J10.2 THE APPLIED METEOROLOGY UNIT: NINETEEN YEARS SUCCESSFULLY TRANSITIONING RESEARCH INTO OPERATIONS FOR AMERICA'S SPACE PROGRAM

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1. INTRODUCTION

The Applied Meteorology Unit (AMU) provides technology development and transition services to improve operational weather support to America's space program. The AMU was founded in 1991 and operates under a tri-agency Memorandum of Understanding (MOU) between the National Aeronautics and Space Administration (NASA), the United States Air Force (USAF) and the National Weather Service (NWS) (Ernst and Merceret, 1995). It is co-located with the 45th Weather Squadron (45WS) at Cape Canaveral Air Force Station (CCAFS) and funded by the Space Shuttle Program. Its primary customers are the 45WS, the Spaceflight Meteorology Group (SMG) operated for NASA by the NWS at the Johnson Space Center (JSC) in Houston, TX, and the NWS forecast office in Melbourne, FL (MLB). The gap between research and operations is well known. All too frequently, the process of transitioning research to operations fails for various reasons. The mission of the AMU is in essence to bridge this gap for America's space program (Figure 1).

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The AMU has received national recognition for its successes in transitioning weather technology into operations, e.g. Best Manufacturing Practices, 1996; National Weather Association, 2006). Previous papers have outlined the processes that have led to this success (Dunn and Merceret, 2008; Merceret and Madura, 1994; Merceret and Manobianco, 2003 a, b) while others have focused more on the products that have been delivered by the AMU (Bauman et al., 2004; Merceret et al., 1995; Merceret et al., 2004). This paper focuses exclusively and in much greater detail on the philosophy, processes, and procedures that have been employed to successfully transition weather technology to operations for nearly two decades. We believe the philosophy as well as the processes and procedures are transferrable to other facilities and programs. There is nothing inherently "space program related" about them.

The next section discusses the reasons and recommendations that led to the creation of the AMU and how these translated to its philosophy and design. Section 3 discusses the essential elements of successful technology transition. Section 4 presents the practices and procedures that the AMU has evolved to assure that we provide all of the elements discussed in the previous section. Section 5 contains additional discussion that may facilitate using what has been presented here in other venues.

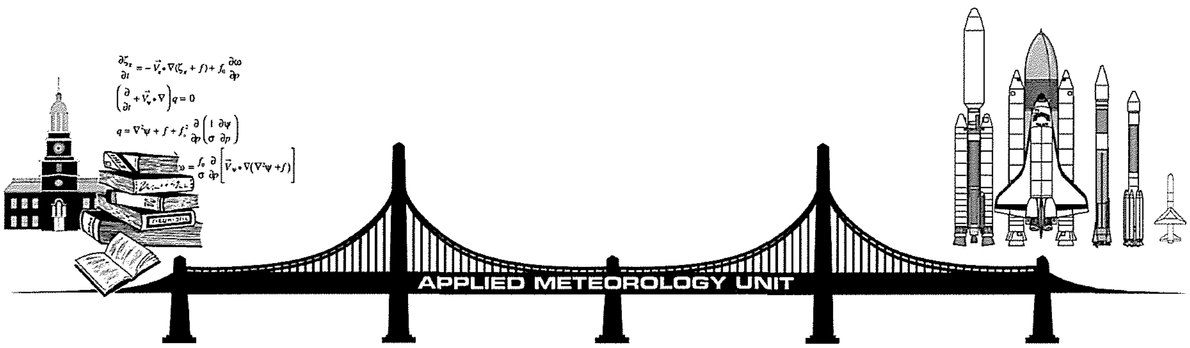

Figure 1. The AMU – a proven bridge between research and operations.

2. CREATION OF THE AMU

In the mid-1980s, the Space Shuttle Program sought ways to reduce the number of costly weather-related mission delays. By increasing confidence in the 90 minute End of Mission (EOM) landing forecast for KSC, the Space Shuttle Program also sought to reduce the number of landings at Edwards AFB, and the subsequent need for Shuttle Orbiter Ferry Flights back to KSC. They convened a "blue ribbon" panel of experts on weather support to spaceflight operations chaired by Dr. John Theon. The report of this "Space Shuttle Advisory Panel" (Theon, 1986) contained a substantial number of recommendations including the creation of a "techniques transition unit" to bring current advances in weather observation and forecasting into operational use. Since there was significant cost to many of the recommendations, NASA requested a "second opinion" from the National Research Council (NRC).

