HEURISTICS APPLIED IN THE DEVELOPMENT OF ADVANCED SPACE MISSION CONCEPTS

Erik N. Nilsen, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California

Abstract

Advanced mission studies are the first step in determining the feasibility of a given space exploration concept. A space scientist develops a science goal in the exploration of space. This may be a new observation method, a new instrument or a mission concept to explore a solar system body. In order to determine the feasibility of a deep space mission, a concept study is convened to determine the technology needs and estimated cost of performing that mission.

Heuristics are one method of defining viable mission and systems architectures that can be assessed for technology readiness and cost. Developing a viable architecture depends to a large extent upon extending the existing body of knowledge, and applying it in new and novel ways. These heuristics have evolved over time to include methods for estimating technical complexity, technology development, cost modeling and mission risk in the unique context of deep space missions.

This paper examines the processes involved in performing these advanced concepts studies, and analyzes the application of heuristics in the development of an advanced in-situ planetary mission. The Venus Surface Sample Return mission study provides a context for the examination of the heuristics applied in the development of the mission and systems architecture. This study is illustrative of the effort involved in the initial assessment of an advance mission concept, and the knowledge and tools that are applied.

Introduction

The use of heuristics in the field of systems architecting was established by Rechtin[1] and extended in subsequent texts[2]. Of the four architecting methodologies (Normative, Rational, Participative and Heuristic), the heuristic method is particularly applicable to the development of advanced space mission concepts. As an early stage investigation, there are few constraints on the design. Some context must be established within which the development can proceed. In essence, the team is dealing with an unprecedented application, and evolving an architecture that is suitable for this new mission concept involves developing a model of the system and its environment. This model can be constructed using prior experience and lessons learned. These lessons learned, or heuristics, are the collected wisdom of the architect and the team, and are essential to the successful completion of the investigation.

The Process

The Jet Propulsion Laboratory has an active program for the development of advanced deep space mission concepts to support NASA and the space science community. This program has been instrumental in examining new exploration goals and assessing architectures and technology readiness. The output of this process is used to establish space science strategic plans[3] and strategic technology development plans[4].

Two complementary approaches have been taken at JPL for the study of advanced mission concepts. For in-depth examination of a mission concept, a team of specialists is convened. This team studies the feasibility of the concept, develops mission tradeoffs and examines the technical challenges. The end result of their efforts is an assessment of the viability of the concept, mission alternatives, technology requirements and rough cost estimates.

JPL has also invested in developing a collaborative engineering environment that is well suited for the investigation of advanced concepts. The Project Design Center (PDC)[5] is a physical facility containing interrelated Computer Aided Engineering (CAE) design tools that share information electronically. A design team (Team X) can convene in the facility and develop mission and spacecraft concepts in a rapid turnaround manner. External customers and specialists can be included in the design process through remote login to the networked computers and videoconferencing capabilities. Oftentimes the PDC and Team X is the primary method of investigation for advanced mission concepts. It is also used as a second look to verify the conclusions drawn by a proposal or concept development team.

The Venus Surface Sample Return Study

The VSSR Study was commissioned to investigate the feasibility of returning a sample of surface material to Earth for study. The impetus for this study was derived from the science priorities as established by the science advisory groups[6] and the president's national space science goals[7]. The perceived difficulty of the task demanded a more in-depth analysis than what could be done in the PDC and Team X environment alone.

Feasibility would be established if a viable science mission could be designed that fell within acceptable limits for cost and schedule. Prior studies by NASA and other space agencies[8] have led to designs that were much more expensive than what is feasible in today's fiscal environment. The goal was to accomplish the mission using a single launch with a Delta IV class launch vehicle, with a launch in the 2005 to 2008 timeframe. A technology cutoff date of 2005 was established.

The study team was composed of the team leader (and system architect), a science lead, systems engineer, and domain experts in selected areas. A mission design specialist was instrumental is developing the launch opportunities and mission tradeoffs of various delivery alternatives. For the flight and surface systems, experts in systems design, materials, thermal, structure, mechanical devices and propulsion were recruited, as well as experts in the Venusian environment. The study lasted for approximately four months, culminating in a Team X study to establish an independent verification of the design and to develop a cost estimate using the latest parametric cost models.

Heuristics for Team Management

In developing and motivating this type of study team, it is important to keep in mind the scope of the task and the expected outcome. This is an initial study to establish feasibility, not a detailed design study. The timeframe for completing the study is constrained, and the allocated budget is usually limited. As a result, the management challenge is to get the most out of the team within the limited resources. The following heuristics are particularly applicable to this type of investigation.

Heuristic: Focus, Focus, Focus!

For the purpose of the advanced study, narrow the expected outcome to the primary goals and work these exclusively. All other goals are secondary and should only be addressed if they do not dissipate the energy of the team. It is very easy to get distracted by secondary goals that end up driving the design and increasing complexity and cost. Maintaining the focus of the team and driving towards a point design is paramount to bringing the study to an acceptable conclusion.

In the VSSR study, the primary focus was to return a single surface sample to earth for study. Secondary priorities were established for returning multiple samples with geographic diversity, as well as bringing back multiple atmospheric samples from various altitudes. While all of these goals are of merit, accommodating them as equal priorities would have driven the design to a more complex and costly solution. In this case, the team focused on meeting the primary goal, and after a point design was established, reexamined the design for the ability to meet some or all of the secondary goals. Those that could be met within the established scope were included in the final point design.

Heuristic: Go deep in the essential disciplines

It is imperative that the necessary disciplines be represented on the development team. There are core competencies that must be present and the team leader must be cognizant of the skills needed. This is where the domain knowledge of the architect is stressed, to insure that the essential skills are represented without bloating the team with an overabundance of specialists. The larger the team, the more difficult the coordination and communications tasks. Inevitably, there are specialists needed for specific expertise. These specialists can be commissioned to augment the team when needed, and can be rolled off the team when their activities are completed. Where core team members are multidisciplinary, the benefits are compounded. The team will include checks and balances internally to continually reexamine and challenge assumptions.

