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AEROSPACE METEOROLOGY LESSONS LEARNED RELATIVE TO AEROSPACE VEHICLE DESIGN AND OPERATIONS

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1. INTRODUCTION

Aerospace Meteorology came into being in the 1950s as the development of rockets for military and civilian usage grew in the United States. The term was coined to identify those involved in the development of natural environment models, design/operational requirements, and environment measurement systems to support the needs of aerospace vehicles, both launch vehicles and spacecraft. It encompassed the atmospheric environment of the Earth, including Earth orbit environments. Several groups within the United States were active in this area, including the Department of Defense, National Aeronautics and Space Administration, and a few of the aerospace industry groups. Some aerospace meteorology efforts were similar to those being undertaken relative to aviation interests. As part of the aerospace meteorology activities a number of lessons learned resulted that produced follow on efforts which benefited from these experiences, thus leading to the rather efficient and technologically current descriptions of terrestrial environment design requirements, prelaunch monitoring systems, and forecast capabilities available to support the development and operations of aerospace vehicles.

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Prior to the advent of aerospace meteorology the early processes for acquiring measurements of the atmosphere, providing descriptions and models, and integration of this information were accomplished to meet the needs for weather forecasting in general and to support civil and military aircraft design and operations. To some degree the processes were the product of cost-risk trade-offs and experiences associated with providing these services. Many lessons about the importance of better meteorological information were learned from these interactions, as more was learned about the atmosphere from ground based, balloon borne, and aircraft measurements. Some were also derived from operational demands at the time. Examples include the need, and inability, to forecast condensation trails from military aircraft, likewise, jet stream wind flow locations and magnitude, aircraft icing, etc., all the result of lessons learned from aircraft encountering these conditions. Then, of course, with the advent of satellite based visual imagery and then sounding data from IR and microwave instruments, including ground based remote sensing measurements, we encountered another set of lessons to learn in trying to relate these observations to in situ measurements from ground, balloon, or aircraft sensors on which we had built a "frame-of-reference" for our atmospheric knowledge. All of these measurements have their own unique characteristics. However, through a series of efforts in interpreting and relating these measurements, we essentially succeeded in developing an integrated understanding of the atmosphere as required by the various applications.

With the advent of large and relatively complex rocket systems such as the Jupiter, Atlas, Titan, and Saturn, all very expensive in terms of cost and operations for a single flight relative to aircraft, considerable effort was expended by NASA and the Air Force to maximize the value of atmospheric inputs in order to minimize risk and thus cost. Such is still the case with vehicles like the Space Shuttle. As a result, specialized measurement systems like the Radar/Jimsphere were developed to acquire needed information on vertical wind structure with resolution beyond the capability of the rawinsonde system. Many small rockets were fired with measurement capabilities to gain data above the rawinsonde balloon limits for use in developing aerospace vehicle design inputs and evaluation of flight performance. Thus, the advent and maturity of aerospace meteorology. During this period the lessons learned contributed to the advancement of aerospace meteorology in varying degrees, some even benefiting other areas of meteorology applications.

One of the simple but visible evidences of lessons learned being used is the current NASA-HDBK-1001 "Terrestrial Environment (Climatic) Criteria Handbook For Use In Aerospace Vehicle Development" and the predecessor editions issued since the early 1960's. This "definition" document provides information on the terrestrial environment formulated and based on experience from applications to aerospace vehicle design and operations, including discussions with and requests from engineers involved in the process. Another is the development of a unique three-dimensional time-dependent "Global Reference Atmosphere Model", initially produced to support re-entry thermal design calculations. As experience was gained, new information was used to update and improve the contents for subsequent editions of these items. They provided source information for the development of specific terrestrial environment requirements for the design, development, and operations of new space vehicles and associated facilities necessary to meet the desired capabilities for their assigned missions.

