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# Comparing Systems Engineering and Project Success in Commercial-focused versus Government-focused Projects

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**Abstract**

This work looks at the relationship between systems engineering and project success industry lead in aerospace, agriculture, defense & security, energy and related areas. The projects included both commercial-focused and government-focused efforts. Differences were found in both the overall risk levels and the measures of success for the two groups. In addition, government-focused projects showed a notably larger number of significant relationships between system engineering processes and project success than the commercial-focused projects. The research notes that further investigation is warranted, in particular looking at individual industry sectors, exploring the impact of team dispersion, and developing a better understanding of interrelationships between the systems engineering processes. This type of analysis will help further our understanding of both the art and science of systems engineering.


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*Keywords:* Systems Engineering; project management; project success metrics

## 1. Introduction

Several studies have been completed over the past two decades that looked at the relationship between systems engineering and project success. Work by Elm et al. [1] identified systems engineering best practices that improved program performance and found that requirements management as well as systems architecture development correlated with schedule performance. Work by Bruff [2] also noted that project planning, requirements management, systems architecture, trade studies, and validation improved budget performance. In addition to studies looking at programmatic success with project budget and schedule, work at NASA by Kludz [3] found that systems engineering reduces risk and enhances technical performance. Further work on NASA projects by Componation [4] noted that programmatic and technical risks could be used to help prioritize which systems engineering processes are used. Later, Elm [5] found that clear and significant relationships exist between the application of systems engineering best practices and project performance. An extensive study by Honour [6]

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identified relationships between common systems engineering activities and programmatic compliance, overall success, and technical quality.

The push for better an understanding of the science of systems engineering has generally focused on standardization of processes. Proficient systems engineers have commented on the need for understanding both the art as well as the science of the discipline. NASA [7] qualified this role by noting "The systems engineer must develop the skill and instinct for identifying and focusing efforts on assessments to optimize the overall design and not favor one system at the expense of another. The art is in knowing when and where to probe." Griffin [8] stated that systems engineering is the link between the art and science of engineering

The discussion on how to view and best use systems engineering can be further extended by looking at other non-technical factors that might influence how it is used. Kludze [3] elaborated on cultural and political effect on complex endeavors, most notably the criticality of communication in diverse and dynamic groups commonly found in complex system development. Work by Bruff [2] argued that systems engineering could be an agent of change with respect to prevalent social issues and Hodgson et al. [9] noted the influence of culture on systems engineering application. Honor [6] also recommended future research in terms of how different cultures perform systems engineering.

The focus of this research is to further extend studies of systems engineering by looking at how it is used... Specifically, how are systems engineering processes and project success related in commercial-focused and government-focused projects? The goal is to provide engineering managers with advice on how to best tailor their systems engineering approach to maximize their probability of success.

## 2. Approach

In order to meet the goal of this study, a survey was developed to collect information on what systems engineering processes were used and project success metrics across a range of commercial-focused and government-focused projects. A mixed-methods approach was used that included a qualitative review of prior research in combination with a qualitative survey given to practicing engineering managers and systems engineers (Figure 1).

An original NASA Systems Engineering & Integration (SE&I) Effectiveness study [4] along with a review of prior research was used as the starting point for this current work. A 50-question survey was then developed that was designed to collect data on five sets of independent variables (Table 1). The survey was revised based on comments by a team of seven Subject Matter Experts (SMEs) who were asked to review the survey for understanding, organization and completeness. The revised survey was then beta tested with a team of 25 practicing engineering managers and systems engineers. The beta test included paper copies of the survey and an open discussion on the apparatus and procedures.

Once the beta test was completed the survey was distributed using individual contacts with professional societies and training organizations, including the International Council on Systems Engineering (INCOSE) Heartland and Huntsville chapters, the American Society for Engineering Management (ASEM), the National Defense Industry Association (NDIA) Iowa-Illinois chapter, the National Science Foundation (NSF) Center for eDesign members at Iowa State University, and the ASEM Professional Training Program in Huntsville, AL.