The Team X concept within JPL illustrates this well. Team X is composed of domain experts in flight and ground systems, end to end information systems, science and mission design, and cost estimation. To effectively perform a full analysis of a mission concept, all of these elements will come into play. Periodically, this core team is augmented with specialists in various disciplines. These specialists are integrated into the team for the duration of that particular study. There is also an even more focused version of Team X, which brings in only those elements that are necessary for the study at hand. This trimmed down team is used extensively when investigating mission alternatives and technology issues that do not require the full team.

Heuristics for Design and Development

This first level investigation of advanced mission concepts shares many of the same heuristics applicable to other stages in the development lifecycle. However, the following heuristics have particular relevance in the context of advanced concept development.

Heuristic: Don't design in the dark, communicate assumptions during the design process.

Effective communications among the members of the design team is essential to maintain focus, identify interactions, and coordinate the investigation. Frequent design team meetings are necessary, as well as side meetings to work special interactions. Documenting decisions and the underlying assumptions is necessary in order to build a good structure. Often it is the unstated assumptions that lead to difficulties, rather than the design decision itself. As Rechtin relates, 'there's no such thing as immaculate communication!'[9], the architect must facilitate the communications process to insure a free flow of information.

Heuristic: Uncertainty is allowed, however it must be bounded

The rapid pace of the development does not lend itself to in-depth analysis of all of the issues. To do that would be too costly, and would be unproductive in this stage of the investigation. However, decisions that are not based on reasonable technical assumptions will lead to problems later in the study. Bounding the uncertainty provides assurance that the issue has been identified and worked, and its interactions with other elements of the design are known. Also, by identifying areas of uncertainty and exploring their bounds, some information can be obtained on the resiliency or robustness of the design.

As an example, the VSSR study assumed as part of its architecture the use of aeroassist at Venus to capture the spacecraft in orbit. This is a technique pioneered by the Magellan mission, where the planetary atmosphere is used to impart velocity changes on the spacecraft. The properties of the atmosphere are very important in the final design of the aeroassist systems, however it was sufficient for this level of investigation to understand the upper and lower bounds of the atmosphere and entry conditions in order to ascertain the validity of the concept. Knowing the system would work for a range of atmospheric models provided additional confidence in the robustness of the design.

Heuristic: Design the system with 'good bones'

This heuristic, and a close corollary (design the system with loose coupling between elements) are fundamental to Rechtin's approach[10]. At this early stage in the conceptualization, many assumptions have to be made which may later prove to be in error. Architecting the system in a manner that minimizes interactions between elements insulates the system from the failure of one or more assumptions. This is also a goal of the following heuristic:

Heuristic: There is no single solution

The focus of the study should be to define multiple solutions to the constraints encountered. All good ideas should be investigated and documented as implementation alternatives. This is a period of creating solutions to the given problem. Further investigation may invalidate baseline assumptions, which can significantly alter the outcome. Being aware of that uncertainty, and developing alternatives that address them is key to the robustness of the concept.

For the VSSR study, a baseline system architecture was developed. Within that architecture, key design drivers were identified, and alternative implementations were investigated. Each mission phase could be considered independently, and solution sets developed for that phase. By loosely coupling the mission phases and clearly communicating the interactions, multiple implementation alternatives could coexist within the same architecture.

Conclusions

As stated in Rechtin and Maier[11], the nature of classical architecting changes as the project moves from phase to phase. The heuristic approach is an architectural methodology that lends itself well to the development of advanced space mission concepts. These studies typically address missions that have not been thoroughly investigated or are addressing new constraints. As a result, the architect is called upon to extend his knowledge base to apply it in new and novel situations. Falling back on lessons learned from prior investigations provides a context within which the architect can begin to structure the system. Once a structure is established, other methods can be gainfully employed.

References

1. Rechtin, Eberhardt (1991), "Systems Architecting: Creating and Building Complex Systems", ISBN 0-13-880345-5, Prentiss-Hall, Englewood Cliffs, NJ, p 18

2. Rechtin, Eberhardt and Maier, Mark W. (1997), "The Art of Systems Architecting", ISBN 0-8493-7836-2, CRC Press, Boca Raton, Fl, p 3

3. "The Space Science Enterprise Strategic Plan", National Aeronautics and Space Administration, November, 1997

4. "The Space Science Enterprise Integrated Technology Strategy", National Aeronautics and Space Administration, October, 1998

5. Smith, Jeffrey L. (1998), "Concurrent Engineering in the Jet Propulsion Laboratory Project Design Center", Society of Automotive Engineers, 98AMTC-83, p 1

6. Gulkis, S. et al (1998), "Mission to the Solar System: Exploration and Discovery – A Mission and Technology Roadmap", National Aeronautics and Space Administration, p 4-1

7. White House National Science and Technology Council (1996), "National Space Policy – Fact Sheet", National Science and Technology Council (NSTC) Presidential Decision Directive (PDD) 8, p2

8. Coradini, M et al (1998), "Venus Sample Return Assessment Study Report", ESA Document SCI(98)3, p 1

9. Rechtin, Eberhardt (1991), "Systems Architecting: Creating and Building Complex Systems", ISBN 0-13-880345-5, Prentiss-Hall, Englewood Cliffs, NJ, p 292

10. Rechtin, Eberhardt and Maier, Mark W. (1997), "The Art of Systems Architecting", ISBN 0-8493-7836-2, CRC Press, Boca Raton, Fl, p 12

11. IBID, p 5