Formalizing Mission Analysis and Design Techniques for High Altitude Ballooning

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Abstract

High altitude balloon (HAB) missions can be and are used to teach concepts related to spacecraft and satellite design. A HAB mission, however, presents unique characteristics, which must be understood and respected to produce a desirable outcome. Because of this, flying an unaltered satellite design as a HAB payload would be as undesirable as utilizing an unaltered HAB design as a satellite.

A well-defined process for HAB mission design is thus needed. The process presented mirrors commonly used space mission design processes to facilitate easy transition between the two. It is also comparatively simple, due to the smaller scale of many HAB missions and to facilitate the use of the HAB mission analysis and design (HAB-MAD) process as a stepping-stone to teach space mission analysis and design to students.

I. Introduction

The use of high altitude ballooning (HAB) payloads provides many of the same benefits as a low Earth orbit satellite for a fraction of the cost. Due to their lower altitude, high altitude balloons can provide higher resolution levels with less camera magnification hardware. They also have significantly lower costs: being able to be launched for hundreds or thousands of dollars instead of tens-of-thousands to millions of dollars.

Despite their lower cost levels, HABs should not be thought of as a poor-man's satellite. HABs have been used in their own right, for decades, for atmospheric measurement [1] and numerous other purposes. The atmospheric measurements enable the routine and severe weather predictive models that we rely on to guide daily activities. With approximately 700 weather stations launching weather balloons with radiosonde payloads twice daily (at noon and midnight, Greenwich Mean Time), more HABs are launched in a week than there have ever been satellites launched [2, 3, 4].

Recognizing the unique nature and myriad possible applications of a HAB, a framework for HAB mission analysis and design is presented that, while well-aligned with common space mission design approaches [e.g., 5, 6, 7], is simplified to acknowledge to lower cost and lower risk levels typical of HAB missions. This HAB mission analysis and design (HAB-MAD) process was designed based on the specific needs and requirements of near-space missions.

II. Uses for HAB Payloads

High Altitude Balloon payloads can be used for numerous purposes. These include near-space science, Earth science, weather forecasting, life sciences work and educational pursuits.

An example of near-space science, the Absolute Radiometer for Cosmology, Astrophysics, and Diffuse Emission (ARCADE) program measured the radiation emitted by the first set of stars produced by the Big Bang [8]. This mission was accomplished by launching seven radiometers to an altitude of 35 km [8, 9]. Another example, the Balloon-Borne Large-Aperture Sub-Millimeter Telescope (BLAST), collected information about the formation of planets and stars [10].

The proposed Global Air-Ocean In-Situ System (GAINS) and SAGE III Ozone Loss and Validation Experiment (SOLVE) seek to improve the understanding of Earth processes. GAINS proposed the deployment of a constellation of high altitude balloons as a set of low-altitude satellites for weather measurement [11]. SOLVE took measurements to aid the understanding of the ozone production and loss [12].

Weather forecasts are aided via HABs. Agencies worldwide launch weather balloons with radiosonde payloads at noon and midnight, Greenwich Mean Time [2]. These balloons are tracked during ascent: their position and altitude are used to determine the wind's direction and speed at each altitude that the balloon passes through [2]. The

National Weather Service operates 92 of these observation stations in United States and 10 in the Caribbean; approximately 700 other stations exist worldwide [3].

HABs are also ideally suited for academic use. Their limited expense and high impact value have generated significant interest in the educational community. Academic missions offer students the opportunity to send payloads (which may include still or video cameras and life science and other experiments) to the edge of the Earth's atmosphere. These projects inspire students and drive interest in the science, technology, engineering and math (STEM) disciplines [13].

III. Types of HABs

High altitude balloons come in three principal varieties. The maximum altitude attainable, mission duration and requirements differ somewhat depending on what style of balloon is selected. These styles include basic latex balloons, zero-pressure balloons and super-pressure balloons.

a. Latex Balloon

The latex balloon is the simplest style of high altitude balloon. Latex balloons are inflated to a pressure level that provides a desired level of free lift (which determines the rate of ascent). As the balloon reaches higher levels in the atmosphere is expands further, maintaining the equilibrium between the elastic force of the balloon and the interior and exterior pressures. During ascent, the atmospheric pressure is steadily declining which causes the balloon to grow in size until the maximum elasticity of the latex is reached. At this point, the balloon bursts and the payload falls, generally with its descent slowed by a small parachute.