2. LESSONS LEARNED IDENTIFICATION

The NASA Technical Standards Program <http://standards.nasa.gov> undertook an initiative to identify lessons learned that might be linked to technical standards plus, subsequently, an effort to develop a lessons learned dataset that can be linked to classroom and electronic engineering training course contents. One of the actions was to identify candidate atmospheric and space environment related lessons learned that might be expanded upon for use in this initiative. Based on the experiences of the authors a number of candidate lessons learned were identified. Several are provided below and in the subsequent section. They are listed in no particular order of priority or relative significance. They illustrate the type of lessons learned encountered during the past forty years and the relative importance of aerospace environment related lessons learned.

Natural Environment Design Requirements For A Program: Control And Single Focus Contact

Background: All space vehicle (launch vehicle and spacecraft) programs and projects are involved with flight through the atmospheric and space environments. There are usually several groups, both industry and government, involved in the design and development of launch vehicles and spacecraft. Having a coordinated and consistent set of natural environment design inputs tailored to meet the mission requirements for the space vehicle is critical, not only from a risk and cost aspect, but from a technical view also. Otherwise, the various trade-off analyses for the vehicle structure, control, thermal; concept designs, etc., designs will not be founded on a common baseline. This will result in non-uniform products that greatly complicates the comparisons and management decisions that must be made.

Analysis: A couple examples to illustrate the importance of this lesson. (1) For the Apollo Block I/II development the contractor was provided a report containing general statistics for in-flight winds over Cape Canaveral without the required specific design wind values being specified for use. This lack of direction resulted in an extensive re-do of the analyses and design

work to meet the vehicle mission requirements. (2) Early in the design trade-off studies, a Space Station contractor utilized an in-house orbital altitude density model for on-orbit analysis that differed from the NASA model specified for use. This resulted in different calculations for drag, re-boost, and control by the various groups involved. Both of these issues were resolved by the recognition and establishment of a single control point for natural environment definitions and control of requirements. This provided the added benefit of a common source for interpretation of the natural environment requirements for design.

Lesson: The specification and control of natural environment definitions and requirements are important for program studies used in vehicle design trade-offs and development activities, given the significance of coordinated and consistent natural environment inputs. This is especially true when there are several organizations involved in the vehicle development activities. It is critical that a single control point be established for natural environment inputs to be used in the design and development of a space vehicle.

“Critical Discipline Area” Designation For Program Development

Background: Essentially all programs, early in their development, designate critical discipline areas from which inputs are required to support the specification of program guidelines, mission requirements, and system design. Often the natural environments were not included in the list of critical disciplinary areas.

Analysis: The natural environments act on the entire space vehicle system. They are usually a key driver as to what can be done and how much it will cost. Judgments must be made on how to handle the definition/requirements of the natural environments to ensure a robust design. Separation of mission critical and function critical requirements is often useful. Knowledge of (and confidence in) the distribution functions that describe environments varies greatly with the specific natural environment and the orbit or launch site. This knowledge needs to be related

back to total mission risk, feasibility, and cost.

Most aerospace contractors have only limited natural environments analysis and assessment capability, with few ties between their environments specialists and their systems engineering teams. Even when the government takes a “hands-off” policy, providing minimal definition of design requirements in order to allow maximum flexibility for trade-off studies, etc., the development of natural environment definitions for the mission will provide guidance for the essential trades and options that need to be examined. The involvement of natural environment specialists in formulating the specific program ground rules on risk and intensity of severe environments that must be considered will help ensure that the obstacles to mission success are addressed in these studies, thus saving a lot of time and funds for both the contractors and government program office.

Lesson: The natural environment definitions and requirements are usually one of the key drivers for the development of an aerospace vehicle program relative to accomplishment of its assigned mission. Thus, to avoid oversight of these inputs early in the establishment of program requirements, the natural environment should always be designated in the initial listing of critical disciplines for the program.

Each program systems engineering office should have a “skills checklist” and routinely review government and contractor capabilities to assure all necessary expertise is available and tied in appropriately. Care should be taken to include the lower profile but essential specialty engineering areas, including natural environment. When gaps are identified action should be taken as appropriate to bring in government or contractor specialists, establish working groups, etc.

