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ARES PROJECT TECHNOLOGY ASSESSMENT - APPROACH AND TOOLS -

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Abstract: The paper discusses the Ares Project's approach to technology assessment. System benefit analysis, risk assessment, technology prioritization, and technology readiness assessment will be addressed. A description of the technology readiness level (TRL) tool being used will be provided.

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Abstract

Technology assessments provide a status of the development maturity of specific technologies. Along with benefit analysis, the risks the project assumes can be quantified. Normally due to budget constraints, the competing technologies are prioritized and decisions are made which ones to fund. A detailed technology development plan is produced for the selected technologies to provide a roadmap to reach the desired maturity by the project's critical design review.

Technology assessments can be conducted for both technology only tasks or for product development programs. This paper is primarily biased toward the product development programs.

The paper discusses the Ares Project's approach to technology assessment. System benefit analysis, risk assessment, technology prioritization, and technology readiness assessment are addressed. A description of the technology readiness level tool being used is provided.

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Introduction

Assessments of technologies are conducted to establish the risk a project may incur if the technology is incorporated in the design. To determine which technology will be inserted in the design, a typical approach is to conduct system benefit analysis to ascertain the enhancements the technology provides to the proposed concept(s). Then their current status is assessed. Once the technology status has been determined, resource estimates are developed for maturing the technology to the desired state. Normally due to budget constraints, technologies are prioritized to determine which ones to fund. For the selected technologies, a Technology Development Plan (TDP) is produced to provide a roadmap to reach the desired maturity by the project's Critical Design Review (CDR).

A technology readiness level (TRL) approach has been in use by the National Aeronautics and Space Administration (NASA) since the 1980's[1]. The United States Air Force (USAF) began using TRL in the 1990's. Today, both NASA and Department of Defense (DoD) utilize the TRL methodology to determine both maturity and risk for a project.

The abbreviated TRL definitions, along with the key focus areas, for each of the nine levels currently used are shown in Figure 1.

Level 1 Definition: Basic principles observed and reported *(Key Focus: Basic scientific principles identified)*
Level 2 Definition: Technology concept and/or application formulated *(Key Focus: Analysis, concept, research approach)*
Level 3 Definition: Analytical and/or experimental critical functions and/or characteristics proof-of-concept *(Key Focus: Components, proof-of-concept, components, demonstration in laboratory environment)*
Level 4 Definition: Component and/or breadboard demonstrated in a laboratory environment *(Key Focus: Requirements & environment definition, components, breadboard, demonstration in lab. Environ.)*
Level 5 Definition: Component and/or brassboard demonstrated in a relevant environment *(Key Focus: Component integration, interfaces, brassboard, demonstration in relevant environment)*
Level 6 Definition: System/Subsystem engineering model demonstration in a relevant environment *(Key Focus: Subsystem/system integration, engineering model, demonstration in relevant environment)*
Level 7 Definition: High-fidelity functionality and scaled form/fit demonstrated in its operational environment *(Key Focus: integrated system, prototype, demonstration in operational environment)*
Level 8 Definition: Final product in mission configuration qualified through test and evaluation *(Key Focus: flight hardware, qualification testing, demonstration in operational environment)*
Level 9 Definition: Final product in mission configuration proven in actual flight *(Key Focus: flight hardware, operations, actual environment)*

Figure 1. Abbreviated TRL Definitions

Technologies are evaluated against three primary elements during the assessment process: hardware fidelity, level of integration, and environment fidelity. Figure 2 shows how these three primary elements relate to TRL.

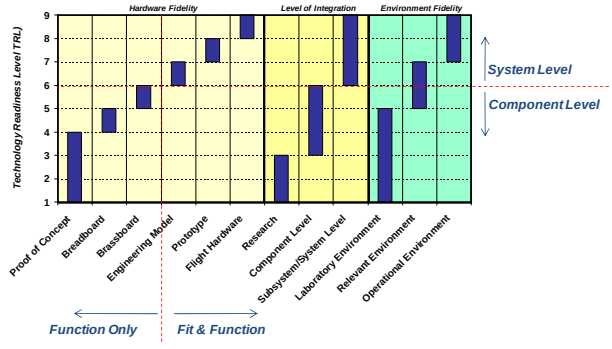

Figure 2. TRL vs. Primary Elements

A typical NASA program's life cycle is shown in Figure 3. The key decision points (KDPs) shown in the figure are defined milestones in the program's approval process that are gates to determine if the program should be approved to progress to the next phase in its development cycle. As shown in the figure, the TRL relates to these milestones and to the following major design reviews:

- SRR ~ Systems Requirements Review
- SDR ~ System Definition Review
- PDR ~ Preliminary Design Review
- CDR ~ Critical Design Review

As noted in Figure 3, TRL spans the entire life cycle of a program and is not only applicable to focused technology efforts. For the PDR and the CDR, the systems should be matured to a minimum TRL of 5 and 6, respectively. The Ares I Project set a TRL of 6 for the PDR goal.

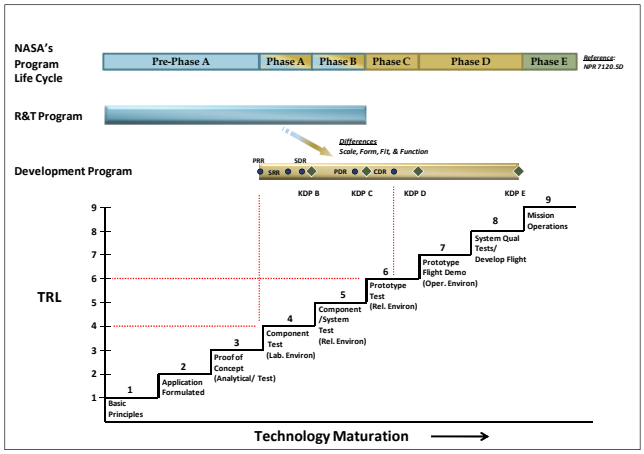

Figure 3. Typical NASA Program Life Cycle

Depending on the maturity of the concept or system, the following approaches have been used to assess technologies:

- Expert Opinion
- Root Source Analysis/ValuStream™
- Analytic Hierarchy Process (AHP)
- Interview

Each of the methods will be discussed in the section titled, TRL Assessment Approaches.