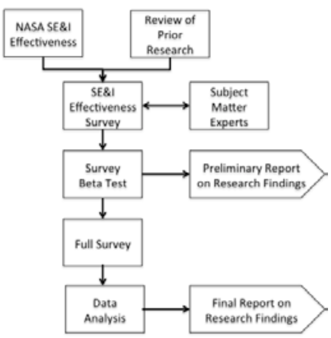


Figure 1. Research Method for Assessing the Relationship between Systems Engineering Processes and Project Success

Table 1. Survey Apparatus Question Sets

| Question Set | Category | Purpose |
|---|---|---|
| 1 | Company Description | Basic demographics of the respondent's organization |
| 2 | Project Description | Descriptive information on the specific project the respondent worked on |
| 3 | Project Success Metrics | Respondent's assessment of project success as measured by programmatic, technical and management metrics |
| 4 | Systems Engineering Processes | Respondent's assessment of which and how well specific processes were used on the project |
| 5 | Distributed Team Member Interactions | Information on the project interaction levels with distributed team members |

The data analysis included a review of surveys to determine if they were complete. Surveys were considered incomplete if they were missing most or all the answers from of one or more sections. Some individual surveys, Individual missing data points in the retained surveys were imputed using multiple imputation by chained equations as described by van Buuren & Groothuis-Oudshoorn [10]. This was done to minimize the impact of missing data points and increase the number of surveys in the data set.

The primary areas of focus in this research were determining the relationships between the Project Success Metrics and the Systems Engineering Processes. Responses were coded using a 4-point Likert response format plus a 'not applicable' option. Pearson correlation coefficients were then used to compare responses and a minimum correlation of $\geq .4$ was used to determine if a significant relationship exists.

## 3. Results

Analysis includes a review of the survey respondents, assessment of the respondents' company and project descriptions, project success metrics and systems engineering processes, differences between commercial-focused and government-focused projects, and comparison of these results with the original NASA study from which this work was derived. Some preliminary work on the distributed team communication patterns is also shown.

### *3.1 Survey Respondents*

A total of 3,637 participant invitations were distributed, of which 47 were in person and 3,550 were by email. All 47 in-person participant invitations resulted in a sufficiently complete survey being submitted. Of the 3,550 email participant invitations a total of 207 surveys were started in SurveyGizmo. A total of 87 of the 207 were deemed fit for inclusion in the analysis. Total response rate was 129 of 3,637 responses, or 3.55%. The response rate was relatively low compared to the work completed by Kludze [3] and Elm [5], but not unexpected as noted by Fan & Yan [11]. Sax [12] did indicate that low response rates do not necessarily suggest as bias.

### *3.2 Respondents' Company and Project Descriptions*

Of the 129 surveys included in this analysis, 83 (64%) were from respondents from projects that were commercial-focused projects and 46 (36%) were from respondents from government-focused projects. An effort was made to draw from a wide range of industries. Most respondents came from four industries, including 34 from aerospace, 31 from agriculture, 25 from defense & security, and 9 from energy.

Since risk is often a driver in project success, respondents were asked to evaluate the project scope of work relative to other projects the organization typically completes, and note their perception of the projects technical, budgetary and schedule risk. For example, participants were asked if this project had significant technical risk and the responses included strongly disagree, disagree, agree, strongly agree, and not applicable. Scoring was from 1 to 4 with strongly disagree coded as a 1 and strongly agree coded as a 4. The average of all responses are shown in Table 2. Both the commercial-focused project respondents and the government-focused project respondents had similar score in the work they were reporting being typical for their organization. However, the commercial-focused project respondents on average reported higher risk levels than the government-focused project respondents.

Table 2. Average Respondent Answer to Questions on if the Project is Typical and what are the Project's Risk Levels (1-4 scale where 1 is Strongly Disagree and 4 is Strongly Agree)

| Question | Overall Study | Commercial-focused Projects | Government-focused Projects |
|---|---|---|---|
| Project Represents a Typical Scope of Work | 3.36 | 3.36 | 3.35 |
| Technical Risk | 3.29 | 3.43 | 3.04 |
| Budgetary Risk | 3.39 | 3.55 | 3.09 |
| Schedule Risk | 3.49 | 3.59 | 3.30 |

To better understand how systems engineering was used in the organization, respondents were asked which systems engineering standard or standards were commonly used. The most common response was that an internally developed standard was used by 50 of 83 (60%) commercial-focused projects and 20 of 46 (43%) government-focused projects. The second most common response was that no standard was used by 29 of 83 (35%) commercial-focused projects and 7 of 46 (15%) government-focused projects. Standards used by respondents included the Defense Acquisition Guidebook (7 commercial and 8 government) and EIA 632 (4 commercial and 2 government).