One Environmental Effect Can Greatly Complicate Solution of Another

Background: As a cost saving measure early in the program, the instrument package for the Chandra (then AXAF) was

reduced and the orbit was changed from low earth orbit to high elliptical, enabling the thermal control concept to be simplified to a passive "cold biased" surface plus heaters. This change in thermal control concept resulted in the mandating of silver backed Teflon thermal control surfaces which, in turn, had important implications for vehicle performance in the plasma environment associated with the new orbit.

Analysis: The Teflon thermal control surfaces plus the high elliptical orbit resulted in severe spacecraft charging and electrostatic discharge environment, which necessitated an aggressive Electrostatic Discharge (ESD) test and circuit protection effort at a cost of approximately a million dollars.

Lesson: Design solutions for one environment effect can greatly complicate design solutions for other problems, including other environment related design issues. Be wary of orbit modifications relative to change in natural environment effects on spacecraft and instruments.

Natural Environments Need To Be Considered In The Probabilistic Risk Assessment (PRA) Process

Background: A popular trend in developing top level requirements for new programs is to include "probability of mission success" or similar criteria that are to be verified by a probabilistic risk assessment (PRA) approach. A major defect often found in this approach is the failure to consider the effects of the natural environment on the system. If a traditional PRA structure is maintained, the usual practice of pushing off natural environmental analysis to a later date will be followed with a detriment to the system design process. The structure of the PRA process needs to be changed because the space and terrestrial environments are handled differently in a risk assessment than other failure modes. As illustrated by some probabilistic risk assessment on-line course charts, "Failures are usually identified as initiating events." However, when failures are caused by natural environmental conditions and events, the probability of the failure is very dependent on the probability of the natural environmental event occurring.

An example would be the occurrence of a solar proton event. The time of its occurrence and the magnitude of the resulting flux are both very probabilistic. Thus, parts failures due to radiation effects are very different than failures due to the statistical failure of parts that are operated within their specifications.

Returning to the illustration, we find the statement, "Mitigating events are events or circumstances that can prevent the undesirable event from occurring once the initiating event has occurred." Initiating events are defined as "...events that cause a perturbation in a system parameter which can cause an undesirable event (or consequence) to occur." "Failures are usually identified as initiating events." When one is undertaking a hardening program, mitigations most often occur before an initiating event, i.e. failure, not just after an initiating event as indicated in the Probabilistic Risk Assessment on-line course. In the PRA on-line course the sequence appears to be initiating event >mitigating event< undesirable event circumvented. With natural environmental issues the sequence may also be that the mitigating action prevents the initiating event from occurring in the first place.

Analysis: The probabilistic risk assessment (PRA) process was given as an online class. This on-line course was set up by a systems and mission analysis team and presented by their contractor to provide the basics of a program's way for performing PRA. During the review of the material it became clear that since the PRA process is a design driver, its lack of consideration of the effects that the various terrestrial and space environments have on the risk would be a major deficiency.

Lesson: Either the probabilistic risk assessment (PRA) process must include the natural environments effects on the system, or the limitations of the PRA process must otherwise be compensated for assessment.

Launch Availability With Respect To Abort Landing Site Weather

Background: The Orbital Space Plane Program had a requirement that

necessitated calculating a probability of launch availability with respect to abort landing site weather. When the contractors' proposed program configurations shifted from lifting bodies to capsules, the resulting loss of cross-range and down-range capability required that all points along the ascent trajectory be considered possible abort landing sites. Thus, instead of a few discrete locations with available long-term weather data, a continuous set of locations is required, many over the ocean with little or no long-term weather monitoring data available. The original requirement did not explicitly state how the probability was to be calculated, and at the systems design review presentations, it became apparent that the prime contractors had not adequately considered this issue. The complexity of the calculations and, more importantly, the issue of data availability, contributed to this factor not being considered in the decisions leading to the capsule concepts.

Analysis: An analysis of this situation reveals that one should state clearly in the given program requirements how the probability calculations are to be performed. This issue is closely related to the PRA lesson learned discussed above.