While the NRC was considering whether to accept the NASA request for a review of the Theon Panel report, Atlas Centaur 67 (AC-67), carrying a communications satellite for the US Navy, was destroyed during ascent by a lightning strike that it had triggered. The launch of AC-67 was conducted by the United States Air Force (USAF) at CCAFS under NASA management. The NRC agreed to review the NASA report, but only if the scope of the review could be expanded from just Shuttle to the entire American space program. Under the circumstances, this was readily agreed upon.

The NRC report (National Research Council, 1988, Chapter 5) approved and expanded on the Theon recommendation for the creation of what they called an "Applied Research and Forecast Facility" (ARFF). They noted that NASA and the Department of Defense had both spent substantial amounts of money trying to develop improvements to the weather infrastructure and techniques, but that the products did not get incorporated into the operational environment. They cited a number of requirements for successful technology transition and specifically recommended that the ARFF be co-located with the operational forecaster at CCAFS but independently managed by NASA. The value of these recommendations will be discussed in Section 4.

The NRC recommendation went considerably beyond what was actually implemented because it envisioned a facility that would not only do technology transition, but would be a major research organization in its own right. NASA, the USAF and the NWS determined that there were enough research organizations already available, so that the new organization should concentrate on the more narrow, and unmet, technology transition function.

In the fall of 1991, the newly named Applied Meteorology Unit was created under a NASA/USAF/NWS MOU. It was funded and managed by NASA and physically co-located in a room immediately adjacent to USAF Range Weather Operations (RWO). The AMU logo (Figure 2) is displayed there to remind visitors of its origin and mission. The five full-time AMU personnel were provided under a NASA contract that was competitively awarded to ENSCO, Inc. It was led by a NASA civil servant AMU Chief. All of the personnel had degrees in meteorology or related sciences and many had operational forecasting experience. Several, including the AMU Chief, had doctorates. This mix of academic and operational qualifications and its co-location with RWO were intentional and crucial to the success of the AMU.

Figure 2. The AMU's logo is based on its mission to transition weather technology into operations in support of America's space program. It also prominently recognizes the founding agencies.

3. ELEMENTS OF SUCCESSFUL TECHNOLOGY TRANSITION

Technology transition is all too frequently an afterthought to the technology development process and is often left to the operational units. This is unfortunate, because several important things must take place between the development of a technology and its application. At least the following six critical elements are required for operational employment of a significant technology development in support of spaceflight (and many other) operations:

- Evaluation
- Development of a concept of operations
- Tailoring
- Installation
- Acceptance testing
- Training

Each of these will be discussed in more detail below.

3.1 Evaluation

Evaluation is required to determine the capabilities and limitations of the new technology in an operational setting as a prerequisite for the development of the concept of operations discussed next. In addition, the evaluation can help the decision-makers decide whether the new technology provides enough of a benefit to operations to justify the expense of adopting it. Failure to critically evaluate a proposed technology upgrade in an operational setting can result in wasted resources or missed opportunities for effective application of the technology. AMU examples in the literature include Nutter and Manobianco (1999) describing evaluation of the performance of the "Eta" forecast model, and Short and Merceret (2005) which describes an evaluation of peak winds measured by an acoustic anemometer. .

3.2 Concept of Operations

It is important to have a deliberate, carefully thought out plan or "concept of operations" (CONOPS) for how the new technology is going to be used for operational support. The evaluation will have revealed strengths and weaknesses in the technology. The CONOPS is designed to ensure that the weaknesses do not compromise operations and that the most effective use of the strengths is made.

Our experience suggests that if forecasters are given a tool that fails in certain situations, they may not trust it in a situation for which the tool is designed. A proper CONOPS and training (see 3.6 below) ensures that the tool is used properly. This can be the difference between the tool becoming a valuable and well-used asset or being underutilized or incorrectly applied.

New CONOPS may also improve the performance of existing technologies. Technology transition organizations like the AMU can contribute to the most effective use of existing assets by developing these new CONOPS. An AMU example may be found in Short et al. (2000) which describes improved scan strategies for the Eastern Range WSR-74C weather radar..