Figure 1: A Latex Balloon & Payload Train [14]

b. Zero-Pressure Balloon

A zero-pressure balloon is designed to vent gas from the bottom to prevent bursting [15]. This allows the balloon to remain at its maximum altitude for approximately two weeks [15]. When the mission is concluded, controllers transmit a command that causes the payload to cut away from the balloon (ripping the balloon in the process) and return to Earth by parachute [15]. NASA zero-pressure balloons can lift payload masses of up 3,600 kg to an altitude of up to 42 km [15].

Figure 2: A Zero-Pressure Balloon Operated by the NASA Goddard Space Flight Center [16]

c. Super-Pressure Balloon

Super-pressure balloons are designed to remain at altitude for extended periods of time. These balloons are sealed to prevent altitude changes due to heat differences between daytime and nighttime [17]. Two types of super-pressure balloons are used: long duration balloons (LDBs) and ultra-long duration balloons (ULDBs). LDBs can have mission lengths of up to three weeks and ULDBs can support missions up to 100 days in length [17]. ULDBs can lift a payload with a mass of up to one ton to an altitude of 100,000 feet (30.5 km) [18].

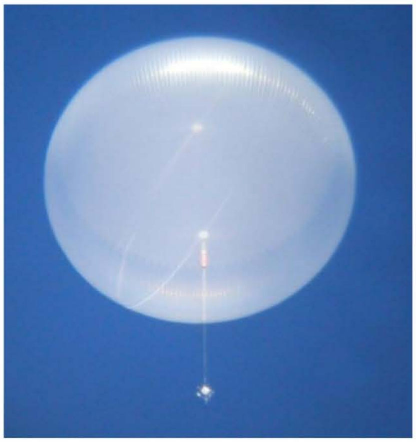

Figure 3: A Super-Pressure Balloon [19]

IV. The Near-Space Environment

During ascent and descent, a HAB payload is exposed to atmospheric pressure ranging from surface-level to 1% of surface [20]. It is also exposed to a wide variety of temperatures ranging from the prevailing surface temperature at the launch site to 90° below zero, Celsius (-130° F) [20]. At peak, the balloon is exposed to cosmic background radiation at 3 K; Yajima, et. al. proffer that the radiation effects of the primary radiation are similar to those found in space [21].

V. Phases of a HAB Mission

A near-space mission consists of several distinct high-level phases. These phases are applicable to any type of mission; however, for smaller missions, they may be conducted informally, with limited process and procedure implementation. The mission starts with the conceptualization phase. It then proceeds into the design phase where objectives are identified and iteratively refined and the various craft components and their interoperation are identified. Next, the mission moves into the development phase, where systems are built, tested and refined. Once craft construction is complete, the mission proceeds to the launch and operations phase where the craft is sent up, data is returned and operational decisions are made. Finally, when the mission is done, the conclusion phase results in the documentation of mission activities.

a. Conceptualization

The conceptualization phase serves, primarily to the answer to the question of why: why undertake the activities? For larger missions, this concept may come from a program objective, sponsor mandate or competitive proposal evaluation process. Smaller missions may be conceptualized by an individual that has appropriate authority and has decided to pursue an identified goal. The conceptualization phase concludes when a concept is selected (formally or informally) and design activities begin.

b. Design

The design phase should start with the identification of mission objectives and a consideration of whether high altitude ballooning is an appropriate way to achieve these objectives. The comparative utility (benefit and associated cost) of other possible approaches should be considered. If a decision to proceed with a high altitude balloon mission is made, at a minimum, this phase must determine what will be launched (e.g., specific details including design details for any components that will be fabricated), how it will be launched (e.g., latex balloon, zero-pressure balloon) and any constraints related to when it will be launched (e.g., it must be launched when Venus can be seen in the sky).

