequence of events. After some frustrating study work at GSFC to squeeze the original concept to fit a tight resource limit the GSFC Director declined to continue the process. This was late 1993. Headquarters made the decision in 1994 to go to APL after GSFC was out. It does seem likely that after the decision was made to go to APL that some of the Maryland Congressional delegation did work to put money in the budget

for TIMED in order to keep the work in Maryland. Had the GSFC/Headquarters break not happened it seems unlikely TIMED would have moved to APL from GSFC.

PHASE TWO LESSONS LEARNED

At least one lesson can be drawn from this phase.

1. Building and employing an ETU for a new hardware development is still a good idea (Project).
The relatively small APL staff was stressed later in the TIMED development by developing the new concept IEM at the same time as the flight mission development. This is a challenge for any project. However, having decided to develop the IEM it was a good idea to also build the IEM ETU. This ETU, while not preventing all problems, did enable a smooth integration later in the process and therefore helped to avoid more cost and schedule problems. It may seem obvious that an ETU for a new development is a good idea but often early cost pressures will tempt one to delete this cost.

PHASE THREE: 1997 to 2001

The GSFC Mission Office started getting involved in late 1996, early 1997, just in time for the Preliminary Design Review (PDR) and another Non-Advocate Review (NAR) in February 1997. The NAR recommended implementation for a January 2000 launch. Following the NAR there was a presentation to the NASA Program Management Council (PMC) for permission to go ahead with TIMED. TIMED was approved but the Solar Terrestrial Probes (STP) program, which had been planned since 1990, was not approved. Co-manifesting TIMED on a Delta with Jason was being considered in lieu of a TIMED Taurus launch. TIMED was now in phase C/D. As part of the move that put TIMED under a program office at GSFC, it was decided to establish a contract directly between GSFC and APL rather than continue going through the Navy contract. The TIMED Mission Manager did establish that contract. The letter contract between APL and GSFC was signed in June 1997.

A common theme among all parties involved from Headquarters, GSFC, and APL in this phase is that there was a poor relationship between the APL Project Office and the GSFC Mission Office. The perceived truth depended on where one was sitting at the time. The difficulties experienced by both parties was due to a number of factors. One was the path that led to this point. Both GSFC and APL had exclusive development rights at one time or another. At first, GSFC had the mission uniquely, before it came to a halt there. Then APL was the sole developer reporting directly to Headquarters. Finally GSFC was brought back and inserted between Headquarters and APL. This process is almost guaranteed to promote resentment. A second factor was that there were some personality conflicts between some of the principals. Third, the way of doing business at APL and GSFC is different, i.e., they have different cultures. Part of the difference can be

attributed to the size difference (3500 staff compared to 500 staff in the APL Space Department).

The situation as seen by the APL Project Office was as follows. They see APL as being perfectly capable of developing a mission, on their own, from the science, through development, integration, and operations. This is unlike a contractor for GSFC who develops a spacecraft, for example, and then integrates GFE instruments, helps launch it and then returns it to GSFC for operations. In this view, it is perfectly natural to have an APL Project Office report directly to a Headquarters program office. Even if the program office is at GSFC they see the APL Project Office reporting directly to it, i.e., not through a GSFC Project Office. The GSFC Mission Office (a.k.a. Project Office[1]) was seen as redundant. The low level oversight provided by a single point-of-contact (program manager) was seen as very compatible with the independence APL felt while developing TIMED in the second phase. Many of the APL actions were seen by the GSFC Mission Office as if APL was operating from this premise.

The GSFC Mission Manager saw it differently. He understood and accepted the challenge to manage APL with a "light touch". The TIMED Program Implementation Plan states," In recognition of JHU/APL's demonstrated performance, GSFC intends to maintain a minimum oversight while executing the Center fiduciary responsibility for the federal funds involved." However, it also states," The [GSFC] Director holds …the TIMED Mission Manager accountable for the development and implementation of the mission at JHU/APL and execution of the mission objectives within the cost and schedule limits." The first quote clearly reflects the "light touch" approach; the second emphasizes the more traditional project control. The light staffing, as stated in the Plan and imposed by the GSFC, reflected the Center's commitment to the light touch approach. However, the expectations on the Mission Manager by GSFC were more in the context of the GSFC culture which is to maintain control over the contract and project. This extended to the processes also. Although the contract SOW allowed APL to use its own processes, observers from GSFC were concerned when they observed these were different from the GSFC processes they were familiar with.

