Spacecraft Requirements Development and Tailoring

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Abstract

Spacecraft design is managed through the use of design requirements. Requirements are flowed from the highest level, the overall spacecraft, to systems, subsystems and ultimately individual components. Through the use of requirements, each part of the spacecraft will perform the functions that are required of it and will interface to the rest of the spacecraft. Functional requirements are used to make sure every component performs as expected and interface requirements ensure that each component works within the larger design environment where it operates.

Writing good requirements is difficult and the verification of requirements can be expensive and time consuming. Because of this difficulty and expense, it is important that each requirement truly be "required" and critical to the overall performance of the vehicle. It is also important that requirements can be changed or eliminated as the system matures to minimize verification cost and schedule.

The Capsule Parachute Assembly System (CPAS) Project is developing the parachute system for the NASA Multi-Purpose Crew Vehicle (MPCV) Orion Spacecraft. Throughout the development and qualification cycle for CPAS, requirements have been evaluated, added, eliminated, or more generically, "tailored", to ensure that the system performs as required while minimizing the verification cost to the Program.

One facet of this tailoring has been to delete requirements that do not add value to the overall spacecraft or are not needed. A second approach to minimize the cost of requirement verification has been to evaluate requirements based on the actual design as it has matured. As the design of the parachute system has become better understood, requirements that are not applicable have been eliminated.

This paper will outline the evolution of CPAS requirements over time and will show how careful and considered changes to requirements can benefit the technical solution for the overall system design while allowing a Project to control costs.

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I. Nomenclature

ADS = Aerodynamic Decelerator System
CDR = Critical Design Review
CM = Crew Module
CPAS = Capsule Parachute Assembly System
CSM = Crew and Service Module Office
GEMCB = Government Equipment and Materials Control Board
GFE = Government Furnished Equipment
JSC = Johnson Space Center
LRS = Landing and Recovery System
MPCV = Multi-Purpose Crew Vehicle (Orion)
PDR = Preliminary Design Review
PTRS = Project Technical Requirements Specification
SAR = System Acceptance Review
SE&I = Systems Engineering and Integration
SRD = System Requirements Document
SRR = System Requirements Review
V&VD = Verification and Validation Document
VSC = Verification Success Criteria

II. Introduction

Spacecraft design is done through the use of requirements. At the highest level, the customer determines what functionality is required from the spacecraft under consideration and then those needs are captured as specific requirements in a top, spacecraft-level document. These needs are usually operational and can be fairly broad or generic. As such, they usually don't provide sufficient specific information to actually drive a design implementation.

As an example, the NASA Orion Spacecraft has a top-level requirement that states "Orion shall return the crew and cargo from beyond Earth orbit destinations to the Earth surface". While this functionality is certainly critical for the spacecraft, the requirement itself is clearly not of sufficient detail to drive a final design, nor is it easily verifiable at this level.

Requirements are then flowed down through several levels and allocated to the appropriate elements, systems, subsystems and components until they reach the final hardware design organization. Each requirement must then be objectively verified, with evidence to demonstrate that the requirement has been met. Requirements verification can be very time consuming and expensive. Verification is done via one or a combination of several of four methods: Analysis, Test, Demonstration or Inspection. Depending on the complexity of the requirement and its verification, these can lead to extensive analysis effort or testing. At a minimum, just the documentation of the work completed as well as tracking each requirement, verification, and closure can drive a significant overhead to the project. Because of these costs and schedule impacts, it is critical that each and every requirement be truly necessary. If the spacecraft ultimately does not need a particular function, then any requirement that drives design and verification is unnecessary cost and time.

With the already high cost of spacecraft development, it is crucially important that money and effort not be wasted on unnecessary functionality. There are always a variety of functions that are vying for funding. Adding an unnecessary requirement drives cost and takes money away from other areas of the spacecraft that present a higher need or risk. As an example, money spent on unnecessary requirement verification of the parachute system is money not available for risk reduction and testing of the heat shield.

Given the cost and complexity to track and verify requirements, it is critical for requirements to be added, deleted, changed, or, more generically, "tailored" as required throughout the hardware development lifecycle. However, tailoring of requirements does present a certain level of risk, so the approach to requirements must vary over time and with hardware maturity and there must be a strong review and control process in place to ensure the hardware delivered still meets the true needs of the spacecraft.