The paper focuses on the Ares Project's approach to technology assessment including a description of the technology readiness level (TRL) tool being used.

Technology Assessment

Early technology assessments provide a program the necessary insight regarding the state of maturity of the elements being considered in the concept(s). A typical process used to establish a candidate technology list is shown in Figure 4. Based on the mission requirements, the system derived requirements are formulated. To satisfy the system requirements, technologies are inserted in to the candidate concepts(s) to determine their influence in accomplishing the requirements. This is an iterative process as depicted by the circular arrows in Figure 4. The results from these system analyses produce a list of potential technologies needed to enable or enhance the mission.

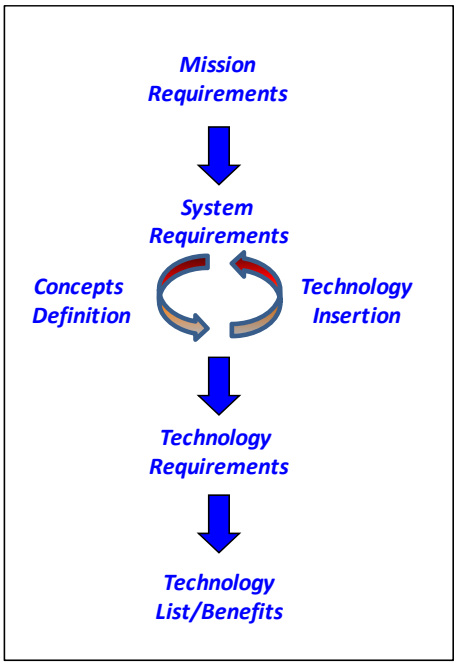

Figure 4. Establishing Technology Needs

Utilizing this list of technologies, an assessment is conducted to establish the programmatic impacts. The assessment process is shown in Figure 5. First, the current state of these technologies are established and displayed by TRL as not started, partially completed or fully completed (blue color scale shown under TRL assessment in Figure 5). Then the degree of difficulty (technical, schedule, and cost) to mature these technologies is estimated. Based on these assessments, a prioritized list of both enabling and enhancing technologies can be developed. Typically the aggregate cost of maturing all of the technologies exceeds the available resources. Normally the enabling technologies are funded and the enhancing technologies providing the best benefits are funded to a level commensurate with the remaining available resources.

The described process' benefits are that it provides a common understanding of the programmatic risk each element contributes to the project. This insight helps management in allocating adequate resources and margins to make the project successful.

The disadvantages of assessments are that it can be very labor intensive depending on the type approach used. NASA requires TRL assessments at each major design review through CDR, so adequate resources have to be allocated to perform this task.

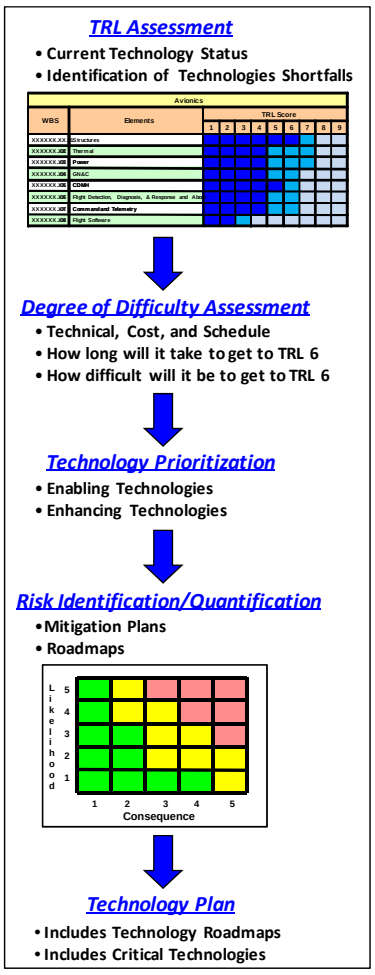

Figure 5. Technology Assessment Process

TRL Assessment Approaches

As mentioned in the introduction, several approaches are available for conducting TRL assessments. Brief overviews of the main approaches are described in the following paragraphs.

Expert Opinion Approach**:** The first and oldest approach, typically used before structured methodologies were available, was to meet with a few experienced people to discuss the merits and establish the technology levels. This approach has been affectionately referred to as BOGSA (**B**unch **O**f **G**uys **S**itting **A**round). The process requires a minimum investment in time and labor. Due to the unstructured nature of the assessment and the strong influence of dominant personalities, the results tended to be inconsistent over the life of a program and is one of this approaches' major weakness.

Root Source Analysis/ValuStream™: Root Source Analysis (RoSA)[2], sometimes referred to as the Valustream method, anticipates, identifies, and prioritizes knowledge shortfalls and assumptions that are likely to create significant uncertainties or risks. It is a systems-engineering methodology developed at NASA over the past ten years. By systematically examining critical assumptions and the state of the knowledge needed to mature the technologies to satisfy requirements. The methodology answers the following critical questions:

- What's been included?
- What's been left out?
- How has it been validated?
- Has the real source of the uncertainty/risk been identified?

An example of a typical two-dimensional matrix utilized in this process is shown in Figure 6.