Payload design will flow from the answers to these high level questions. An iterative process of refining the near-spacecraft design from a high level concept to actual identified parts and integration methods will result in the specifications required to begin the development phase.

c. Development

The development phase includes not only fabricating, integrating and testing components, but also an iterative process of ensuring that the components work together as a system. Components should be fabricated or procured and tested individually (called unit testing) and then assembled and tested together (called integration or system-level testing). For larger projects, clusters of components (called assemblies) can and should be tested before being incorporated as a piece of a larger cluster. The development phase concludes when all requirements are met (or deviation is documented and approved) and this adherence has been affirmed via successful unit and system-level testing.

d. Launch & Operations

Many high altitude balloon missions will be launched informally by mission participants at a chosen date, time and location. Others, such as those launched through NASA's Announcement of Flight Opportunities program and the High Altitude Student Program (HASP) will be required to follow a formal process to propose for a launch. They will then be rostered on to a specific flight, which may require some amount of waiting.

The operations phase begins at launch. Depending on the mission specifics, this phase may consist of tracking and chasing a balloon across the countryside – or it may include communication with and commanding the payload. In any event, the operations phase is the key time during the mission where engineering work is tested, objectives are achieved, and relevant data is collected. The operations phase concludes when the mission activities are terminated (e.g., when the HAB payload is recovered or deemed lost).

e. Closeout

Any project or mission requires a period of time following its main activities to clean up. For academic and scientific missions that are part of an ongoing program, this may be as simple as documenting the missions' success (or failure), assessing the consumption of supplies and returning reusable hardware to appropriate storage locations in preparation for future missions. Missions with scientific goals may require data reduction and reporting to be performed. Larger missions (particularly those that are not part of a continuing program) may need to follow a more rigorous conclusion process. The conclusion phase should wrap up the loose ends of the project.

VI. High Altitude Balloon Mission Analysis and Design

The high altitude balloon mission analysis and design process (HAB-MAD) is designed to be a lightweight approach that mirrors critical elements of the space mission design process. This three-phase approach begins with the definition of objectives, requirements and constraints. From this, a mission concept and architecture are developed. The mission architecture is used to define and analyze critical drivers, which are used to create a final mission plan.

a. Defining objectives, requirements & constraints

Once a prospective mission is conceptualized, it must be formalized by identifying the pertinent objectives, needs, requirements and constraints. Objectives are, quite simply, the goals that drive the creation of the solution. Goals should be broad in nature and specify what is desired to be accomplished – not how it should be accomplished.

The needs defined by the objectives flow through into the definition of requirements and constraints. Requirements are specific statements that a mission concept must achieve in order to successfully satisfy the objectives that have given rise to the requirement (requirements that cannot be tracked to an objective should be examined carefully and likely removed). Wertz and Larson propose that requirements should be broken down into two distinct categories: functional requirements, which define the desired performance characteristics and operational requirements, which define system operation and user interaction [22].

Constraints are effectively negative requirements, which remove a part of the solution space from consideration. Constraints may be generated from objectives; however, they can also be born from economic and programmatic realities (such as the level of budget available, etc.). Requirements and constraints can be either quantitative or qualitative, but must be specific enough that compliance with them can be easily determined.

b. Concept and Architecture Development

The process of concept and architecture development is similar – albeit at different levels of detail. The mission concept is the first level where one determines how the mission will be conducted. Wertz and Larson proffer that at least four key questions should also be answered: what data will be collected and how will it be provided to its users, how will various parts of the solution-system talk to each other, how will the system be controlled, and what is the schedule of the mission-project [23].

The architecture is even more detailed. At this level, however, the focus turns to trading various elements with each other to maximize mission performance in terms of the metrics defined by the objectives, requirements and constraints. The mission concept, under the approach taken by Wertz and Reinert, forms one of the possibly tradable elements [24]. Figure 4 describes the HAB-MAD mission architecture elements.

Figure 4: Mission Architecture Elements

Element	**Description**
Mission Concept	Approach that is taken to the mission.
Subject	The target of the mission: what is being imaged, sensed or affected by the mission
Payload and Subsystem Elements	Various integral components that together provide the capabilities to perform whatever actions the mission must take. Only critical elements should be identified at this point.
Balloon Type, Target Altitude & Mission Duration	The desired maximum altitude and mission duration may dictate the type and size of balloon that is chosen. Zero-pressure balloons offer the ability to stay at altitude for an extended duration; however, a mechanism for ending the mission must be incorporated
Communications Approach	Will the mission involve communication with the ground? Just one-way position transmission? One-way data transmission? Two way data transmission and control?
Operations Approach	Will the mission require a control station? Only monitoring? Will chasers be required to track the balloon and recover it?

c. Drivers, Requirements, Analysis & Selection

The final steps of the mission design process involve performing analysis in support of final selection and making a final selection that defines all elements of the mission. This process begins by identifying drivers: the features of the mission that are controllable and have influence on key mission metrics including cost, schedule and performance. Risk, while not a stated metric, is also a source for drivers, as it impacts the ability of a mission to deliver on the other metrics. Driver identification can be performed by starting with the key metrics and reviewing each controllable mission element to determine whether changing it impacts the metric.