Respondents were also asked where in the organization systems engineering effectiveness was tracked. Of the 129 respondents, 51 (40%) identified their organization as not tracking effectiveness. Of the remaining respondents, 31 (24%) noted it was tracked at the project level, 11 (9%) track it at the organizational level, 9 (7%) at the project task level and 4 (3%) track at the individual level. The remaining 23 (17%) respondents noted systems engineering effectiveness was tracked at multiple levels in the organization.

### *3.3 Project Success Metrics and Systems Engineering Processes*

Respondents were asked to assess their perceptions of project success using nine metrics (Table 3). For example, the first question on project success asked respondents their level of agreement with the statement "This project was a success when compared to the original technical requirements." There are two patterns of interest. First, for 7 of 9 metrics the average score for the government-focused projects were higher than the average score for the commercial-focused projects. Second, average scores for project success metrics comparing the project success to similar projects was higher than when compared to the initial requirements, schedule and budget. Also of note is that the average scores for technical success and overall project success were higher than other project success metric average scores.

Table 3. Respondents' Average Scores on Technical Success Metrics (1-4 scale where1 is Strongly Disagree and 4 is Strongly Agree)

| Project Success Metric | Overall Study | Commercial-focused Projects | Government-focused Projects |
|---|---|---|---|
| Technical success relative to initial requirements | 3.17 | 3.08 | 3.33 |
| Technical success relative to similar projects | 3.23 | 3.16 | 3.37 |
| On schedule relative to original project plan | 2.57 | 2.48 | 2.74 |

| | | | |
|---|---|---|---|
| On schedule relative to similar projects | 2.83 | 2.77 | 2.93 |
| On budget relative to original project plan | 2.57 | 2.42 | 2.85 |
| On budget relative to similar projects | 2.98 | 2.94 | 3.04 |
| Satisfaction with project management process | 2.84 | 2.86 | 2.80 |
| Overall project success (organization view) | 3.26 | 3.27 | 3.24 |
| Overall project success (stakeholder view) | 3.23 | 3.22 | 3.26 |

Respondents were asked to assess their perceptions of system engineering processes (Table 4). For example, the first question on systems engineering processes asked respondents their level of agreement with the statement "This project identified all the stakeholders and their expectations for the system under development."

A clear pattern of responses was not evident. Some observations of note were the similarity in average scores for some systems engineering processes such as Stakeholder Expectations Definition. Other systems engineering processes showed notable differences between respondents from commercial-focused projects and respondents from government-focused projects, such as Design Solution, Product Validation, and Technical Risk Management.

*3.4 Differences between Commercial-focused and Government-focused Projects,*

To determine the relationship between systems engineering processes and project success in commercial-focused and government-focused projects, the two groups were analyzed separately. The 83 commercial-focused project responses were analyzed and correlated to the results of the original NASA study (Figure 2). In this study, as in the original NASA study, a minimum correlation of ≥.4 was used to determine if a relationship exists. Specific correlations with one significant figure are shown. Correlations from the original NASA study are shaded. In the original study 28 of a possible 153 relationships (18%) were found significant. In this analysis of commercial focused projects a total of 24 of 153 relationships (16%) were found significant. Of interest is the relative importance of the systems engineering processes typically found later in design life cycle over process found earlier in the life cycle. Also, systems engineering processes are also seen to be correlating with programmatic metrics related to schedule and budget as well as technical success metrics.