III. Design-Agnostic versus Design-Specific Requirements

There are two fundamental ways to view requirements. Requirements can either be “design-agnostic” or “design specific”. Design-agnostic requirements are those that do not express any knowledge of the underlying system that they are flowed down to. A design-agnostic requirement does not consider the system design or hardware content in any way. The benefit of design-agnostic requirements is that they protect for any possible design implementation, and they protect for design changes that might incorporate additional features / hardware / functionality in the future. The downside to this type of requirement is that it imposes the maximum number of requirements and verifications on each system and does not take advantage of clear design limitations and approaches. In effect, this is the “kitchen sink” approach to requirements, where every possible spacecraft requirement is flowed to every system within the spacecraft. Unfortunately, many people believe that this is the “safest” approach to requirements flow. The standard viewpoint is that this approach prevents the requirements from “missing something”, and in many ways it treats all requirements as being “equal”. This approach to requirements flow is also the most time consuming and expensive.

Alternatively, “design-specific” requirements takes into account the current design content of a system. At a very high level, it could be something like “The system does not contain any electronic parts; therefore, electronic related requirements are not flowed to the project”. The obvious benefit of this approach is that it limits the number of requirements and verifications to those that the individual system might truly need. The risk associated with this type of requirement, however, is that the system design might change as the design matures. One could imagine a system that implemented some type of smart logic in hardware to improve system performance. If the new device that was added was electronic, then the requirements that had not been previously flowed could become critical to the functional performance of the parachute system.

With the competing goals of minimizing cost and schedule while ensuring that every system performs as required and expected within the spacecraft, a flexible approach to requirements flow is best. While it may seem counter-intuitive that the fundamental requirements can change or be tailored over time, good communications and good control can make this the best overall approach.

IV. Requirements Neutrality Based on Design Phase

At the NASA Johnson Space Center (JSC), hardware development projects follow a standard lifecycle process that incorporates design phases followed by a major system design review. The major design phases of this lifecycle are show in Fig. 1.

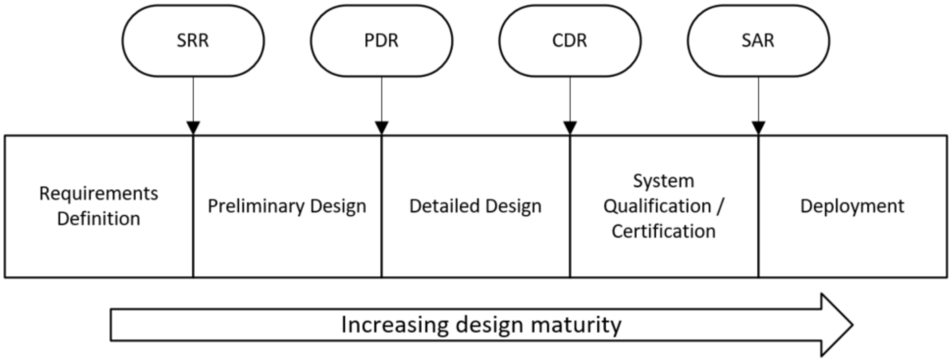

Fig. 1 NASA JSC Project Design Lifecycle

Once a project is approved, the first step is to define all of the requirements that should be applicable to the system. This includes any higher level, programmatic requirements (like design and construction standards, pyrotechnic standards, etc.) that govern the development of all hardware within the overall spacecraft design. This can also include the definition of contractual requirements and quality requirements for the hardware. This requirements definition phase ends at the System Requirements Review (SRR). At SRR, the project’s requirements are baselined and captured in a Project Technical Requirements Document (PTRS). In theory, the PTRS is the sum total of all requirements and functionality that the system must deliver to the spacecraft. Also “in theory”, this document should not change over the life of the project.

Once SRR is complete and the requirements are baselined, the design team can move forward with a preliminary design of the hardware. During this phase, the team is developing system design and performance, with many final choices and decisions to come. Once the design has reached a sufficient maturity that risks are well understood and a conceptual design is available, a Preliminary Design Review (PDR) is held. At PDR, external experts and stakeholders review the design and the team takes actions to resolve to ensure that the design is sufficiently mature and feasible.