The trade analysis process seeks to maximize the mission utility via selecting the best set of mission requirements. Utility analysis requires that each metric be quantifiable (even if this quantification is arbitrary and only done for the purpose of this analysis) and that the relative importance of the metrics be defined via the assignment of coefficients. Each possible solution then has its score calculated and the one with the highest utility value wins.

Once iteration does not seem to be having a meaningful impact in increasing solution utility, it is time to pick a mission solution. This process starts with the solution that has the highest utility. The solution must then be evaluated to ensure that it meets all requirements and constraints. If so, it is selected; if not, further refinement may be required or an alternate solution must be considered.

Figure 5: Correlation of Mission Engineering Phases

HAB-MAD	**SMAD 3**[23]	**SME-SMAD**[24]	**SSE 4**[25]
A. Defining objectives, requirements & constraints	1. Definition of Mission Objectives	1. Define the Broad Objectives & Constraints	A. Feasibility
		2. Define the Principal Players	
		3. Define the Program Timescale	
	2. Preliminary Estimate of Mission Needs, Requirements and Constraints	4. Define the Quantitative Needs, Requirements & Constraints	
B. Concept and Architecture Development	3. Identifying Alternative Mission Concepts	6. Define Alternative Mission Concepts	
	4. Identifying Alternative Mission Architectures	5. Define Alternative Mission Architectures	
C. Drivers, Requirements, Analysis & Selection	5. Identifying System Drivers	7. Define the Likely System Drivers & Key Requirements	B. Detailed Definition
	6. Characterizing the Mission Architecture	8. Conduct Performance Assessments & System Trades	
	7. Identification of Critical Requirements		
	8. Mission Utility	9. Evaluate Mission Utility	
	9. Mission Concept Selection	10. Define the Baseline Mission Concept & Architecture	
		11. Revise the Quantitative Requirements & Constraints	
		12. Iterative & Explore other Alternatives	
		13. Define System Requirements	C/D. Design, Development, Manufacture, Integration and Verification
		14. Allocate the Requirements to System Elements	
			E. Mission Operations & Data Analysis

VII. Comparison of Mission Engineering Processes

The goal of the HAB-MAD process is two-fold. First, it is designed to provide a framework that is right-sized to the design of most HAB missions. The three-step framework can be scaled up by spending additional time and resources on various sub-components. Alternately, by minimally covering each of the three design phases, a small mission can be designed in an amount of time commensurate with its scope.

Figure 5 contrasts the HAB-MAD model with the models presented in Space Mission Architecture and Design, 3rd Edition (SMAD 3) [25], Space Mission Engineering: the New SMAD (SMAD 4) [26] and Spacecraft Systems Engineering, 4th Edition (SSE 4) [27]. These texts form the basis of most university space mission design courses and the alignment of HAB-MAD with these common frameworks makes it suitable for an introductory space mission design course by ensuring that the knowledge gained can be applied to the follow-on, more detailed courses.

One approach that could be taken would be to begin with an introductory course that includes a complete HAB project. This would be followed by a set of courses that cover each subsystem and payload design in greater detail. A capstone course, utilizing SMAD 3, SMAD 4 or SSE 4 could then complete this process. The use of HAB-MAD for the introductory course allows students to comprehend the value of learning about the subsystems, without getting bogged down in detail.