3.3 Tailoring

Often, an organization proposes to acquire equipment or software that has worked well for other organizations at other locations. In many cases, the performance of the new capability can be improved with some location and environment-specific fine tuning that the AMU calls "tailoring". At a minimum, this may include providing for the ingest of unique, local data sets and output to unique, local data transmission and display systems. For an AMU example in the literature, see Case and Manobianco (2002) which describes local data integration for a mesoscale model operated by the NWS at Melbourne.

In cases where the evaluation has identified some weaknesses, tailoring may be used to adjust hardware settings or empirical software constants for better performance at the proposed operational location.

3.4 Installation

Before the new capability can be used, it must be installed at the operational location. Although the AMU does not do installation, because that service is provided for our customers by other contractors, it is an inherent part of technology transition and should be considered carefully in planning the technology transition process. The AMU does occasionally recommend installation procedures, especially for complex software packages.

3.5 Acceptance Testing

In an operational setting, systems are thoroughly tested before they are accepted from a vendor or other supplier for making operational decisions. The technology transition process should include guidance to the acceptance testing team to ensure that all critical features and components of the system are adequately exercised and verified. The AMU has reviewed proposed acceptance test procedures and provided recommendations to the 45th Space Wing on several occasions.

3.6 Training

As noted above in Section 3.2, a CONOPS is essential to effective use of technology and techniques. No matter how carefully the CONOPS is designed, it will fail if it is not actually implemented. For the users of the capability to follow the CONOPS, they must know what it is, how to execute it, its strengths and weaknesses, and appropriate conditions under which it should be used, etc. – and that requires training.

The AMU regularly prepares training documents and presents training briefings for its customers, not only for products delivered by the AMU, but also upon request for commercially acquired systems for which the commercial documentation or training is inadequate. The AMU is sometimes tasked to develop tools specifically for training, such as a computer based training package for the NASA Lightning Detection and Ranging (LDAR) system. The AMU is also available for informal consultation.

3.7 Technology Transition Summary

There are at least six critical elements to the successful transition of technology from the laboratory to the operations arena. Planning for the accomplishment of these should be incorporated into the technology acquisition process from the initial development or procurement phase. While it is not necessary for all six elements to be performed by the same entity or contractor, it is highly desirable that all six be coordinated and conducted as part of an integrated plan.

A dedicated technology transition organization such as the AMU, working in close cooperation with the customer, can simplify the required coordination and lead to a much more effective transition process through the use of management practices such as those described in the next section.

4. AMU PRACTICES AND PROCEDURES

Over the nineteen years of its existence, the AMU has evolved and refined its practices and procedures based on experience, and especially based on the comments and suggestions of our customers. The sections below discuss the general elements of successful management of technology transition followed by the specific management practices the AMU has adopted to achieve those elements.

4.1 Managing Technology Transition

Management of technology transition means incorporating human factors in the process. Section 3 addressed the work that needs to be done. Here, methods to get people to do it are presented. The elements for managing the transition are as follows:

- Address real customer requirements
- Meet those requirements
- Have adequate resources
- Secure customer buy-in

Technology transition should be undertaken only when there is a clear customer requirement for it. Evaluation, CONOPS development, and tailoring, all involve interaction between the technology and the requirement it is designed to meet. If the requirement is vague or technology transition is being mandated from above without a perceived need for it at the operational level, the probability of failure rises sharply.

Technology transition is only successful if it delivers a system which meets the requirements. The elements presented in Section 3 above are essential to assure that requirements are actually met. The temptation to leap directly from the development phase to operations should be vigorously resisted.

Technology transition must be properly conducted to ensure customers receive quality evaluations, CONOPS and other elements of a well-transitioned system. The transition process should be funded at a level sufficient to actually accomplish the required functions. If it appears that adequate resources are not available to properly transition a planned technology acquisition, the organization should consider delaying or down-scoping the acquisition to match the work to the resources.

Finally, change often breeds resistance. People are generally more comfortable with the familiar. It is important that users welcome the introduction of new technology. The transition team's evaluations, CONOPS development and tailoring should involve users from the start. Installation, testing and training should be structured to minimize disruption to the normal daily routine. Training should be designed not only to explain when and how to use the new capability, but also to explain the benefits to the user. Likewise, a completely honest evaluation is required—any weaknesses should be fully and openly disclosed.