Table 4. Respondents' Average Scores on Systems Engineering Processes (1-4 scale where 1 is Strongly Disagree and 4 is Strongly Agree)

| **Systems Engineering Process** | **Overall Study** | **Commercial-focused Projects** | **Government-focused Projects** |
|---|---|---|---|
| Stakeholder Expectations Definition | 3.06 | 3.06 | 3.07 |
| Technical Requirements Definition | 2.98 | 3.04 | 2.89 |
| Logical Decomposition | 2.57 | 2.70 | 2.85 |
| Design Solution | 3.15 | 3.06 | 3.30 |
| Product Implementation | 3.23 | 3.22 | 3.26 |
| Product Integration | 3.17 | 3.22 | 3.09 |
| Product Verification | 3.40 | 3.46 | 3.28 |
| Product Validation | 3.29 | 3.40 | 3.11 |
| Product Transition | 3.22 | 3.25 | 3.17 |
| Technical Planning | 2.81 | 2.80 | 2.85 |
| Requirements Management | 3.04 | 3.01 | 3.09 |
| Interface Management | 3.07 | 3.02 | 3.15 |
| Technical Risk Management | 3.03 | 3.11 | 2.89 |
| Configuration Management | 3.16 | 3.16 | 3.17 |
| Technical Data Management | 3.18 | 3.17 | 3.20 |
| Technical Assessment | 2.92 | 2.89 | 2.98 |
| Decision Analysis | 2.81 | 2.78 | 2.85 |

| **ORIGINAL NASA STUDY AND NEW STUDY COMMERCIAL FOCUSED PROJECTS: CHECK** Correlation of 0.4 or greater noted Project Success and System Engineering Processes | 1. Stakeholder Expectations Definition | 2. Technical Requirements Definition | 3. Logical Decomposition | 4. Design Solution | 5. Product Implementation | 6. Product Integration | 7. Product Verification | 8. Product Validation | 9. Product Transition | 10. Technical Planning | 11. Requirements Management | 12. Interface Management | 13. Technical Risk Management | 14. Configuration Management | 15. Technical Data Management | 16. Technical Assessment | 17. Decision Analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technical success relative to initial req. | | | | | | | | | .4 | .4 | | | | | | | .4 |
| Technical success relative to similar projects | | | | | | .7 | .6 | | .6 | | | | | | | | |
| On schedule relative to original project plan | | | .4 | | | | | | | .6 | | .4 | | | | | |
| On schedule relative to similar projects | | | | | | | | | | .4 | | .4 | | | | | |
| On budget relative to original project plan | | | | | | | | | | .5 | | .5 | .5 | .4 | | | |
| On budget relative to similar projects | | | | | | | | | | .4 | | | .4 | | | | |
| Satisfaction with project management process | | .5 | | .5 | | | | | | .5 | | | | | | | |
| Overall project success (organization view) | | | | | | .6 | | | .5 | | | | | | | | |
| Overall project success (stakeholder view) | | | | | | .4 | | | | | | | .5 | | | | |

Figure 2. Correlations Between Systems Engineering Processes (Horizontal Axis) and Project Success Metrics (Vertical Axis) in Commercial Focused Projects Compared to the Original NASA Study (Shaded)

The analysis was then repeated to determine the relationship between systems engineering processes and project success in the government-focused projects. The 46 government-focused projects were analyzed and the results were correlated to the results of the original NASA study (Figure 3). Again, a minimum correlation of ≥.4 was used to determine if a significant relationship exists. Specific correlations with one significant figure are shown. Correlations from the original NASA study are shaded. In the original study 28 of a possible 153 relationships (18%) were found significant. In this analysis of government-focused projects 55 of 153 relationships (36%) were found significant.

| **ORIGINAL NASA STUDY AND NEW STUDY GOVERNMENT FOCUSED PROJECTS: CHECK** Correlation of 0.4 or greater noted Project Success and System Engineering Processes | 1. Stakeholder Expectations Definition | 2. Technical Requirements Definition | 3. Logical Decomposition | 4. Design Solution | 5. Product Implementation | 6. Product Integration | 7. Product Verification | 8. Product Validation | 9. Product Transition | 10. Technical Planning | 11. Requirements Management | 12. Interface Management | 13. Technical Risk Management | 14. Configuration Management | 15. Technical Data Management | 16. Technical Assessment | 17. Decision Analysis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Technical success relative to initial req. | .5 | | .6 | | | | .4 | | .5 | | .5 | .4 | .5 | | | .4 | .5 |
| Technical success relative to similar projects | .5 | | .6 | .5 | .5 | | .5 | | | .5 | .4 | | | | | .5 | .5 |
| On schedule relative to original project plan | .4 | .5 | | | | | | | | .4 | | | | | | .5 | |
| On schedule relative to similar projects | .5 | .4 | | | .4 | | | | | .5 | | | .5 | | | .5 | .5 |
| On budget relative to original project plan | .4 | | | | | | .4 | | | .6 | | | | | | .6 | .4 |
| On budget relative to similar projects | .4 | .4 | | | | | .5 | | | .5 | | | | | | .5 | |
| Satisfaction with project management process | .5 | .5 | | | .4 | | .4 | | | .6 | | | .6 | | | .6 | .6 |
| Overall project success (organization view) | .5 | | | | | .5 | | .5 | .5 | | | | | | | | |
| Overall project success (stakeholder view) | .6 | | | | .4 | | | | | .4 | | | | | | .5 | .4 |