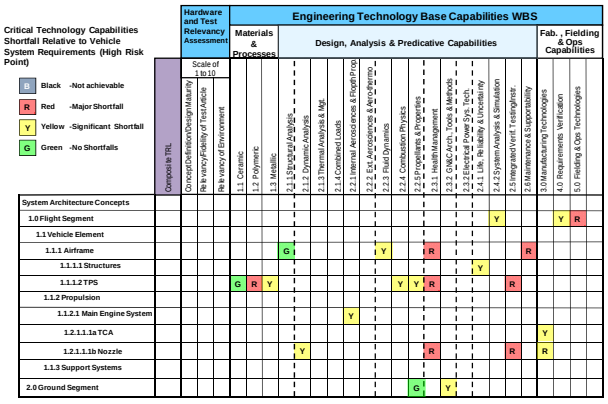

Figure 6. Value Stream-Example

The left side of the matrix is the project's work breakdown structure (WBS). The engineering base capabilities needed to mature the technologies are shown across the top of the matrix. The cells of the matrix identify the shortfalls that need to be addressed.

This approach is the most labor intensive approach of all the approaches discussed. It requires large groups of people and an inordinate investment in time to complete. The status of each technology is discussed in detail with specific experts advancing these technologies in the laboratories. It probably provides the most accurate assessment, especially in the early formulation of a project when the concept is not well defined and system analyses are limited or non-existent. This methodology was utilized by the precursor of the Ares project named the Next Generation Launch Technology (NGLT) project. It was also used when first establishing the technology needs for the Ares V launch vehicle, the heavy-lift cargo vehicle of the Ares Project.

AHP Approach[3]: The Analytic Hierarchy Process (AHP) is based on the hierarchical decomposition of the prioritization down to the level at which the decision alternatives can be pair-wise compared for relative strength against the criteria. That decides the relative importance of technologies by comparing each pair of objectives and weight ranking them on a scale of importance, see Figure 7.

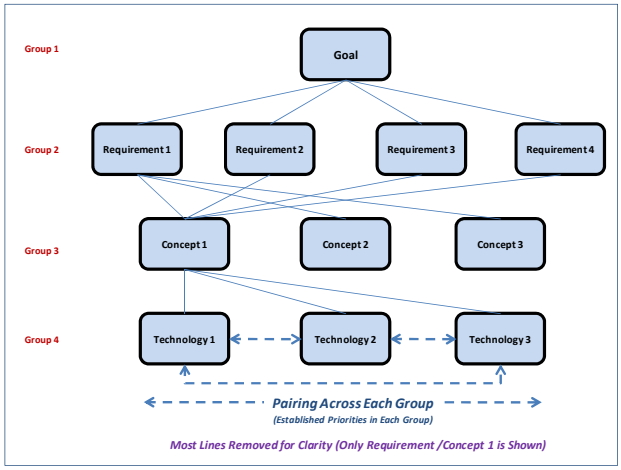

Figure 7. Analytic Hierarchy

Both qualitative and quantitative aspects of the assessment can be utilized in the process. The pair-wise comparisons are usually made by teams of subject matter experts. These comparisons are then translated onto a numerical ratio scale. The intensity of importance is based on the scale shown in Figure 8. Available software converts the opinions provided by the participants to priorities and calculates a consistency ratio that provides insight into the variances between participant's responses.

Intensity of Importance	Description
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance

Figure 8. Pairwise Scaling Factors

The AHP process can be broken down into the following five primary steps:

- Hierarchical modeling of the problem including decision goal, the alternatives, and the criteria.
- Establishing priorities among the groups of through judgments based on pairwise comparisons.
- Calculating the overall priorities for the hierarchy.
- Checking judgment consistency.
- Making a decision based on the results.

The process is less labor intensive than the RoSA approach but still requires a substantial labor investment involving a large group of people over several days of continuous assessment. This methodology was utilized by the NGLT project.

Interview Approach: The interview approach is based on a Microsoft Excel based TRL calculator developed by Mr. William Nolte of the Air Force Research Laboratory (AFRL)[4]. The approach taken was to interview subject matter experts based on very structured and very specific set of questions to establish the technology level. The questions at each level of technology are based on the technology readiness level scale shown in Figure 1. The main parameters the questions focus on are requirements, hardware fidelity, scaling, tests completed, and test environments, see Figure 2. The technology assessment can be conducted for each of the following categories:

- Hardware Readiness Level (TRL)
- Software Readiness Level (SRL)
- Manufacturing Readiness Level (MRL)

As an example, the hardware questions for TRL 6 are shown in Figure 9. Each level and category has a set of individual tailored questions that are assessed by the person(s) being interviewed.

1. System requirements finalized?
2. Operating environment definition finalized?
3. Subset of relevant environments identified that address key aspects of the final operating environment?
4. M&S used to simulate system performance in an operational environment?
5. M&S used to simulate system/subsystem engineering model/protype performance in the relevant environment?
6. External interfaces baselined?
7. Scaling requirements finalized?
8. Facilities, GSE, STE available to support engineering model testing in the relevant environment?
9. Engineering model or prototype that adequately addresses critical scaling issues fabricated?
10. Engineering model or prototype that adequately addresses critical scaling issues tested in the relevant environment?
11. Analysis of test results verify performance predictions for relevant environment?
12. Test performance demonstrating agreement with performance predictions documented?

Figure 9. TRL 6 Hardware Questions

This process requires an acceptable amount of time and resource commitment. Due to the structured nature of this approach, it also provides a consistent set of parameters that must be considered for each assessment.

Ares Approach to TRL Assessment

The NASA Procedural Requirements (NPR) document, "NASA Program and Project Management Processes and Requirements", designated as NPR 7120.5 establishes the requirements by which NASA will formulate and implement space flight programs and projects. NPR 7120.5 specifies that a Technology Development Plan (TDP) is to be base lined by KDP B and the TRL Assessments be base lined by KDP C (see Figure 3).