4.2 AMU Management Practices

The AMU succeeds because of its management practices that ensure the elements described in 4.1 above are all provided. These practices include:

- Customer-driven tasking
- Co-location with an operational facility
- Managed and funded separately from the operational units
- Customer involvement throughout the process
- Flexibility throughout the task
- High skill level and flexible skills mix
- Attention to customer relations

Under the AMU MOU, the AMU is tasked directly by its customers. This practice was cited as a "best practice" during a survey on management practices at the Kennedy Space Center in 1996 (Best Manufacturing Practices, 1996, page 24). Annually, NASA, the USAF and the NWS meet to determine the AMU taskings for the next 12 to 18 months. Prior to the meeting, a Call for Proposals is sent to all participants. Responses are distributed to all participants, and prior to the meeting the proposals are discussed and refined by email and teleconference. These pre-meeting discussions frequently result in withdrawal, revision or combination of proposals, thus reducing the workload at the ensuing meeting.

A standard format is used in the proposals to ensure all necessary elements are covered and to facilitate review of the proposal by the AMU and other customers. The sections of the standard proposal are listed in Table-1. Having the proposing organization include a resource estimation was very useful. When the AMU did their own independent resource estimation, a large difference between the two cost estimates would flag that a miscommunication had occurred on the expected scope of the project, which could then be resolved by further discussion between the proposer and the AMU.

The tasking meeting has three phases. In the first phase, each customer with a proposal presents it to the group. Questions on the content of the proposal are welcome, but criticism and evaluation are not. That will come later. The goal of the first phase is to make sure every proposal is fully and correctly understood by everyone at the meeting.

Title	Justification
Proposing Organization	Priority
Technical Point of Contact	Risks
Description Problem to be solved Suggested approaches Deliverables Resource estimate Requested delivery date	Additional Comments

Table-1. Standard format for proposals from customers to AMU contain the following sections.

During the second phase, each customer has the opportunity to evaluate and comment on the others' proposals. The ultimate goal is for the group to rank the proposals in priority order by their importance to the group as a whole rather than to any single organization. Thus, in principle, a proposal that would improve forecasting methods for 45WS, SMG and MLB would outrank one that improved them for just one of these organizations. Factors such as whether the proposal would reduce the risk of accident or injury, or reduce the costs associated with scrubs and delays are also considered.

During the second phase, it may be found that several proposals are so closely related that they can either be combined, or one of them withdrawn. In addition, there is usually a general consensus that certain proposals rank highly and others are of lesser importance. Eventually, a list of revised projects remains for consideration. Often, the AMU contractor is able to devise a scheduling plan that will enable all of these remaining projects to be done within 12 to 18 months, and the meeting is finished.

When the remaining proposals cannot be accomplished within the available resources, the third phase of the meeting ensues. This involves the formal ranking of the proposals with additional discussion and negotiation. A process is provided to take a formal vote if a consensus cannot be reached. In 19 years, that process has rarely been invoked. Part of the reason that consensus has almost always been reached is that a customer supporting a proposal which everyone else ranked as low would realize that they would not benefit from a formal vote. This encouraged those with low-ranking proposals to agree to the general consensus in return for support for their project at a later tasking meeting or with other resources.

Co-location with the customer was strongly recommended by the NRC report (National Research Council, 1988, page 45). This assures that the AMU and its customers communicate daily and have direct experience of each other's "worlds". The AMU also provides at least one person to attend all space launch attempts. This is done in case no-notice technical advice is needed, and also to help the AMU to maintain awareness of how weather operations to space launch are conducted. For example, AMU personnel attend the "hot wash" (Figure 3) after every launch or launch attempt. The hot wash is an open and free discussion among 45WS and its support contractors (including the AMU) regarding any problems or concerns arising from the operation just completed. Because of the co-location with Range Weather Operations and participation in operations, the AMU is instinctively aware of the capabilities and limitations of the 45WS, and they are aware of AMU capabilities and limitations. The result is that 45WS proposes better taskings and the AMU delivers better products than would otherwise be likely.

Figure 3. Post-launch "hot wash" allows 45WS and its contractors (including the AMU) to discuss concerns and "lessons learned" from the operation.

Since the AMU is too small to be split among several locations, it maintains contact with its other primary customers, SMG and MLB through scheduled visits to their facilities on a regular basis. These visits are usually scheduled during major operations so AMU staff can observe how those customers support their primary weather operations.