Once all of the actions from PDR are complete, the team can move into final, detailed design of the system. This is where all design choices are completed and complete system analysis is performed. This is also the phase during which verifications for each requirement are proposed. Once the design is complete, the team conducts a Critical Design Review (CDR) to document the proposed final design solution. One of the key documents delivered during PDR is a Verification and Validation Document (V&VD). This V&VD has a verification success criteria (VSC) written for each requirement. The VSC is the objective evidence that will be required to demonstrate that the requirement has been successfully met or implemented.

The design documented at CDR then undergoes final assembly and qualification testing to produce all of the required evidence (analysis, test, inspection or demonstration) for each requirement. This qualification and certification ends with a System Acceptance Review (SAR). At SAR, the final design is documented, with appropriate flight hardware delivered. Each requirement is verified and objective evidence is provided that all requirements have been met. This is the end of the design and development phase for the system, and it moves into production and ongoing, sustaining engineering.

Throughout all of these phases, the PTRS contains the requirements, the design goals that the system must meet. It is important to remember that the PTRS is not only the source of all the functions required of the system, it is also a limiting document to prevent additional functions from being added to the system. Additional functionality, hardware and design features all cost time, money and mass to implement. Given that all three of these can be extremely limited on a spacecraft, it is important to realize that if a function is not in the PTRS, then that function is not required and should not be implemented in the final design. Engineers always want to do the best job possible and adding features and functionality is often viewed as “better”. In spacecraft design, the PTRS acts to limit these additions and “improvements” and so ensures that the hardware delivers does only what is required at the minimum cost, schedule and mass.

Clearly, the design of the system matures throughout this lifecycle. The design team understands exactly what components and functionality are included in the system by CDR. At PDR, there is typically just an idea or rough design of the system. As the design becomes better understood, it is natural that the requirements would also become better understood. It is also natural that the type of requirements themselves would change over this lifecycle, with certain “not applicable” requirements being dropped while other, new requirements could be added as the higher level system is matured. The entire spacecraft design team is becoming “smarter” throughout the lifecycle of the design and it is entirely reasonable that the requirements should change to reflect this. In effect, requirements change from being design-agnostic early in the life of a project to more design-specific as the project matures and the actual hardware design and content becomes better understood.

V. Capsule Parachute Assembly System Approach

A. CPAS Context Within the Orion Spacecraft

The Capsule Parachute Assembly System (CPAS) is a government furnished equipment (GFE) parachute system for the NASA Orion Crew and Service Module (CSM), within the overall Multi-Purpose Crew Vehicle (MPCV) Program. As a GFE project, CPAS is led by the NASA JSC Engineering Directorate personnel, with contractor and sub-contractor design, development, analysis and testing support. GFE projects within the Orion program report through and deliver hardware to the Government Equipment and Materials Control Board (GEMCB). The GEMCB is a multi-disciplinary board that includes representation of the prime contractor, JSC engineering, safety, quality and other technical experts as required. In addition, CPAS reports through engineering via the Landing and Recovery System (LRS) Manager. This structure is shown in Fig. 2.