Inexperience and personality conflicts were said to play a part in the difficulties. The GSFC Mission Manager, for example, was said by some to make some unreasonable demands, and could have used a lighter touch. Personality conflicts are hard to quantify objectively, and claims they existed could easily be colored by the different world views described above. Nevertheless this could have been a factor that could have been eased.

The third of these issues is the cultural difference between GSFC and APL. To exaggerate a bit to make a point, if this was binary, one could say GSFC is process oriented and APL depends on individual experience and expertise. This is clearly an exaggeration because APL does have processes and GSFC could not operate without very

[1] The designation Mission Office at GSFC is used here because that is how it is identified in the Program Implementation Plan (PIP). However, this office operated and reported as a Project Office at GSFC and was located in the Flight Programs and Projects Directorate.

talented people. Ideally you need both good processes and experienced people to be successful. Nevertheless, the cultural difference is acknowledged by both parties.

The issue of either lack of processes or not following existing processes, however, is more than a perceived difference between organization cultures. The Mishap Investigation Board (MIB) convened to investigate the Guidance and Control (G&C) post launch anomalies concluded that these were consequences of inadequate procedures. Refer to the MIB report (References). The conclusion was that the root and/or contributory cause in all four anomalies are related to the lack of management processes. The observation was made that APL relies on the knowledge and integrity of key staff in lieu of a more process oriented approach. There were observations by members of the GSFC technical staff, that the processes used at the spacecraft integration and test level were not consistent with the ones they were used to at GSFC. However, the contract did allow APL to use their own methods and procedures whenever possible if they met the requirements of the statement of work. APL does have processes but acknowledged these were not appropriately followed in the G&C area.

Along with the disagreements on lines of authority, having to do with how the program evolved, and personality conflicts, this difference in approach was also fundamental in the conflict between the APL Project Office and the GSFC Mission Office. The Mission Manager was trying to do a light touch management but still expecting APL to meet the processing standards of a more process oriented GSFC culture even though the contract SOW allowed APL to use its own processes. He had to report to GSFC management in this mode. APL, on the other hand, was proceeding in their, generally successful, key person mode.

The TIMED Program Implementation Plan (PIP) was developed by the GSFC program office (SSPO) and signed in November 1997. The Level 1 Requirements Document was signed by OSS in February 1998 and the Program Commitment Agreement (PCA) was signed in March 1998. All three of these documents were very late in the program cycle compared to normal program practices. The latter two came after the December 1997 CDR. These were probably late because there was an attempt to catch up on the program documentation following the dramatic program changes of the previous years. The APL Systems Requirements Document (SRD) Rev A, a Level 2 document, was signed in January 1997, which was before the final Level 1 requirements document. This document (7363-9001) records the system requirements for the TIMED mission. The document was updated following major design reviews. Although the PIP specified a cost cap of $129.3M through phase C/D (FY2000), it did not specify a launch readiness date (LRD). The PCA specified a phase C/D cost cap of $129.3M but also specified a May 2000 LRD (slipping from January 2000).

In 1999 STP became an approved program located at GSFC. TIMED was placed under the STP program office. This provided additional infrastructure for the Mission Office which eased some of the Mission Manager's burden. Additionally regular meetings were established between the Program, Project, and Mission Managers at both APL and GSFC. This helped ease some of the tension between the respective offices.