It is important that management and funding for the technology transition capability be separated from the operational customer's organization. When budgets get tight and personnel ceilings are threatened or lowered, operations always get priority within an operational organization. This is completely appropriate, but the practical result has nearly always been that the technology transition staff is slowly reduced as it is incorporated into operations and eventually the capability vanishes. By maintaining independent funding and management, the technology transition function remains viable over an extended period of time.

The AMU tasking process involves the customers from the beginning. After each tasking meeting the AMU contractor assigns a project lead for each project and prepares a "Task Plan" that describes what will be done, how it will be done, the deliverables, and the schedule for the work. This is circulated to the customers for their approval. Thereafter, brief monthly management progress reports and detailed quarterly technical progress reports are circulated. After release of each quarterly report, a teleconference is held to discuss the report and answer any questions the customers may have. If the AMU has any questions, they don't wait for the quarterly telcon. They contact the appropriate party immediately! Likewise, the operational unit keeps involved with the AMU task throughout the process. The 45WS has discovered that assigning two people to each task works best. One is the operator who has the most operational interest in that topic. This keeps the design of the task focused on what will work best for operations and increases 'buy in' from the operators. The second person assigned to the topic is always the AMU Liaison who has a background in both operations and research and knowledge of all current and past AMU tasks and other research projects for 45WS. This improves communication between the AMU and researchers, improves the research design, and avoids duplication of effort or takes advantage of the opportunity for synergy between projects.

When a project nears completion, the semi-final product and/or report is provided to the customer for review and comment. Software packages and forecast tools are beta-tested by the customer before the final report and other documentation is completed and released. "Punch-lists" from the beta-testing are acted upon where feasible or included in recommendations for future work if existing resources are insufficient. The continual involvement of the customer throughout the process was also recognized as a "best practice" during the 1996 survey (Best Manufacturing Practices, 1996, page 22).

Flexibility throughout the tasking process is another important AMU management practice. As lessons are learned while fulfilling a task, the work-plan is adjusted in coordination with the customer and the AMU. For example, a technical approach that was initially promising may not be working as well as planned, or a better technical solution might be devised. In extreme cases, the entire task may be failing and should be cancelled rather than wasting resources. Exit decision points are built into the work plan from the very beginning if a task appears risky, but would yield significant operational improvement if successful. If major changes to the work-plan are required, the entire AMU tasking community becomes involved.

The AMU contract contains "key personnel" provisions that ensure retention of the contractor's flexibility to adjust the AMU skills mix to the current tasking while assuring that NASA requirements for a high level of professional skill are maintained. Personnel changes are discussed with NASA before being made by the contractor. Effective technology transition requires research-grade technical skills, preferably accompanied by at least some operational experience. The AMU has been fortunate to attract both throughout its existence. The ENSCO on-site program manager has always held a Ph.D. in meteorology or a related subject while often being retired from the USAF after serving in operations at CCAFS. Other members of the staff generally have advanced degrees and operational experience as well. Some have even worked at the 45WS or NWS before joining the AMU.

Finally, in addition to all of the formal processes and procedures designed to foster and maintain good formal communications with our customers, the AMU encourages informal contact between the operational personnel and the AMU specialists. This informal contact generates personal relationships that build trust and a sense of teamwork that has important practical benefits.

5. DISCUSSION

The AMU's continued existence, fully funded, for over 19 years is strong testimony to the utility of the AMU and support from the operational customers and funding authority.

Few technical transition units in operational meteorology have survived this long. During the mid-1990s, NASA suffered large cuts to its budget (Columbia Accident Investigation Board, 2003, Section 5.3) but continued to fully fund the AMU. The national recognition mentioned in the introduction is gratifying, of course, but the AMU costs money and the AMU MOU grants NASA the right to shut it down on just 30 days notice.

What makes the AMU an obvious investment, an asset, rather than an accountant's "cost cutting target" is that it reliably produces useful products, usually on time and always on budget. Technology transition is about getting effective usable products out of the laboratory and into the hands of the operational forecasters, and that's what the AMU actually does. For a look at the many AMU products and services that have been delivered over the years, please visit our website (Applied Meteorology Unit, 2010).

The customers the AMU serves and the missions it supports may be unique, but the methods and philosophy that has made us successful are not. These principles can be used profitably by any weather organization – indeed, by any organization that uses technology. Perhaps the single most important principle is customer involvement in all aspects of the process.

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