NPR 7123.1, "NASA Systems Engineering Processes and Requirements", clearly articulates and establishes the requirements on the implementing organization for performing, supporting, and evaluating system's

engineering to ensure NASA products meet customers' needs. NPR 7123.1 specifies that one of the entrance criteria for the SDR, PDR, and CDR is an updated Technology Readiness Assessment Report (TRAR).

Due to the Ares I project rapid buildup; the project studied how the required TRL assessment could be conducted with minimum impacts to an already overworked work force. The approach by the Ares project was to minimize the impact of an assessment on the project without compromising the fidelity of the assessment. Programs whose life cycle span multiple years need an approach to accurately and consistently assess progress through use of a well defined set of criteria. After assessing the various methods available, the project decided on the Interview approach and the use of the AFRL TRL calculator.

After initial use of the AFRL calculator, the Marshall Space Flight Center (MSFC) decided to modify the calculator because the questions posed were very DoD centric and did not relate well to the NASA mission model. The modifications were conducted under the direction of the Assistant Director for Technology/Chief Technologist at MSFC[5] with support from the Ares Project. Most of the questions were restructured and reordered to follow the process established by the NASA program life cycle requirements.

The restructuring of the program was somewhat problematic due to the large number of embedded macros in the spreadsheet and no available instruction on how the underlying logic was connected. Mr. Nolte was therefore recruited to help in making the desired changes. During this conversion, a simplified Advanced Degree of Difficulty (AD^2) calculator was added to the program. The AD^2 calculator quantifies at the first order the risk associated with the technology[6]. It assesses technical, cost, and schedule risk against user defined ranges. The questions are primarily associated with the existence of facilities, tools, materials and skills and capabilities. The questions are answered in terms of the difficulty in acquiring the elements based on a 9 level set of criteria. The range and criteria for the AD^2 levels are shown in Figure 10.

Degree of Difficulty	Development Risk	Criteria
9	100%	Requires new development outside of any existing experience base. No viable approaches exist that can be pursued with any degree of confidence. Basic rersearch in key areas needed before feasible approaches can be defined.
8	80%	Requires new development where similarity to existing experience base can be defined only in the broadest sense. Multiple development routes must be pursued.
7	60%	Requires new development but similarity to existing experience is sufficient to warrant comparison in only a subset of critical areas. Multiple development routes must be pursued.
6	50%	Requires new development but similarity to existing experience is sufficient to warrant comparison in only a subset of critical areas. Dual development approaches should be pursued in order to achieve a moderate degree of confidence for success. (Desired performance can be achieved in subsequent block upgrades with a high degree of confidence.)
5	40%	Requires new development but similarity to existing experience is sufficient to warrant comparison in all critical areas. Dual development approaches should be pursued to provide a high degree of confidence for success.
4	30%	Requires new development but similarity to existing experience is sufficient to warrant comparison across the board. A single development approach can be taken with a high degree of confidence for success.
3	20%	Requires new development well within the experience base. A single development approach is adequate.
2	10%	Exists but requires major modifications. A single development approach is adequate.
1	0%	Exists with no or only minor modifications being required. A single development approach is adequate.

Figure 10. AD^2 Levels-Range and Criteria

The TRL and AD^2 calculators are intended to be used together to perform an integrated technology assessment. The AD^2 calculator uses the results from the TRL calculator as inputs. As such, they are linked together. However, TRL assessment can be performed without performing the AD^2 assessment.

Benchmark tests utilizing SRR data and independent subsystem experts were conducted for the TRL calculator. The AD2 calculator was not utilized during the review process. The results from the modified tool were much more in line with the status the subsystem expert had assessed than what the original tool had predicted. Several minor adjustments were still needed, especially in the software area, before the conversion was completed.

The TRL calculator of the modified tool was utilized by the Ares project for the SDR and PDR reviews. The tool was also utilized to assess the Ares I thrust oscillation (T-O) design options. One novel use of this process was to assess the test plan of one of the T-O options to determine if the planned testing were adequate to bring the design to a TRL of 6 by CDR. The results pointed out that an additional test would be required, resulting in a test plan change.

Since the tool resided primarily on a personal computer and most assessors reside in different localities, a collaborative assessment could not be easily performed. Also, any modification to the tool required the originator of the tool who has since retired. Therefore in 2009 the Ares project commissioned the Science Applications International Corporation (SAIC) in Huntsville, Alabama, to convert the Excel-based tool to a web-based system.

The tool coding was conducted on an internal SAIC server during the development process. After completion, a benchmark test was performed to assure the results matched those of the Excel-based tool. The benchmark test used the data from the Ares I PDR. Due to the large amount of manual manipulation required in the Excel-based tool, a couple of minor errors in the original PDR data were discovered during the benchmark testing. The exceptions were small and were primarily due to rounding errors. The resultant calculator minimizes manual manipulation and therefore is less prone to introducing human errors.

The converted web-based TRL tool was completed November of 2009 and placed in on a Constellation program development server. Final checkout and verification that the program did not cause any systemic problems in its operating environment was completed in February of 2010. The web-based TRL tool is now considered operational. The tool is described in the following section.

Ares TRL Tool Description

The conversion of the Excel-based tool to a web-based system required reprogramming of all the logic. In that process, the lessons learned in the use of the Excel-based tool were applied to make the tool more user-friendly. Toward that end, as much flexibility as was possible was incorporated. The program now exports the results in either a Microsoft Excel or Word format for easy incorporation into a summary document. Also, the flexibility of adjusting the interview questions or selecting only those questions applicable to a certain program can readily be made. The tool has two levels of control, administrator and assessor. The flowchart of the tool structure is shown in Figure 11. The administrator sets up the assessment for his project by specifying the project's WBS to the level desired for the assessment. There is no restriction to the level and, if desired, could be perform down to the component level. The administrator then assigns the assessors who should have access to specific WBS elements.