VIII. Processes for HAB Mission Management

HAB missions, like any project, require strong management to be successful. In an academic setting, this management need allows the expansion of involved students to include those who may be pursuing business or public administration degrees (in additional to the traditional HAB engineering focus) and desire an experience in project management. Irrespective of student involvement, however, maintaining control of the mission is the only way to ensure a successful result. Important considerations include project / mission management, implementing appropriate systems and processes, and assurance activities.

a. Project / Mission Management

Planning, as an iterative process, can expand to fill whatever time is available to it. In many cases, this time expansion occurs without any benefit in terms of planning quality or outcomes. As such, it is critical to properly manage the planning process. In fact, the first step in planning management should be to make a plan for the planning process. Specifically, this plan should identify the required outcomes, verifiable milestones, and the artifacts (documents) to be produced.

The defined outcomes should include both technical (problem solving / design) and team interaction goals. Just as the plan itself should include verifiable milestones to allow project sponsors and others to assure that the mission is proceeding as planned, the plan for the planning process should also include milestones.

It is critical to define what specific artifacts should be produced during each phase and any format constraints which are applicable. This plan should also identify target completion dates and include a management time reserve to accommodate the invariable slippage that will occur when a technical problem is discovered.

It may seem, at first glance, like the planning process can be ignored or dramatically simplified for small mission – like many academic missions. However, in some ways these small and academic missions require the planning process to a greater extent than large ones. Small and academic missions will likely utilize the services of individuals who have alternate full-time commitments. These individuals will have various levels of commitment, which may vary from week-to-week, due to other pressures, which they face [28]. By defining what is required from each member during the planning process, the leader is ensuring that a clear understanding is held by all participants – and creating a document that can be used to later remind individuals of the commitments that they have made and the impact that failing to meet them will have on the large group.

b. Systems & Processes

Any effective management methodology must employ systems and processes to control and document the various management and managed activities that are performed during a project or mission. HAB missions are no exception to this rule. Systems and processes should be employed starting from project initiation to track objective, concept and requirements generation and any changes that are made to these and other key project elements.

A management system should be selected. One management system that is very well suited to small projects and also scales reasonably well is management by exception. The fundamental notion of management by exception is that the manager determines what an acceptable range of performance is (e.g., an upper and lower bound of time that a task should take). Processes that perform within the designated acceptable range are not reviewed (except, perhaps as part of an overall process audit), allowing the majority of the manager's time to be spent on tracking areas that are significantly over-performing or under-performing expectations.

Project deliverables must also be retained and tracked. The objects that need to be retained and tracked fall into two primary categories: artifacts and deliverables. Artifacts are any document (or similar) associated with the project that is not a defined outcome of the project (e.g., management documents, change tracking logs, etc.). Deliverables are, quite simply, anything that must be provided to a stakeholder as a part of completing the project's requirements.

Both artifacts and deliverables must be retained and tracked appropriately. However, the process that is implemented differs somewhat depending on whether they are physical objects or electronic documents (including software, etc.).

Changes that impact mission objectives, requirements or constraints are particularly problematic, after decisions that rely on these foundational elements are made. Given this, most projects devote substantial efforts to the management of changes that impact these areas. By tracking and documenting these items one can ensure that the change's impact is properly propagated throughout the project. Tracking the changes also allows identification of what various cost and schedule overruns are attributable to.

c. Assurance

There is little point to having objectives, requirements or constraints if action is not taken to ensure that these elements are met by project activities. Assurance activities ensure that defined high-level parameters are met by lower-level design and development activities. They also ensure that artifacts and deliverables meet the specifications required of them.

Requirements mapping is a technique that can be used to ensure that various high-level elements (e.g., objectives, requirements and constraints) are implemented in lower-level design documents. With requirements mapping, the performing team member is required to determine and document how each high-level element is implemented in the area being reviewed.

Even with the best of intentions, mistakes do happen. Quality management mitigates these risks by identifying areas where high quality is required and defining assurance activities to validate that this quality exists. Quality management can be conducted in two ways. One approach to quality management is to design it into a production or operations system. A second approach to quality management is validation-based. In many cases, this approach is called for due to difficulties incorporating quality directly into a process or the high cost of a quality-integrated process failing.

IX. Defining Objectives

The objective definition process can take a large variety of forms. In some cases, objectives may be highly influenced by a funding source or program mission statement (or program objectives). In other cases, objectives may have to be defined in an effort to seek funding (or other aid such as launch site access) and thus incorporate elements appropriate to this goal. In still other cases, requirements may be less constrained by funding and resource considerations.