Figure 3. Correlations Between Systems Engineering Processes (Horizontal Axis) and Project Success Metrics (Vertical Axis) in Government-focused Projects Compared to the Original NASA Study (Shaded)

The pattern of responses is notably different from both the original NASA study (shaded) and the commercial focused projects from this study (Table 2). Of particular note is the importance of stakeholder expectations definition, technical planning, and technical assessment. Of the 17 systems engineering processes, 15 of them show one or more significant correlations with project success metrics. Systems engineering processes found early in the design life cycle, stakeholder expectations definition and technical requirements definition appear to have a much greater role in government-focused projects. Technical assessment, which did not show indications of significant correlations in commercial-focused projects (Table 2), is shown with significant correlations for 8 of 9 project success metrics for government-focused projects (Table 3).

### *3.5 Distributed Team Communication Patterns*

One comment that was raised by our SMEs was the need to better understand how the use of a distributed team structure, defined as team members working in separate geographical locations, impacts use of systems engineering processes and as a result project success. Data was collected on team distribution for later use in this study. Some findings from the initial look at the data indicated that commercial- focused projects tended to have a larger percentage of their team members interacting remotely, 45%, versus government-focused projects that report their team members interacting remotely 25% of the time.

Respondents were asked how often their project teams were in contact with distributed team members (Figure 4). While most respondents noted contact weekly or more often, a notable number reported less frequent contacts. Respondents also reported what methods they used to communicate information with distributed team members (Figure 5). The most common communication channels included telephone conferencing systems, electronic distribution of documents, and shared desktop software. Video conferencing and shared drawing surfaces were only reported by a smaller number of respondents.

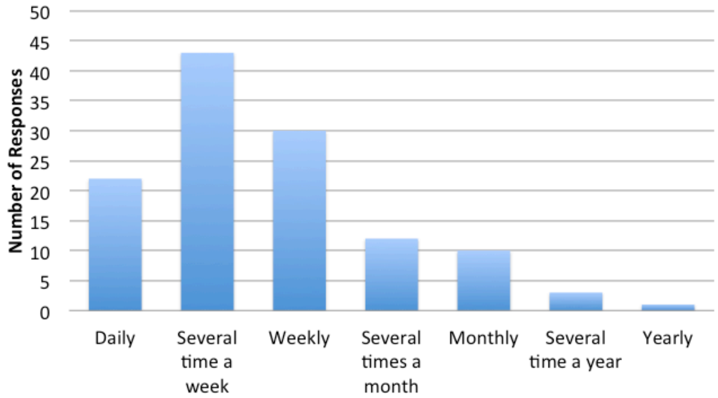


Figure 4. Reported Contact Frequency with Distributed Team Members

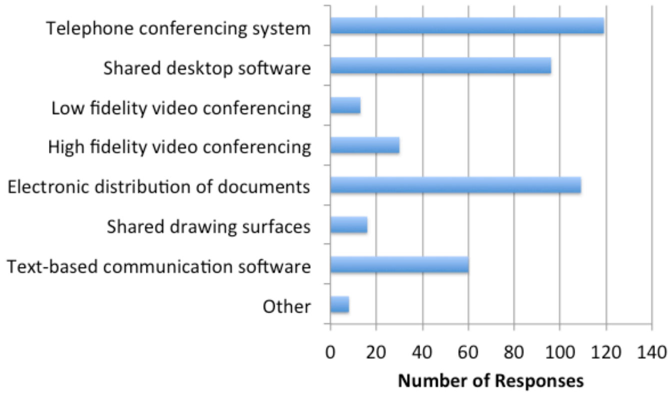


Figure 5. Methods used to Communicate with Distributed Team Members

## 4.0 Conclusions

There have been several studies completed that have identified relationships between systems engineering processes and programmatic compliance, overall success, and technical quality. Often the goal has been to find and recommend best practices or the best processes, hence to find the best science behind the systems engineering. This study focused on developing our understanding of the art of systems engineering; understanding how and where we should apply systems engineering processes to maximize project success.