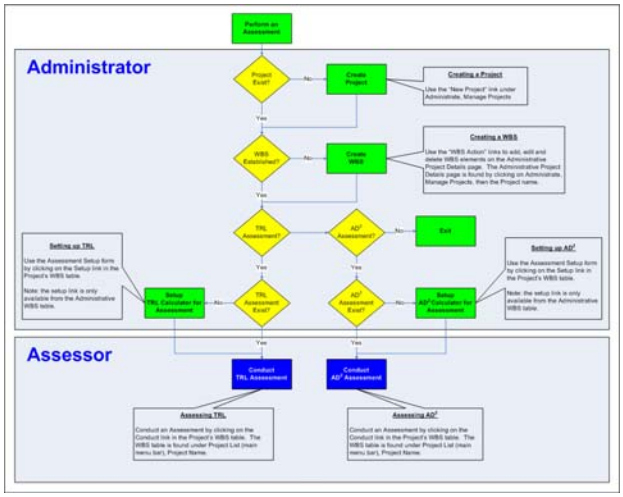

Figure 11. Flowchart of Tool Structure

The next major step is to define how the assessment is to be conducted by establishing the question to be utilized. The basic questions, which have been vetted through benchmarking exercises during the development of the modified NASA calculator are part of the calculator's database and are provided. The TRL assessment can be performed for any combination of the following groups: TRL, SRL, and MRL. However, the tool has the capability of modifying, deleting, or adding additional questions if desired. The tool also allows for adjusting the thresholds where the TRL is considered either partially completed or fully completed based on the percentage of questions answered at each level. The set of questions for each TRL are normally not weighted (all questions have equal value). However, the tool does have the provision to allow weighting of each individual question.

Once completed, the technology assessors can access the tool on the web and perform their assessment individually or collaboratively as a group. After all the WBS elements' assessments have been completed, the tool will automatically aggregate the results which can be exported for incorporation into the final report. A typical WBS setup and output is shown in Figures 12 and 13, respectively. Figure 13 uses notional data.

WBS #	Name	Element	TRL Assessment	AD^2 Assessment
136905	Ares I - PDR	Project		
136905.08.02	Vehicle Integration (VI)	System		
136905.08.02.04	GN&C & Integrated Performance	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.02.06	FDDR and Abort	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.02.08	Separation	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.02.06.03	Flight Softw are	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.01	First Stage (FS)	System		
136905.08.01.02	Forw ard Structure	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.01.02	Parachutes	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.01.02	Pyrotechnics and Separation	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.01.02	Aft Skirt	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.01.03	Thrust Vector Control	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.01.03	Avionics	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.01.11	5-Segment Motor-RSRMV	Subsystem	Conduct | Summary	Conduct | Summary
136905.08.01.11	Nozzle	Subsystem	Conduct | Summary	Conduct | Summary

Figure 12. Example - WBS Setup

Technology Assessment Scoring Summary

WBS #	Name	Element	Level 1	2	3	4	5	6	7	8	9
xxxxxx	Design Review	Project									
xxxxxx.08.02	Vehicle Integration	System									
xxxxxx.08.02.04	GN&C	Subsystem									
xxxxxx.08.02.05	Abort	Subsystem									
xxxxxx.08.02.06	Separation	Subsystem									
xxxxxx.08.02.07	Software	Subsystem									
xxxxxx.08.03	First Stage	System									
xxxxxx.08.03.01	Forward Structure	Subsystem									
xxxxxx.08.03.02	Parachutes	Subsystem									
xxxxxx.08.03.03	Separation	Subsystem									
xxxxxx.08.03.04	Aft Skirt	Subsystem									
xxxxxx.08.03.05	TVC	Subsystem									
xxxxxx.08.03.06	Avionics	Subsystem									
xxxxxx.08.03.07	Motor	Subsystem									
xxxxxx.08.03.08	Nozzle	Subsystem									

Figure 13. Example - Assessment Output

After completion of the TRL assessment, the AD^2 assessment can be performed. The TRL results are transferred automatically into the AD^2 portion of the tool. The AD^2 assessment can be conducted at several levels as outlined in Figure 14.

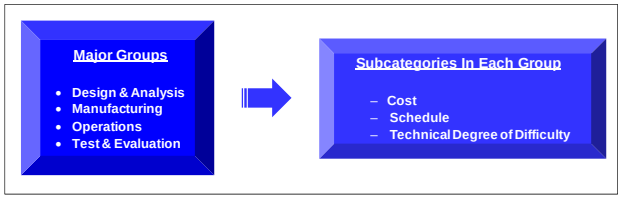

Figure 14. AD^2 Major Assessment Groups

The program provides the outputs in the form of the most driving parameters and their respective values (cost, schedule, or development risk) for each major group being assessed. The items highlighted in yellow in Figure 15, are the resultant questions that contain the maximum values of each of the three subcategories for the set of questions in each of the four groups.

Drivers	Schedule	Cost	Technical Readiness	Comments
Design and Analysis				
Necessary design tools	1yr to 2yr	$10M to $20M	80% Dev Risk	
Manufacturing				
Necessary mfg facilities	2yr to 3yr	$10M to $20M	30% Dev Risk	
Necessary mfg. machines	1yr to 2yr	$20M to $50M	40% Dev Risk	
Operations				
Optimized for min. annual cost	1yr to 2yr	$10M to $20M	60% Dev Risk	
Test and Verification				
Test tooling	0 to 6mo	$1M to $10M	30% Dev Risk	

Figure 15. Example - AD^2 Output

Also provided is a first order schedule and cost risk assessment. This assessment can then be compared to the historical parameters based on the norm for several programs. An example of the risk output table is shown in Figure 16.