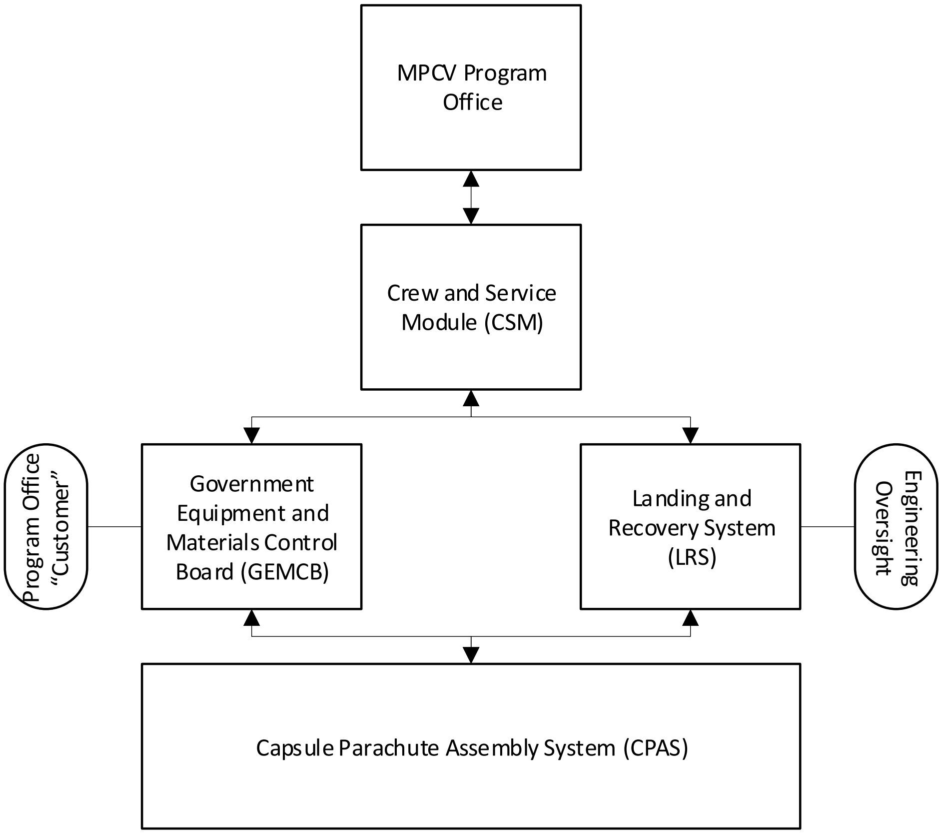

Fig. 2 CPAS GFE Reporting Structure

As a GFE Project, CPAS had the opportunity to work directly with the "customer" via the GEMCB to ensure that cost, schedule and risk were carefully managed. This board had final decision making ability to add, modify or delete requirements for CPAS, with input from the prime contractor and JSC engineering. This unique relationship made requirements tailoring very efficient for CPAS, as proposed changes to requirements could be coordinated through the GEMCB, with final decisions made quickly. The GMECB also provided oversight and guidance as spacecraft systems changed. Effectively, there was a two-way process that allowed for requirements review; CPAS could propose requirements for modification / deletion and have these reviewed and approved by the GEMCB, and other spacecraft systems and the prime contractor could bring requirements changes to the GEMCB and have these modified / added or deleted from the CPAS baseline. This structure worked very well for CPAS, as the GEMCB customer was responsible for delivering a high-reliability parachute system to the spacecraft but was also responsible for managing the costs associated with that system.

B. CPAS Requirements Changes

CPAS requirements are flowed down from this spacecraft level through the spacecraft prime contractor. NASA spacecraft requirements are flowed to the prime contractor. It is then the responsibility of this prime contractor to provide the entire spacecraft to NASA. Several systems and projects within the spacecraft were identified as being appropriate for GFE, based on expertise, risk, schedule and other factors. This GFE hardware is then provided to the prime contractor for integration into the vehicle. The requirements flow for CPAS is shown in Fig. 3