A total of 129 surveys were analyzed, including 83 (64%) from commercial-focused projects and 46 (36%) from government-focused projects. The results showed that in general government-focused projects were perceived to have been of lower risk and had higher reported success. This perception may be relative rather than absolute since conventional wisdom is that government projects are often of higher risk. The application of specific systems engineering processes between these two types of projects did not show notable patterns, however there were distinct differences between individual processes and project success metrics in commercial-focused and government-focused projects. Projects that were government-focused showed more correlations and influenced more success metrics than similar commercial-focused projects.

There were several limitations in this research. A 4-point Likert response format was used to tie this study in with prior work. There is some debate in the literature on using a numerical analysis on this type of data. Surveys of this nature also typically have a low response rate, which could influence the results.

Further investigation is warranted, in particular looking at individual industry sectors, exploring the impact of team dispersion, and developing a better understanding of interrelationships between the systems engineering processes. This type of analysis will help further our understanding of both the art and science of systems engineering.

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[1] J. P. Elm, D. Goldenson, K. El Emam, N. Donatelli, and A. Neisa, "A Survey of Systems Engineering Effectiveness - Initial Results," Software Engineering Institute, Pittsburgh, PA, USA, Dissertation 2008.

[2] R. S. Bruff, "Systems Engineering Best Practices as Measured for Successful Outcomes in Selected United States Defense Industry Aerospace Programs," Walden University, Dissertation 2008.

[3] J. K. K. Kludze, Jr., "Engineering of Complex Systems: The Impact of Systems Engineering at NASA," George Washington University, Dissertation 2003.

[4] P. J. Componation, A. D. Youngblood, D. R. Utley, and P. A. Farrington, "Assessing the Relationship between Project Success and Systems Engineering Proccesses," in *Conference on Systems Engineeering Research*, Los Angeles, 2009.

[5] J. P. Elm and D. R. Goldenson, "A Business Case for Systems Engineering Study: Results of the Systems Engineering Effectiveness Survey," Software Engineering Institute, Pittsburgh, Report 2012.

[6] E. C. Honour, "Systems Engineering Return on Investment," School of Electrical adn Information Engineering, University of South Australia, 2013.

[7] NASA, "NASA Systems Engineering Processes and Requirements," National Aeronautical and Space Administration, 2007.

[8] M. Griffin. (2007) Systems Engineering and the "Two Cultures" of Engineering. [Online]. http://www.nasa.gov/pdf/173108main_mg_purdue_20070328.pdf

[9] A. Hodgson, E. M. Hubbard, and C. E. Siemieniuch, "Toward an Understanding of Culture and the Performance of Teams in Complex Systems," *IEEE Systems Journal*, vol. PP(99), 2013.

[10] S. van Buuren and K. Groothuis-Oudshoorn, "Multivariate Imputation by Chained Equations in R.," *Journal of Statistical Software*, vol. 45, no. 3, pp. 1-67, 2011.

[11] W. Fan and Z. Yan, "Factors Affecting Response Rates of the Web Survey: A Systematic Review," *Computers in Human Behavior*, pp. 132-139, 2010.

[12] L. J. Sax, S. K. Gilmartin, and A. N. Bryant, "Assessing Response Rates and Nonresponse Bias in Web and Paper Surveys," *Research in Higher Education*, vol. 44, no. 4, pp. 409-432, 2003.

[13] M. Ryschkewitsch, D. Shaible, and W. Larwon. (2009) Teh Art and Science of Systems Engineering. [Online]. http://www.nasa.gov/pdf/311199main_Art_and_Sci_of_SE_SHORT_1_20_09.pdf