In October 1999 the first information was received that Jason could not make the May 2000 LRD. This caused the first of a number of slips in the co-manifested launch. This is normally a difficult situation anyway but here was exacerbated by the fact that TIMED and Jason were from two different NASA Enterprises. Thus it was not possible for one Associate Administrator (AA) to change his priorities and move money to accommodate the slips. The slips impacted two Enterprises. There seems to be general agreement that although APL might not have made the January 2000 LRD, they had a chance of making the May 2000 LRD. As it turned out, the delays until the December 7, 2001 launch date were caused by Jason. At least six launch date revision notices were issued after May 2000.

The cost overrun on TIMED was in the 10% to 15% range. This was caused primarily by JASON imposed launch delays, NASA Integrated Assessment Team (NIAT) compliance, and a belated decision to use engineering models in developing the IEM. Considering the wide swings early in the program ($300M to $400M) once the decision was made to go to a small single spacecraft with four instruments in 1994 the program costs have been generally under control.

A Red Team review was held in October 2000. The team expressed some of the same process concerns expressed previously by GSFC. There was also concern about flight software and the lack of a classical Independent Verification and Validation (IV&V) on the software. A number of actions were assigned and completed. More confidence was gained as the actions were completed as reported in the Red Team presentations to GSFC management. The definition of the mission success criteria, motivated by the Red Team, was completed on November 17, 2000. At the April 4, 2001 presentation to the GSFC PMC the Red Team, although still concerned about flight software, concluded that TIMED had a high probability of achieving the minimum success criteria and a medium to low probability of achieving full mission success (2 years). At the Mission Readiness Review the Goddard Systems Review Office assessed the probability of full mission success as medium.

TIMED and Jason launched successfully on December 7, 2001. TIMED experienced four G&C anomalies early in the mission. These were quickly overcome and the mission is now in the operational phase. On February 11, 2002 a Mishap Investigation Board was convened to investigate the anomalies. The MIB reported to the GSFC PMC on May 17, 2002 and August 28, 2002.

TIMED met the minimum mission success criteria on April 22, 2002.

PHASE THREE LESSONS LEARNED

Some lessons can be drawn from this third and final phase of the TIMED development.

1. Clear lines of authority and reporting are necessary and must be followed (Program/Project).

In the implementation of a project there must be a single line of authority proceeding from the Headquarter Enterprise through the program office to the implementing project. The formal communications must follow that line. The official link was from the GSFC program office, originally the SSPO, and then the STP, through the GSFC Mission Office to the APL Project Office as specified in the PIP and the APL contract. This line was apparently followed for formal communications.

However, there were acknowledged contacts between the APL Project Office and persons in the Enterprise office at Headquarters. This was most likely a holdover from the previous phase in which the contact between Headquarters and APL was direct. Headquarters and APL saw these as informational or status discussions appropriate to the PIP. However, some in the Mission Office at GSFC perceived that it was often bypassed. They often saw Headquarters as siding with APL when there were disagreements between the Mission Office and the Project Office and, at one time (early), this was expressed openly. Open, non-directive communications among all members associated with a project should be encouraged and guided to apply the strengths of all members to help the project. This communications link needs to be proactively managed by the government office to reap its full benefit.

2. <u>The rules of engagement must be agreed to and put into writing (Program/Project).</u>
When a contract is let from a NASA Center to an aerospace contractor normally the rules on implementation are understood ahead of time. They are based on the government's Statement of Work (SOW), requirements, quality assurance requirements, reporting requirements, etc. They follow the processes of the NASA Center. In this case when the decision was made to go directly to APL from Headquarters, the Headquarters program office (phase two) depended on APL's proven capability as a spacecraft developer and did not impose development rules as a Center would have. APL, therefore, depended on its own experience and processes. When GSFC came back into the picture, the GSFC/APL contract that was established did provide for APL to use their own processes which would be consistent with the cost and schedule estimates they proposed. In fact though, this might not have been fully accepted because the Mission Office was reporting to a management team that seemed to expect adherence to its culture because GSFC still had ultimate responsibility. The former Director of Flight Programs and Projects (FPPD) said that APL had agreed to adhere to NPG 7120.5 and agreed to do no more and no less than GSFC would do. APL claims they did so. This NPG does not get into the details of the processes so there was still misunderstanding. It should be ensured that such expectations are well spelled out and adherence maintained.