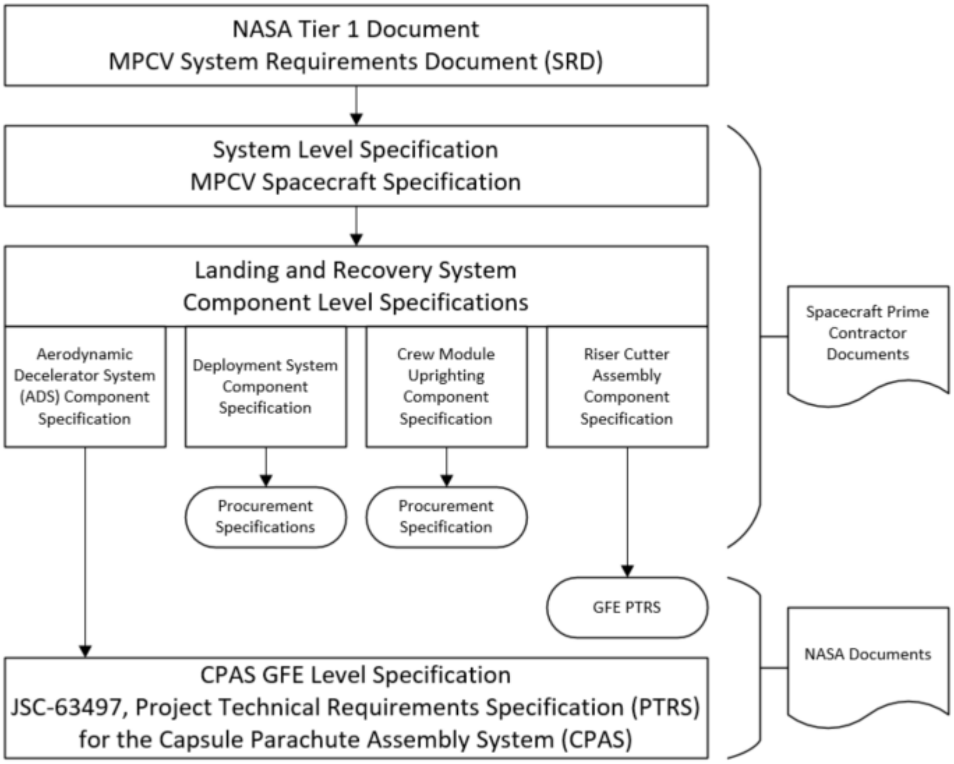

Fig. 3 Requirements Flow for CPAS

While it is theoretically possible, and perhaps the expectation of classical systems engineering, that requirements will be baselined at SRR and not changed, the reality is that this rarely if ever happens. The CPAS requirements document (PTRS) underwent a baseline release and then five revisions prior to SRR. At each of these revisions, the document added, subtracted and changed requirements as appropriate for the system as it was understood at that time. The evolution of the PTRS and the number of requirements it contained is shown in Fig. 4.

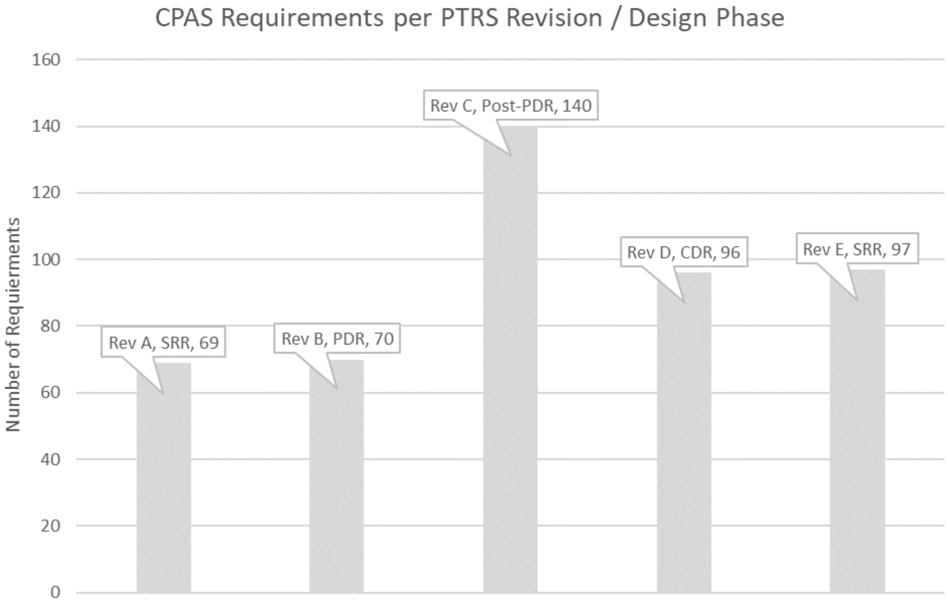

Fig. 4 PTRS Requirements by Design Phase

As this figure shows, the number of requirements doubled after PDR. This occurred because the higher level spacecraft design was not fully mature at the time of the CPAS PDR. As that design matured, and as the CPAS design itself matured, certain additional requirements became obvious. But, there was not sufficient design maturity yet to allow requirements to be tailored out of the CPAS baseline.

Throughout the critical design phase, it became clear that the number of requirements to be formally verified was very high and that the cost to provide objective evidence for each of these requirements could become excessive. An effort was undertaken to reduce the number of requirements verified by CPAS. This tailoring of requirements led to a reduction from 140 requirements post-PDR (PTRS Rev C) to only 96 requirements presented at CDR (PTRS Rev D).