WBS #	Name	Element

Calculated Schedule Risk

Today's Date	1/28/2010
Milestone	CDR
CDR Date	3/1/2011
Estimated time to achieve CDR	0 months
Actual time to CDR	14 months
Current TRL	5
Historical average program time from TRL 5 to CDR	35
Variance$_H$ - Variance, Historical	7%
SR$_H$ - Prog. Sched. Risk, Historical	150%
SR$_E$ - Technology Sched. Risk, Estimate	0%
SR - Schedule Risk	150%

Calculated Cost Risk

Today's Date	1/28/2010
Milestone	CDR
CDR Date	3/1/2011
Estimated Δ cost to CDR	$0
Δ budget remaining to CDR	$0
Current TRL	5
CR$_H$ - Cost Risk, Historical	47%
Variance$_H$ - Variance, Historical	35%
CR$_E$ - Cost Risk, Estimated	0%
CR - Cost Risk	47%

Figure 16. Example - AD^2 Risk Output

Summary

The TRL approach for assessing technologies has been in use by NASA since the 1980's. The USAF began using TRL in the 1990's. Today, both NASA and DoD utilize the TRL methodology to determine both maturity and risk for a project.
Early technology assessments provide a program the necessary insight on the state of maturity of the technologies being considered in the concept(s). It also provides a common understanding of the programmatic risk each element contributes to the project. This insight helps management in allocating adequate resources and margins to the project for the maturation of the selected technologies. Depending on the maturity of the concept or system, various approaches have been used to assess technologies. The four methods discussed were:

- Expert Opinion
- Root Source Analysis/ValuStream™
- Analytic Hierarchy Process (AHP)
- Interview

Ares chose the Interview approach for conducting the required technology assessments over the life cycle of the project. The benefits of this approach were the structured nature of the methodology, the accuracy of the results verified through benchmark testing, and acceptable manpower expenditure for conducting the assessment.

MSFC modified the AFRL calculator developed to better relate to the NASA mission model. The modified tool was utilized by the Ares project during the SDR, and PDR. The tool was also utilized to assess the Ares I thrust oscillation (T-O) design options. One novel use of this process was to assess the test plan of one of the T-O design options to determine if the planned testing were adequate to bring the design to a TRL of 6 by CDR. The results indicated that an additional test would be required, resulting in a test plan change.

Since the tool resided primarily on a personal computer and most assessors reside in different localities, a collaborative assessment could not be easily performed. Also, any modification to the tool required the originator of the tool who has since retired. Therefore in 2009 the Ares project commissioned the Science Applications International Corporation (SAIC) in Huntsville,

Alabama, to convert the Excel-based tool to a web-based system.

The converted web-based TRL tool has been named Technology Readiness Assessment Tool (TRAT) and was completed November of 2009 and placed in on a Constellation program development server. Between November 2009, and March of 2010, additional features were installed to make it more user-friendly. Final checkout and verification that the program did not cause any systemic problems in its operating environment was completed in February of 2010. The web-based TRL tool is now considered operational.

Based on Ares' experience, the time per subsystem assessment ranged from 15 minutes to 45 minutes, depending on whether this was an updated or a first time assessment. Generally, the assessments were conducted with a minimum number of subject matter experts (subsystem engineers in the engineering department). Each subsystem was scheduled separately to minimize unproductive time and extraneous discussions. Although initially some resistance was encountered during the TRL assessment process, the procedure was more widely accepted once the process had been experienced. Eventually the process was even utilized for assessments outside of the required reviews.

References:

1. Mankins, John C. "Technology Readiness Levels" a White Paper, April 6, 1995.
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Ares Project Technology Assessment

- Approach and Tools -

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September 29, 2010

IAC-10.D2.5.7

Observations

Perceptions

- TRL is for technology programs only
- TRL assessment is duplicate to program reviews

Reality

- TRL covers the life span of a development program
- TRL assessments actually provide additional data to program
  - Develops resource requirements
  - Identifies Risks
  - Tracks progress
  - Provides record for external auditing
  - Required by NASA