3. <u>A clear decision on the method of implementation of a project must be made and the relationship of the program and project defined for that method (Program).</u>
A mission funded by NASA will always be seen as a NASA mission whether it is developed in-house, with an aerospace contractor, with an independent Principal Investigator, or almost exclusively by another organization such as APL. In most cases a GSFC project reports to a NASA program office often at GSFC. The project contracts with one or more aerospace contractors for parts of the project, e.g., the spacecraft or some instruments, and possibly the integration and test. The contractor establishes a

project office reporting to the GSFC project for their part in the mission implementation. However, it is possible that a GSFC program office can have a contract such that the project office of an organization capable of full mission development can report directly to the GSFC program office without an intervening GSFC project office. In this situation the project needs to agree to the NASA ground rules and processes or the program office needs to be assured the ones used by the project are equivalent. This is necessary because NASA is still the steward of taxpayer money and is ultimately responsible for ensuring proper implementation and mission success. If there is to be a GSFC project office involved besides the program office, the ground rules and processes must be made clear in writing. They need to be those of the funding organization (NASA) or equivalent to them and acceptable to the funding organization.

Phase three was the third method of implementation imposed on TIMED. It was caught in the changes the Agency was undergoing in this period. As a result there were some misunderstandings in the implementation in this phase.

4. The Center must take ownership of any project for which it has responsibility and staff it accordingly (Program).
This seems self evident and a lesson already learned at GSFC. However, in the mid 90's there was talk about mission developers other than NASA being very capable of taking full responsibility for mission success. This was interpreted to mean the developer would be provided the funds and little direction by NASA which would use a "light touch" management. This was the approach used in phase two between Headquarters and APL. The result, in phase three, was that at GSFC the Mission Office was staffed very lightly (2 people) and put into a small office with little support. The message was to work with APL but don't impede them. "Light touch" management was directed in the PIP but de facto guidance was not provided in this admittedly new approach across the Agency. The lack of GSFC ownership exacerbated the issues discussed above. Had GSFC taken a stronger ownership position and been more proactive it is possible that some of the issues that divided the Project Office and Mission Office could have been worked out earlier.

5. Management processes appropriate for NASA funded projects need to be in place, verified and used no matter where the project is developed (Program/Project).
The Mishap Investigation Board report to the GSFC PMC said the root cause on the initial failure of the spacecraft to stabilize was that, "The customary NASA project management processes were not in place for the TIMED G&C development. APL relied on having experienced people in lead positions and didn't rely on processes for documentation and checks by others." They emphasized this again later by saying, "The choice to rely on the knowledge and integrity of key staff in lieu of a process oriented approach led to inadequate levels of testing and inadequate procedures when the key staff lacked crucial experience and insight into their tasks." If this is the case, the processes deemed to be inadequate by GSFC should have been corrected during the contract negotiation process. The processes need not be identical to the government processes but should be equivalent. The TIMED contract did allow APL to use its own methods and procedures whenever possible as long as they met the requirements of the statement of work. APL does have processes in place and they worked on most of the subsystems.

They acknowledge that there was a breakdown of the G&C processes and some changes have been made in this area.

A competent and experienced staff is always needed for development of these complex spaceflight missions. However, as the missions become more complex and involve more people it is not possible to keep everything as it was for simpler missions. Backup, independent eyes, and configuration control available to everyone, are necessary for mission success.

6. It is necessary to adhere to the processes developed for integrating and testing a spacecraft. (Project)
All the subsystems on TIMED worked well on orbit except the G&C subsystem. It experienced some anomalies. It has since been acknowledged that there was a breakdown in the APL G&C test processes that led to these anomalies. The possession of good processes for integration and test alone does not guarantee success. They must be implemented correctly.