One additional aspect that became more clear over time was what organizations would be responsible for verification of spacecraft integrated performance, versus what performance would be verified at the system or subsystem level. Several requirements that began as a CPAS system level verification of capability ultimately moved to a higher level, integrated system verification. The prime contractor was responsible for verification that the integrate spacecraft could successfully re-enter, be controlled and decelerated through landing and ultimately survive a water impact for crew recovery. Because this over-arching landing and recovery verification requires systems beyond the parachutes, it is an integrated spacecraft level verification. CPAS was providing a piece of that sequence, and would verify that piece, but the prime contractor was responsible for the overall performance.

As the CPAS design matured, requirements were tailored based on several criteria; requirements were changed as it became clear that verification would be difficult as originally proposed and requirements were deleted once the design was sufficiently well understood to identify that the requirement was not applicable. Several examples of each are discussed below. While this list is not exhaustive, these deletions and changes reflect the requirements tailoring strategy that CPAS employed to manage cost and schedule.

Deleted Requirements:

Lighting Conditions

In early iterations of the PTRS, there was a requirement flowed to CPAS that said “The CPAS shall perform landing regardless of ambient lighting conditions”. At the spacecraft level, this is an important requirement. Operation of a spacecraft must include anytime operation, and return / re-entry at night is critical, both in nominal operations and especially in contingency operations. The requirement exists to ensure that critical systems do not rely on ambient lighting either for power (solar) or for visualization.

However, at the CPAS level, it is clear that parachutes do not require sunlight to operate, and CPAS was not designing for the use of solar powered devices (CPAS is completely non-powered). With these design realities, the requirement is not needed at the CPAS level, and the requirement was deleted, with the concurrence of the GEMCB, the prime contractor and JSC engineering.

Electromagnetic Emissions

Another deleted requirement was for electromagnetic emissions control. The requirement as written stated “The CPAS shall comply with the programmatic Electromagnetic Environmental Effects (E3) Requirements Document”. Like the lighting requirement, it is important that all electronic hardware on the spacecraft comply with requirements and work in the electromagnetic environment. Once the parachute system was fully defined, it was clear that the CPAS system did not contain any electronic components and this entire document was no longer invoked as required.

Linear Acceleration

A third requirement that was deleted was for CPAS to control linear acceleration at the crew module (CM) center of gravity. The requirement as originally flowed stated; “CPAS shall limit the linear acceleration applied to the CM center of gravity to less than 5 g’s in any direction for any parachute-induced load event”.

This requirement was deleted by CPAS for two reasons. First, the parachute project does not have control of where the parachute attachment point is located relative to the CM center of gravity. Without this control, it was not possible for CPAS to assess the actual acceleration. More importantly, however, is the fact that the requirement is redundant. CPAS has another requirement to limit the amount of load that the parachutes can apply to the vehicle structure. This requirement ensures that the structural interface is designed sufficiently strong to survive all parachute loading cases. With this load, or “force” limit in place, and given any crew module mass (another parameter that was not within the control of CPAS), it is trivial to calculate the vehicle acceleration. This verification is one that moved from the CPAS system level to the higher, integrated spacecraft level. The prime contractor still has to verify that the crew is not exposed to excessive accelerations during re-entry and parachute operations, but CPAS is only responsible for control of the loads applied to the structural interface.

Modified Requirements:

Roll Rate

There was originally a requirement flowed to CPAS that stated "The CPAS shall meet functional and performance requirements when the CM roll rate is between -120°/sec and +120°/sec. This is an important spacecraft level requirement because of contingency return cases, where spacecraft control might be compromised. However, the current state of the art in parachute design does not allow for modeling of this roll condition. In effect, the best CPAS analytical models cannot account for spacecraft roll rates. In addition, while CPAS did use an extensive airdrop test campaign to verify models and parachute performance, it would have proven to be impossible, or at least very expensive to create this roll condition during testing.

Working with the spacecraft prime contractor, CPAS developed contact models that showed the contact locations, durations and loads for the parachute risers against spacecraft structures. With these contact models, CPAS could perform ground abrasion testing to demonstrate riser robustness against the type of contact predicted. The roll rate requirement was then replaced with a series of contact requirements (one for each parachute type), and these contact requirements were verified through ground testing. With this approach, CPAS was able to protect for the required functionality (parachute must be able to survive when the spacecraft is experiencing roll during deployment) while using a ground test that was both schedule and cost efficient.