TRL vs. Program/Ares V Milestones

NASA's Program Life Cycle

Pre-Phase A	Phase A	Phase B	Phase C	Phase D	Phase E

Reference: NPR 7120.5D

R&T Program

Development Program

Differences
Scale, Form, Fit, & Function

PRR SDR SRR PDR CDR

KDP B KDP C KDP D KDP E

TRL

1 Basic Principles

2 Application Formulated

3 Proof of Concept (Analytical/ Test)

4 Component Test (Lab Environ)

5 Component /System Test (Rel Environ)

6 Prototype Test (Rel Environ)

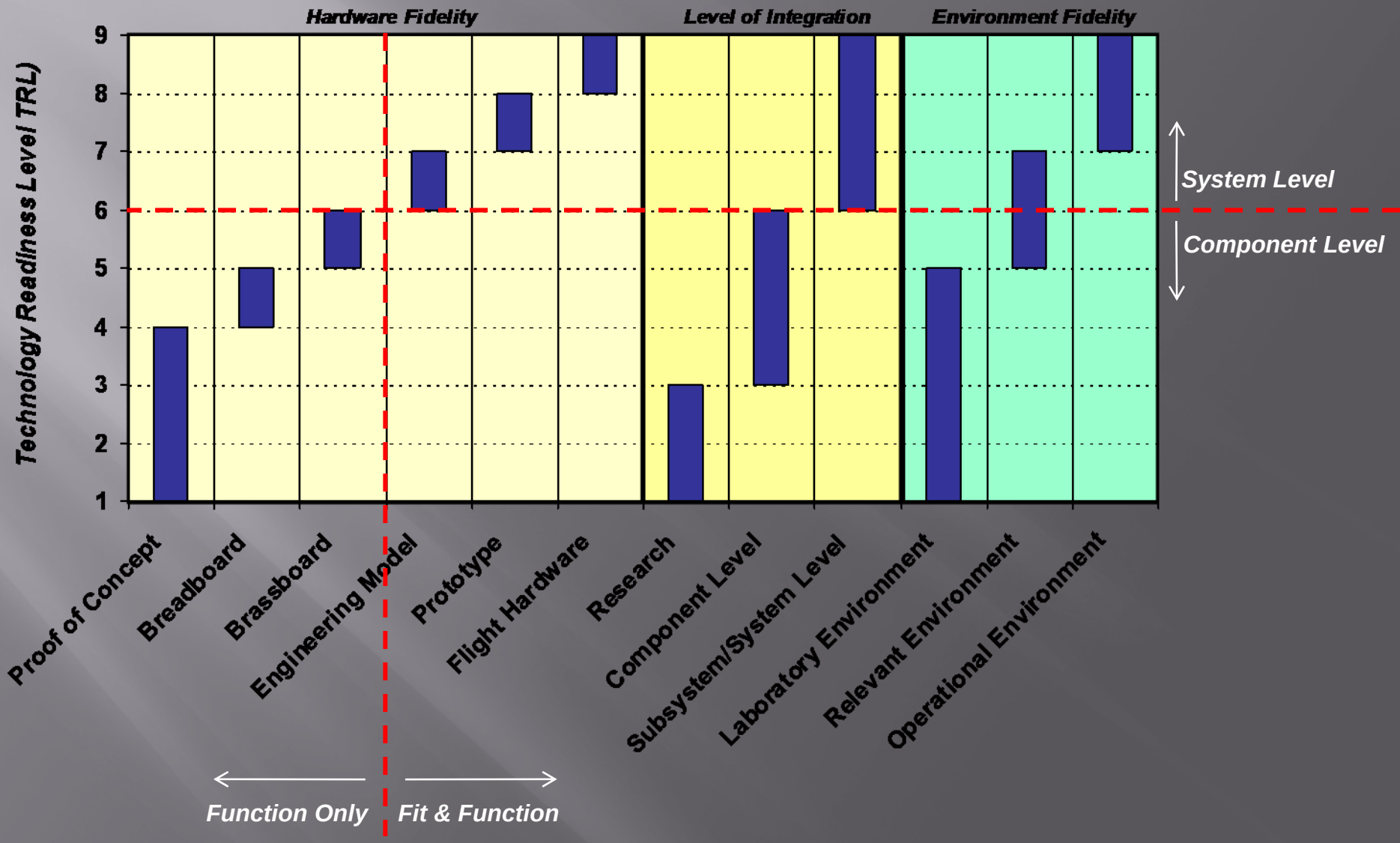
7 Prototype Flight Demo (Oper Environ)

8 System Qual Tests/ Develop Flight

9 Mission Operations

Technology Maturation ⟶

TRL Primary Elements

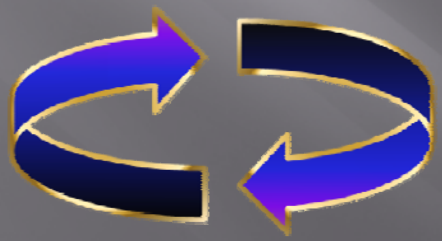


Establishing Technology Needs

Mission Requirements

System Requirements

Concepts Definition



Technology Insertion

Technology Requirements

Technology List/Benefits

Technology Assessment Process

TRL Assessment

- Current Technology Status
- Identification of Technologies Shortfalls

Avionics										
WBS	Elements	TRL Score								
		1	2	3	4	5	6	7	8	9
XXXXXX.XX.01	Structures									
XXXXXX.XX .02	Thermal									
XXXXXX.XX .03	Power									
XXXXXX.XX .04	GN&C									
XXXXXX.XX .05	CDMH									
XXXXXX.XX .06	Flight Detection, Diagnosis, & Response and Abort									
XXXXXX.XX .07	Command and Telemetry									
XXXXXX.XX .08	Flight Software									

Advanced Degree of Difficulty Assessment

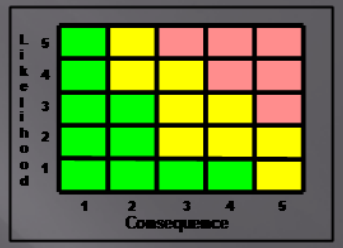
- Technical, Cost, and Schedule
- How long will it take to get to TRL 6
- How difficult will it be to get to TRL 6
- Major Groups
  - Design & Analysis
  - Manufacturing
  - Operations
  - Test & Evaluation

Technology Prioritization

- Enabling Technologies
- Enhancing Technologies

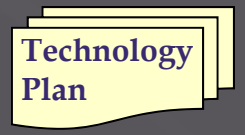
Risk Identification

- Mitigation Plans
- Roadmaps



Technology Plan

- Technology Roadmaps
- Critical Technologies



TRL Assessment Methods

Expert Opinion

- The oldest approach
  - Meet with a few experienced people
    - Establish the technology levels
    - Bunch of Guys Sitting Around (BOGSA)
  - Unstructured assessment
- Inconsistent results over lifetime of program
- Minimum Resource Requirements
  - Time
  - Manpower

Analytic Hierarchy Process (AHP)

- Hierarchical modeling of the problem including decision goal, the alternatives, and the criteria
- Establishing priorities based on pair-wise comparisons
  - Relative strength against the criteria
  - Comparison based on a scale of importance
  - Calculating the overall priorities for the hierarchy
- Good Accuracy
- Medium Resource Requirements
  - Time
  - Manpower