Lesson: Whenever a program requirement is written that depends on the probability of occurrence of natural environmental phenomena or of a particular set of conditions, the requirement needs to be very explicitly stated as to how the probability is to be computed, what data and models are to be used, etc.

3. ADDITIONAL CANDIDATE LESSONS LEARNED SUMMARIZED

1. TITLE: Metric-English Units Application Understanding.

BACKGROUND: Example--Radiosonde measurement calculations from the launch site used incorrect units for mean sea level. These measurements were used to calculate vehicle responses for use in flight evaluation analyses, leading to a mismatch with flight data. Mars Rover experience is another example of the importance of verifying the units used in performance

calculations. SI (metric) system has been used in the scientific and international communities for over four decades. More and more data sets and technical models needed in the engineering process are only available in metric units. The aerospace engineering community needs to accelerate its transition to metric units to alleviate this technical and cost issue.

LESSON: The incorrect application of units to an application can result in considerable opportunity for technical data interpretation errors and operational consequences. This is particularly true for programs that use mix of Metric and English units. Double-checking of units being used is critical to avoid issues associated therewith.

2. TITLE: Wind Vectors Vs Engineering Vector Conventions.

BACKGROUND: Example - Flight mechanics use of wind vectors and conventional meteorological usage. In the case of flight mechanics, vector is stated relative to direction a force is being applied. However, for meteorology, the wind vector is stated relative to direction from which wind force is coming.

LESSON: The proper interpretation and application of wind vectors is important to avoid a 180 degrees error in the vehicle's structural loads and control system response calculations.

3. TITLE: Design Requirements, Not Climatology.

BACKGROUND: Example—While based on climatology and models, both physical and statistical, natural environment requirements are part of the overall vehicle design effort necessary to ensure mission operational requirements are met. Thus they must be selected and defined on this basis. Simply making reference to climatological databases will not produce the desired vehicle performance. This was done with respect to an action for the Apollo Block I/II spacecraft and produced a costly re-design situation.

LESSON: Members of the natural environment group assigned as the control

point for inputs to a program must also be part of the requirements development process. Likewise, they should be an integral part of the vehicle design team and participate in all reviews, etc. to ensure proper interpretation and application of natural environment definitions and requirements relative to overall vehicle design needs.

4. TITLE: Need For Involvement of Engineering Applications Knowledgeable Natural Environment Person to Interpret Inputs for Design, etc.

BACKGROUND: Example—Expensive icing re-analysis was required on the Shuttle External Tank. This was due to the contractor trying to sort out what information to use from the atmospheric environment database obtained from NOAA archives relative to the specific needs and interpretation required for the External Tank analysis.

LESSON: The interpretation of natural environment definitions and requirements for engineering applications requires someone with both disciplinary and aerospace vehicle engineering experiences. This is important to ensure the proper selection and application of natural environment information relative to interpretations for engineering usage.

5. TITLE: Need to Maintain Good Records On All Natural Environment Inputs, Deviations, Interpretation, and Rational.

BACKGROUND: Example—A Skylab early re-entry issue developed relative to the natural environment requirements versus the ballistic factor estimate used for the design lifetime decision. A similar issue developed regarding the Shuttle Challenger on-pad design ambient temperature. Having the records to validate the natural environment definitions and requirements were important relative to the investigations that developed on vehicle loss accountability, etc.

LESSON: From initial studies through design, development, and operations, the responsible natural environment group must maintain complete records on all inputs

relative to basis, specification and interpretation of values for engineering use.

6. TITLE: Early Input of Natural Environment Requirements Based On Interpretation Of Mission Purpose and Operational Expectations.

BACKGROUND: Example—Need to develop natural environment definitions and requirements for a program as soon as practical after one has the level one requirements for the program's mission. Thus, all concerned with the development will have a common base with associated control on changes made to natural environment definitions and requirements relative to the associated vehicle operational impacts.