Descent Velocity

A second modified requirement affected one of the most fundamental aspects of parachute design; the parachute size, or drag area. Original requirements were written that "The Main Parachutes shall limit the terminal vertical descent rate of the CM to less than a prescribed velocity". In working with the prime contractor analysis team at the vehicle level, it became clear that the landing velocity was not being used in their models. In addition, the landing velocity is affected by the vehicle mass, which is not controlled by CPAS.

CPAS provides a parachute parameter and description document. This document describes how to model each CPAS parachute and provides parachute performance parameters and dispersions. The prime contractor uses this document for their own parachute modeling for use in their integrated performance verification. While it is not possible to write a requirement for each parachute parameter, with a mature design the plan negotiated with the prime contractor was to control the drag area of the main parachutes as a surrogate for overall integrated performance. In other words, given the current design of the parachute system, as long as the drag area did not change below a certain level, the integrated spacecraft performance would not change dramatically.

With this understanding of the integrated modeling, and with the agreement that CPAS would continue to update the parachute parameters document, the requirement was changed to "The Main Parachute cluster shall provide a minimum prescribed drag area". This negotiation took a great deal of time and cooperation between all of the responsible organizations. It also took a significant level of trust. There are many ways that a parachute could be modified to affect its performance while still holding a set drag area. The understanding was that CPAS would not make any of this type of change, and certainly wouldn't do it without agreement and coordination.

Operating Temperature

In another situation, CPAS had performed testing to certain environmental temperatures. When this testing was performed, there was significant uncertainty associated with the thermal environment, and CPAS tested to higher temperatures than the models predicted. In effect, CPAS tested with margin because of this uncertainty. As the spacecraft thermal models were refined, it became clear that the actual expected temperatures were higher than originally expected. The CPAS operating temperature requirements were changed to a higher value, but CPAS had already tested to these temperatures so there was no impact.

C. Requirements Tailoring – Moving from Design-Agnostic to Design-Specific

While all of these examples are interesting and demonstrate the idea of requirements tailoring, it is more important to understand the process than the end results. Throughout the life of the CPAS project, as the design matured and changed, the CPAS team identified potential changes and deletion of requirements to the Orion Program. This is somewhat contrary to the "classical" systems engineering approach, where the requirements are baselined and then are not changed, but it does reflect reality for most projects. The real issue then becomes how to manage requirements tailoring and what characteristics are required for a project to be successful in the face of these changes.

Integration and Coordination – understanding the "Real Need" behind the requirement

It is not possible to make these changes to requirements without strong coordination with all external stakeholders and all other interfaces. In every case discussed above, the effect of deleting or changing the requirement was reviewed with other organizations and with Orion Program management. In some cases, the higher level spacecraft deleted the allocation of the requirement to CPAS and accepted verification at their, higher, level.

Another aspect of this integration and coordination is to fully understand the "real reason" behind the requirement. In some cases, the requirement itself at the higher level is just a "left over" from previous design phases or a time when the design was less mature and less understood. In others, there has just been a blind allocation of requirements to the lower level. It's much easier to simply pass requirements down to lower level systems than to screen each requirement for applicability.

The descent velocity / drag area requirement change is a perfect example of understanding the real higher level need. The spacecraft system did not need the descent velocity, nor was that parameter being used for any verification or design at that higher level. What the spacecraft did need was to control the physical size of the parachute so that it would match the models they were using for verification. While it's not a perfect solution, the drag area requirement was put in place as a "hook" to ensure that the parachute was not changed without coordination.

Strong Control – having an Arbiter

Even with good coordination and integration, decisions whether to delete or change requirements ultimately have to be made. To make effective decisions, there has to be a balance between cost, schedule and risk. Spending unnecessary money to track and verify an requirement ultimately takes those resources away from other areas of the spacecraft that need them.