The objective definition process should begin with stakeholder identification and a needs analysis. Stakeholder identification involves determining who is affected by a proposed activity. This includes individuals or entities who may fund the activity, those involved in the activity and those that may be positively or negatively impacted by the activity, without direct participation. Once each stakeholder or group of stakeholders is identified (stakeholders with very similar needs should be grouped – if differences are found, then these groups can be sub-divided, etc.), members of the group should be interviewed to determine their interest in the mission. Once a set of representative interviews has been completed, needs analysis should be conducted. Needs statements must then be refined into broad statements of objectives that are qualitative and easily understood. Again, the goal of objectives is to provide a general set of mission goals – not a quantitative set of requirements. The generated objectives should be shared with the stakeholders to ensure that they are in line with stakeholder's expectations, and are understandable.

X. Identifying Requirements & Constraints

Requirements and constraints should be specific, quantifiable (where possible) statements that can be evaluated as being attained (or not). Requirements and constraints are generated from objectives as well as additional information.

a. Functional and Operational Requirements

Functional and operational requirements define capabilities that the system must have (functional) and be able to do (operational). There are two key considerations when generating requirements. The first is the mission objectives. Each objective should be decomposed into one or more requirements. The complete set of requirements associated with each objective should be sufficient to ensure that the objective is met, if all requirements are met. The second key consideration for requirement generation is the test-ability of the requirement. Peter Drucker famously noted the extreme difficulty of managing what cannot be measured [29]. Ensuring that your requirements are measurable eases management processes and avoids later confusion and disagreements.

b. Constraints

Constraints share many traits with requirements and could, generally, be reworded and presented as requirements. However, the separation is valuable for working purposes, as the two may originate from different sources. Constraints can be considered as being restrictive statements of what a project cannot do (while requirements are positive statements of what it should/must do). Constraints can relate to budget, schedule, safety considerations, legal considerations, ethical consideration and such. A successful project must, thus, satisfy all requirements and not violate any constraints. Like requirements, constraints must be test-able and specific.

XI. Creating & Selecting a Mission Concept

With the objectives, requirements and constraints in place, a variety of brainstorming techniques can be used to identify approaches that may fulfill them. One approach that can be taken for concept generation and selection is based on the approach to conducting spontaneous creativity challenges applied by the Odyssey of the Mind organization.

This creative problem solving activity is designed to produce a large set of divergent answers within a short period of time. The approach also combines the benefits of the two previously described systems of idea generation. In the competition, participants are given one minute to silently think and two to respond [30]. Participants, thus, benefit from generating ideas without interruption or having their direction of focus shaped by others involved in the process. The communal sharing, however, also provides the opportunity for stating ideas which 'piggyback' off of the ideas of other team members.

It is suggested that participants in the mission concept generation process be given a set amount of time to record as many possible approaches to satisfying the objectives and requirements as come to them. The ideas should be recorded as short conceptual statements and not developed any further. Once participants are done, the ideas can be shared, in a round-robin fashion, with others in the group. Participants should be encouraged to record and share any additional ideas that come to them during this process. No judgment should be made – all non-duplicative ideas should be recorded by the process leader.

A mission concept should provide a complete answer to how the mission will be conducted, albeit with a low level of specific detail. For orbital missions, it is recommended that the key questions to be answered include what data will be collected and what will be done with it, how data and commands will be transmitted to and from the craft, how the activities of the craft will be decided and controlled and what the timeline of the mission is [31]. These questions are also very relevant for HAB missions.

XII. Defining the Mission Architecture

A mission architecture is born from a mission concept and enumerates a set of mission characteristics that flow from the concept. The creation of several concepts and architectures (possibly including multiple architectures born from a single concept) is desirable to ensure that the mission solution space is well-explored before an architecture is selected. For near-space missions, architecture elements include the subject, payload elements & bus, balloon, target altitude & flight time, ground systems and communications approach.

a. Subject

The subject is the reason for conducting the mission. It is the target of the mission's investigations. This would include a remote sensing target or an onboard plant or animal, whose exposure to near-space conditions was being observed.

b. Payload Elements & Bus

For a basic mission, the payload elements include the transmitter that is used for recovery, any onboard instruments and/or any onboard experiments. A basic HAB mission will not generally have a bus; however, more complex missions may be equivalent to their orbital cousins and consist of a bus and analogous interconnected subsystems.