LESSON: The definition of a common set of natural environment requirements for the design and development of a vehicle is important for all concerned. This provides visibility to all, especially the program manager and systems engineers, on the operational impact of the natural environment design requirements.

7. TITLE: Free Agency To Explore And Develop New Measurements Descriptions And Models That Are Directly Applicable to Engineering Applications.

BACKGROUND: Example—The development of the Radar/Jimsphere System, Global Reference Atmosphere Model, Vector Wind Model, Radar Wind Profiler, etc., and their subsequent value for application to programs in addition to one for which they were developed, has proved to be a sound technical and cost saving approach. There is usually no time after a program starts to develop new models or data sets.

LESSON: The group responsible for natural environment definition and requirements needs to also have the free agency to expend some resources in the development of improved models and measurement systems, plus acquisition of unique data sets that will have engineering applications for the development and operation of future aerospace vehicles in addition to one currently being developed.

8. TITLE: Consistent Natural Environment Input For All Users, Especially For Trade-off and Design Studies

BACKGROUND: Example—The natural environment is one of the key drivers for much of the design efforts on an aerospace vehicle's thermal, structure, avionics, materials, and control. Variations in natural environment inputs used by different design groups can mask critical engineering design issues if not avoided by consistent and coordinated natural environment inputs and interpretations for engineering applications.

LESSON: The need for a focused natural environment group that provides coordinated and consistent environment definitions, requirements, and interpretations is key to having all concerned direct their efforts toward the same inputs. This contributes to engineering applications that can readily be interpreted from a common base.

9. TITLE: Common Source and Guideline Document For Definition of Applicable Natural Environments For Reference...

BACKGROUND: Example - Aerospace vehicle development should use natural environment definitions and requirements that are based on engineering questions and issues, with answers provided and maintained in a common guideline source document for future use. Such a reference document saves time and resources relative to duplicating the same information.

LESSON: The expenditure of some resources is necessary to maintain common guideline documents to provide terrestrial and space environment definitions that have resulted from past engineering applications. This will provide reliable and ready reference for future questions and development of environment definitions and requirements for new vehicle programs.

10. TITLE: The "1% Risk With 100% Confidence Of Not Being Exceeded" Mentality

BACKGROUND: Example—During the Vertical Assembly Building (VAB) design wind loads requirements development, a

senior person involved with the engineering design effort made a comment such as in this lessons learned title. Once the limitations of the winds database frame-of-reference and the physical meaning of the design winds criteria on was understood, a reasonable design requirement with less than 100% confidence was accepted. The clincher was comparison of design wind loads criteria for his home versus VAB, Most natural environment phenomena do not have concretely defined extreme limits, i.e. it is always possible one will encounter a strong wind or more severe solar flare than previously observed. All rational natural environment design inputs have some degree of risk for being exceeded and this must be recognized and appreciated by all concerned.

LESSON: The close interaction between the natural environment group and those responsible for the engineering design effort is important to ensure proper interpretation and understanding of the natural environment risks and design requirements.

11. TITLE: Reputation Of Natural Environment Group Must Be Developed And Maintained Through Professional Involvements And Activities Within Both The Engineering And Scientific Communities

BACKGROUND: Example—Both professional journal and technical report publications are of considerable importance in this regard. Participation in conferences, seminars, briefings, working groups are key to this matter. Awareness opportunities are necessary to ensure understanding of the natural environment definitions for engineering applications.

LESSON: The group responsible for the natural environment definitions and requirements must maintain their professional status and recognition within a dual disciplinary community (engineering and environmental science). This ensures awareness of the state of the art, respect for talents of group and their products, and maximum benefit from their work to both communities.

12. TITLE: Follow-up On Natural Environment Definitions and Requirements

For Engineering Applications And Interpretations

BACKGROUND: Example—This type follow-up by the responsible natural environments group during design played an important role in the Saturn/Apollo lightning strike incident relative to the Saturn vehicle-bonding requirement. Had the Saturn/Apollo vehicle been on spacecraft control it may have been lost due to lack of adequate spacecraft structure bonding at the time.