In the CPAS model, the GEMCB acted as the control board responsible for delivery of the GFE parachute system to the spacecraft. The GEMCB ultimately had the responsibility and authority to accept CPAS recommendations for requirement deletion of modification. Of course, these decisions can't be made purely from a programmatic (and often cost) basis, but must consider technical aspects of the design. The GEMCB had representation from all affected disciplines, including the prime contractor, Orion program management, Safety and Mission Assurance, JSC engineering and other subject matter experts brought in to the board as topics dictated.

This multi-disciplinary approach led to spirited debates and honest differences of opinion. In the end, it was the responsibility of the board chairman to make decisions, based on all input. The advantage that the GEMCB offered to CPAS was rapid and certain decision-making. CPAS routinely took issues to this board and decisions were made during the presentation. This clarity and decisiveness allowed CPAS to make changes to requirements easily. Of course, not all decisions were favorable to CPAS, as the overall interest of the spacecraft prevailed. In some cases, there were additional requirements that were added to CPAS, but the ability to make quick decisions regardless of outcome allowed for effective requirements changes and tailoring.

Strong System Experts

Part of the reason that the GEMCB could make quick decisions was because CPAS had a strong group of parachute experts who would evaluate changes and make recommendations. The Theodor W. Knacke Aerodynamic Decelerator Systems Award is given by the AIAA to recognize significant contributions to the advancement of aeronautical or aerospace systems through research, development and application of the art and science of aerodynamic decelerator technology. CPAS was fortunate to have seven of the last ten Knacke Award winners working on the project. Experts on the project ranged back to the Apollo Program, and all of our experts provided invaluable advice and guidance.

Beyond this guidance, these experts gave CPAS a technical authority that was recognized and valued by the Orion Program. It is hard to underestimate the value provided by this group of experts, as parachute design and development can be very empirical. The experience that they brought to all of the decisions made by the project could not be replaced.

The Orion Program and the GEMCB respected these opinions and would frequently proceed based on their recommendations. Having this level of expertise on the project provided a level of technical authority that could not be matched or argued with. When this group of experts made recommendations, it was hard to ignore their advice.

Risk Identification – balancing spacecraft resources

Finally, the key to tailoring requirements lies in the balance of risks. While it is always the goal of any spacecraft development to eliminate risk completely, that is not realistic. Money spent unnecessarily in one area is not available for risk mitigation in another. With this trade in mind, it is important to minimize requirements and verification costs for any system, so that spacecraft management can spend their money for maximum risk reduction.

Risk identification and communication is actually a combination of the other factors already discussed. It takes strong integration, a strong arbitrator and subject matter experts to accurately reflect the risk that any decision incurs. It also takes a high level of integrity and engineering honesty to accurately report these risks to management. It is always easy to ignore or minimize risks associated with any requirement tailoring.

Trust

Perhaps the single, over-arching consideration for most if not all of these changes is a level of trust between all of the interested parties. In changing a requirement, it is important that the customer, engineering oversight and the prime contractor all had trust that CPAS would not take actions that would harm system performance, functionality or reliability. Certainly when a requirement is deleted completely, there is a high level of trust required to ensure that something isn't being missed or forgotten and there is trust required that if something changes in the future, requirements can be added back to the project.

Just as requirements are built over time, through addition, subtraction and modification, trust is also built. This is critical to the success of tailoring. Often, requirements are put in place to make sure that organizations take the right actions. Trust between all the stakeholders works the same way. If all of the interested parties trust each other, there is more willingness to drop and change requirements and less of a need to apply the "kitchen sink" approach.

VI. Conclusion

Classical systems engineering approaches rely on allocating requirements from the top level spacecraft down through various systems, subsystems and ultimately to individual components where those requirements drive design solutions. There is typically an effort to make sure that requirements don't change, as changes are seen as drivers to increased costs. However, having requirements that add little value to the design also can add unnecessary cost to hardware development and verification. In addition, money spent to carry and verify unnecessary requirements for one system take money away from other, potentially higher risk elements of the spacecraft design.

With this backdrop in mind, it is valuable to consider that requirements changes over time, or more generally, requirements tailoring is a valuable method to reduce cost and schedule. When tailoring is done with good integration, appropriate controls, strong technical expert support, risk balancing and communication, and, perhaps most importantly, trust, it can save a project significant money and time and still allow for the delivery of a high quality product that meets all of the true functional needs of the spacecraft.