c. Balloon

The choice of a balloon type and size is, in some ways, analogous to the choice of a launch vehicle (rocket) for a space mission. The balloon carries the payload to the edge of space and its type and size determine how high the payload will go, how long it can stay there and the maximum level of mass that can be transported. Balloon types were presented in section III.

d. Target Altitude & Flight Time

The target altitude and flight time are a key mission consideration. These architecture elements are born from mission requirements related to the subject of the study and the duration of time that is required in the air. Ballooning, unfortunately, does not provide a great level of control as to exactly what is overflown during the mission.

e. Ground Systems

At a minimum, it is required that telemetry be received in order to determine where the balloon is and what point it is at (ascent, peak altitude, descent) during its flight. The specific communications plan for the mission may dictate additional requirements for ground stations, if extended telemetry is being transmitted or commands will be sent to the HAB payload.

f. Communications Approach

The communications approach determines when the HAB payload will be communicated with and what will be communicated. Most small HAB payloads support only one-way communications, providing only a minimal telemetry downlink. Payloads, such as those that must be able to cut-away from their balloon on command, can also receive commands from the ground and take corresponding actions.

The communications approach that is selected will also have a significant bearing on the autonomy of the craft (or conversely, a decision to operate autonomously or not may drive the communications approach). Craft that do not support two-way communications must operate independent of any ground support throughout the mission.

XIII. Driver Identification

The refinement of a mission architecture is performed by identifying the elements that affect it and determining the impact of trades (changes that may add benefit in one area and reduce the benefit in another). Drivers are the mission elements that impact cost, schedule and other key metrics.

Driver identification can be performed by starting with the key metrics and reviewing each controllable mission element to determine whether changing it impacts the metric. If it does, the element is a driver for the metric. Some elements may be identified as having an impact only in conjunction with another element.

XIIII. Requirements, Analysis & Selection

With the drivers identified, the key requirements – those which have the most impact in determining the mission's performance in terms of metrics (e.g., cost, schedule, performance, etc.) – can be identified. Key requirements can be identified by reviewing the identified drivers, identifying what requirements influence them and how significantly. Key requirements are the requirements that have a significant impact on one or more drivers – or a more minimal impact on numerous drivers. The identification of key requirements is a critical part of solution selection as the key requirements are the focus of the requirements trade analysis process. The trade analysis process will, logically, focus only on the key requirements that have been deemed tradable, previously.

The trade analysis process seeks to maximize the mission utility via selecting the best architecture that fulfills all mission requirements. Utility analysis requires that each metric be quantifiable (even if this quantification is arbitrary and only done for the purpose of this analysis) and that the relative importance of the metrics be defined via the assignment of coefficients. Each possible solution then has its score calculated and the one with the highest utility value wins. The identification of key metrics constrains the search space (the number of combinations that should be considered) by allowing the process to focus on only the most important possible trades. Practically, the process is somewhat more complicated than this as the analyst may identify new possible solutions upon seeing what elements have the most impact and what prospective solutions perform the best. Given this, an iterative process will likely occur with possible solutions refined and compared several times.

Once iteration does not seem to be having a meaningful impact in increasing solution utility, it is time to pick a mission solution. This process starts with the solution that has the highest utility. The solution must then be evaluated to ensure that it meets all requirements and constraints. Its risk must be evaluated to ensure that it is acceptable. If any of the above validations fail, the solution may need to be further retooled (and compared to others, if its utility value has changed). The result of this final step is to choose a mission solution and make a go/no-go decision as to whether to proceed with the mission at all.

XV. Conclusion

The foregoing has presented a scalable framework for the design and optimization of a HAB mission. Skillful users may determine that additional areas can be combined or further simplified to make the process even more lightweight for particularly small projects. The various sections can also be expanded for use in larger projects. For particularly large-scope projects, the HAB specific implementation elements can be used to replace the roughly analogous sections of the SMAD or SSE process and the full heavyweight model can be utilized.

By utilizing this framework in an academic environment, the requirements for students are better developed. This translates into additional leadership opportunities for student participants, who can implement designated areas (based on the plan) without requiring the detailed understanding that would be otherwise required (to lead without a plan). The framework also exposes students to engineering and project management best practices and prepares them to step-up to more robust engineering and management approaches.

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