7. Co-manifesting multiple missions on the same launch vehicle is still an appropriate cost saving technique but it should be employed within one Enterprise only (Program).
The significant delays caused by Jason (approximately 18 months) had a significant impact on TIMED which came out of a different Enterprise (Space Science). While a delay is always expensive if it concerns two missions within a single Enterprise, at least that AA can make decisions based on his/her priorities and move money around, and/or delay something based on their priorities or trade studies. In this case a much larger impact was felt on the Agency because the delay impacted two Enterprises instead of one.

8. Personality conflicts can be real and should be addressed and resolved to assure efficient functioning of the project team (Project).
In this case many of the factors attributed to personality conflicts could have been caused by the tortuous route the project followed through development and the real differences in processes and procedures between APL and GSFC. Nevertheless, addressing them is important perhaps by getting others involved. In this case, involvement of the STP program office did help. The experience of the managers should also be taken into account when the communication interfaces are very complex and the need to lead people through these interfaces is important for the project.

Some of the lessons learned proposed by the MIB after their review were similar to some of the ones discussed above. However, they had some additional, more narrowly construed lessons learned also. For completeness these are listed in Appendix A. For more details see the referenced MIB report.

CONCLUSIONS

The TIMED mission has been successful, meeting its minimum success criteria in April 2002. Its performance is a tribute to the tenacity of a number of people at NASA

Headquarters, APL, and GSFC in keeping the project going despite the difficulties. This determination might be the most important lesson learned. The project started in the early 90's and followed the dramatic changes in the Agency over that time period. It was in danger of being terminated before being turned around, under different ground rules, and finally implemented. The successful implementation meant some real-time changes had to be made along the way to keep it viable. TIMED was in more trouble than it need have been as a result of the reactions to the changing environment not always being efficient. From this a number of lessons can be drawn in retrospect that, had they been applied at the time might have eased the development and perhaps avoided the near termination.

Although it is unlikely that other projects will go through the exact environmental changes experienced by TIMED the lessons learned are generic. Each program goes through a unique cycle and should be able to apply some of these lessons learned. There are indications that many of these are already being applied in the STP and LWS programs.

Appendix A

The Mishap Investigation Board (MIB) investigated the post-launch anomalies in some detail. The MIB report proposed a number of lessons learned. Some are similar to those presented in this report and are not repeated here. Others are more detailed and narrowly construed. These are listed below for completeness. See the MIB report.

a) **True end-to-end testing of subsystems is extremely valuable in verifying that the subsystem has been properly designed, hardware has been installed correctly on the spacecraft, flight software has been developed and coded correctly, and that the assumptions made by the developers and engineers are correct and have been implemented into the design correctly.** It is very important in conducting these end-to-end tests that the tests be designed to **"**test as you fly**".**

b) **Ensure that Lead Engineers are assigned ownership of all aspects of their subsystem.** On TIMED, the G&C organization did not assume total ownership of the sun sensor orientation or magnetic torquer bar position and orientation. As a result, both of these elements were used in the control algorithms incorrectly.

c) **It is very important to plan on contact with the spacecraft as soon as possible following separation from the launch vehicle.** This contact was difficult to achieve for TIMED with available ground stations and the project decided to make use of TDRSS during this initial period of operation. The decision to use TDRSS turned out to be important because of the sign error in the G&C systems.

d) **Contingency planning and contingency development should be based on top down considerations.** All contingencies developed for the TIMED mission were based on bottoms-up considerations; e.g.," what happens if a particular component fails?" Because of a lack of a top-down contingency design, there was no contingency plan for the case where "the spacecraft failed to despin". The recommendation is that such planning be based on a top-down based on such tools as fault tree analysis and failure modes and effects analysis.

e) **Use the same ground system for I&T and operations**. Some members of the flight team worked with the systems during I&T, which increased their knowledge of the observatory and facilitated post launch response to problems. The Project responded rapidly and correctly to the post-launch problems.

f) **Have a software management plan which defines the required software processes and which is not waived**. This should include configuration management, peer reviews, regression testing, end-to-end testing, and stress testing.

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