LESSON: The responsible natural environments definitions and requirements group must exhibit the necessary initiatives to follow-up on the application and interpretation of natural environment design requirements by the engineering groups. This will serve the interests of both groups and especially the program's mission accomplishment.

13. TITLE: Ground Winds Identification And Reference For Aerospace Vehicle Design And Operations

BACKGROUND: Example - Monitoring peak ground winds is much easier to realize and visualize for design requirements and operational capability than steady state winds (that depend on the integration interval used) with a design gust value taken into account accordingly. Also, a common reference height is critical for consistency in monitoring and interpretation relative to design requirements. During the early days of operations at KSC, confusion between contractors and NASA KSC, MSFC, and JSC on this subject led to the selection of a common 18.3 m reference height for ground wind statements for design and operations.

LESSON: Providing a common reference height, where appropriate, for natural environment statements will ensure minimum risk in engineering interpretations and operational applications.

14. TITLE: Vehicle Effects On Natural Environment Must Be Addressed Early And Action Taken To Assess And Resolve Actual Or Perceived Consequences

BACKGROUND: Example—The Shuttle solid rocket toxic exhaust by-products at

launch and subsequent public reactions at the Cape are illustrative of this lesson. Also, a public ozone depletion scare in stratosphere developed relative to Shuttle solid rocket exhaust until an assessment and awareness initiative assured public that it was not a threat.

LESSON: Potential environment impacts, whether real or imaginary, must be addressed early in the development of a program. The results need to be made readily available to the public in language all will understand. Follow-ups to all public inquiries and statement, especially negative, need to be made promptly with adequate engineering and scientific documentation. It is also a matter of law that environmental impact issues be assessed prior to any major commitment of funds for a program.

15. TITLE: Ability To Test Planned New or Changes In Natural Environment Requirements Versus Engineering Results Is Important Before Implementing Them As Formal Requirements

BACKGROUND: Example—Preliminary assessment of natural environment definitions and requirements must first be accomplished in collaboration with a responsible engineering group with respect to effect on engineering interpretations. Based on this information, then the appropriate natural environment definitions and requirements can be provided, implemented, and controlled accordingly.

LESSON: To avoid problems with the engineering interpretation of natural environment definitions and requirements, the natural environments group responsible must first interact directly with an appropriate engineering group on their use and engineering application. This will ensure proper use and interpretation when formally implemented as part of the overall program design and operational requirements.

16. TITLE: Unique Relationship Between Natural Environment Requirements, Other Vehicle Design Requirements, and Vehicle Operational Requirements.

BACKGROUND: The environmental constrains and flight rules for a space vehicle operations must be different from, but related to, the natural environment design requirements and technical constraints. In the operational realm environment monitoring, forecast, mission optimization and risk avoidance become the norm. These activities require very different environment data sets, models, and working criteria. Therefore, it becomes very important that the environmental risks and constraints be book-kept separately from other failure risks, and added-on after the analysis of factors internal to the vehicle. This will enable the vehicle to be considered as a stand-alone capability which can be assessed later against the (different) operational environment factors. By taking this action, it provides a viable and robust operational vehicle capability that will accommodate the vehicle mission operational requirements. Otherwise a vehicle will be produced that will have a lower than expected operational capability.

LESSON: Do not design an aerospace vehicle with the required design natural environment definitions and requirements incorporated and "root sum squared" as part of the other non-nominal inputs to the vehicle design. Environmental risks and constraints must be maintained logically and analytically separate so that accurate assessments against the operational environments can be made at a later date.

17. TITLE: Natural Environment Elements That Cannot Be Monitored and Avoided by Operational Decision Must Be Set at the Minimum Risk Level Possible, Consistent With Mission Capability Requirements. This Also Includes Those Natural Environment Elements Needed To Meet Safety And Emergency Situations.

BACKGROUND: Example—For an aerospace vehicle launch, most natural environment elements can be monitored and thus taken into account before a launch decision is made. The same is true for a few on-orbit and deep space spacecraft operational requirements. In such cases, less robust design for the environment may be allowed, consistent with the mission requirements, along with subsequent

savings on cost. Vehicle ascent winds through max Q are an example of where higher probability (higher risk of occurrence) natural environment design requirements may be considered for a vehicle depending on the mission. However, for situations like re-entry which occurs over a long flight path, monitoring and operational options are minimal, and a robust design / acceptable minimum risk approach must be utilized.

LESSON: It is necessary to carefully analyze the mission requirements relative to vehicle operations and provide the natural environment definitions and requirements accordingly. This should be accomplished in collaboration with the vehicle program manager to ensure understanding of the operational risk and full life cycle cost implications of the natural environment design requirements.

18. TITLE: Atmospheric/Space Parameter Analysis Model.

BACKGROUND: The capability for a program manager to easily access information on the operational impact of a vehicle design change relative to the operational natural environment conditions is an important tool for decision-making. In addition, such a tool provides additional insight into mission planning activities including launch and landing delay probabilities.

LESSON: Mission managers, chief engineers, mission planners, etc. are often not aware of the availability and capability of Atmospheric/Space Parameter Analysis Models. This valuable decision making tool should be utilized in making trade-off engineering design decisions where the desired operational natural environment is a factor.

19. TITLE: Reference Period For Natural Environment Definitions And Requirements Relative To Launch And On-Orbit Operations.

BACKGROUND: Launch operations costs are usually significant, so it is important that launches occur in a timely manner. Hopefully, within a few days of the planned

date. Thus, for launch related statements on atmospheric environment definitions and requirements, the worst reference month should be used. This provides an operational capability for the natural environment that ensures that for any given month, the desired operational capability will be met or exceeded. Thus, for the worst month reference period, the maximum acceptable risk of launch delay due to natural environment will occur with other months having less probabilities of launch delay. A corresponding situation exists for natural environments associated with on-orbit operational capability and deep space operations. For these cases, the anticipated lifetime in these operational conditions must be taken into account along with the acceptable risk for comprising the mission timeline relative to natural environment conditions exceeding the design requirements.

LESSON: All launch atmospheric environment definitions and requirements for the design of a vehicle must be made with respect to a worst month reference period. For defining the reference period for natural environments associated with on-orbit and deep space operations, the anticipated lifetime in these operational conditions must be taken into account along with acceptable risks for the spacecraft's operations.

20. TITLE: Life-Cycle Cost Estimates And Natural Environment Operational Constrains Of Vehicle.

BACKGROUND: The most frequent cause of launch delays, for both the Space Shuttle and expendable vehicles, is weather. Therefore, early in concept development, and repeatedly as the vehicle matures, the constraints relative to safe operations in the natural environment should be assessed based on the capability of the vehicle. This is the case for launch, on-orbit, and deep space aspects of the mission. An Atmospheric/Space Environment Parameter Analysis Model can be especially helpful in this regard. The resulting operational risk information should be incorporated into the development of the full life-cycle cost estimates and model for the vehicle program.

LESSON: Consideration needs to be given to the natural environment operational constraints for space vehicle launch and spacecraft operations when developing full life-cycle cost estimates and models.

4. CONCLUDING REMARKS

In modern government and aerospace industry institutions the necessity of controlling current-year costs often leads to high mobility in the technical workforce, "one-deep" technical capabilities, and minimal mentoring for young engineers. Thus, formal recording and teaching of lessons learned is especially important in the maintenance and improvement of current knowledge and development of new technologies, regardless of the discipline area. Within the NASA Technical Standards Program Website <http://standards.nasa.gov> there is a menu item entitled "Lessons Learned/Best Practices". It contains links to a large number of engineering and technical disciplines related data sets that contain a wealth of lessons learned information based on past experiences. This paper has provided a small sample of lessons learned relative to aerospace meteorology. There are many more whose subsequent applications have improved our knowledge of the atmosphere and application of this knowledge to a variety of aerospace engineering programs.

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