Root Source Analysis/ValuStream™

- Assessment at the technologist level
  - Requirements vs. capabilities
- Most accurate assessment
  - Especially in the early formulation of a project
    - Concept is not well defined
    - System analyses are limited or non-existent
- Maximum Resource Requirements
  - Time
  - Manpower

Interview Process

ADOPTED BY ARES

- Interview subject matter experts, normally subsystem engineering experts
  - Based on very structured approach
  - Specific set of questions
- Good Accuracy
- Medium-to-Low Resource Requirements (Between AHP & Expert Opinion)
  - Time
  - Manpower

Technology Readiness Assessment Tool (TRAT) Assessment Options

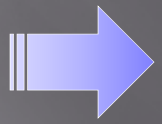
Technology Readiness Assessment

- Technology Readiness Level (TRL): Levels 1-9
- Manufacturing Readiness Level (MRL): Levels 3-9
- Software Readiness Level (SRL): Levels 1-9

Advanced Degree of Difficulty (AD^2)

Major Groups

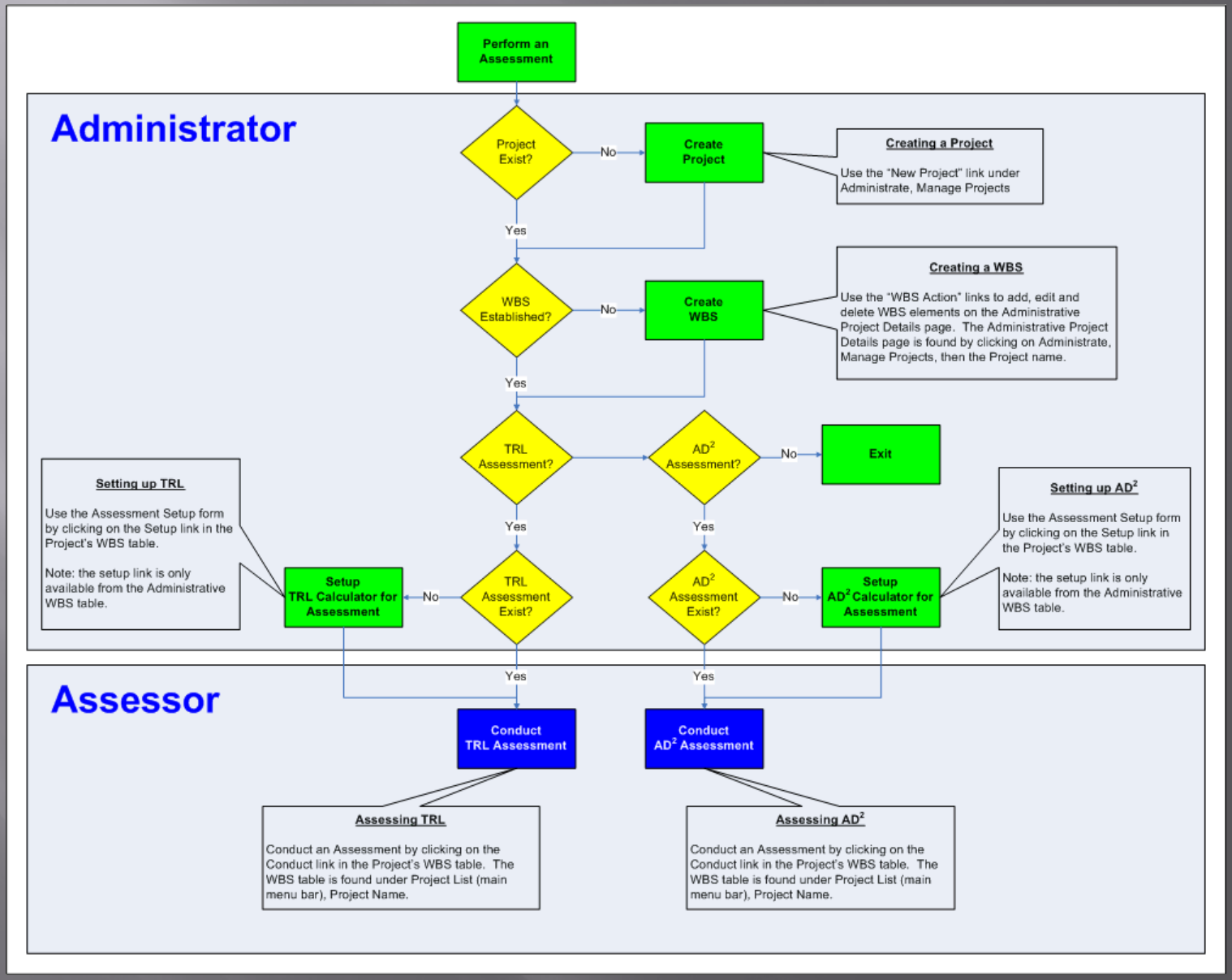
- Design & Analysis
- Manufacturing
- Operations
- Test & Evaluation



Subcategories In Each Group

- Cost
- Schedule
- Technical Degree of Difficulty

Flowchart of the Tool Structure



TRAT - Example of Results

Technology Readiness Assessment

Technology Assessment Scoring Summary

WBS #	Name	Element	Level 1	2	3	4	5	6	7	8	9
xxxxxx	Design Review	Project									
xxxxxx.08.02	Vehicle Integration	System									
xxxxxx.08.02.04	GN&C	Subsystem									
xxxxxx.08.02.05	Abort	Subsystem									
xxxxxx.08.02.06	Separation	Subsystem									
xxxxxx.08.02.07	Software	Subsystem									
xxxxxx.08.03	First Stage	System									
xxxxxx.08.03.01	Forward Structure	Subsystem									
xxxxxx.08.03.02	Parachutes	Subsystem									
xxxxxx.08.03.03	Separation	Subsystem									
xxxxxx.08.03.04	Aft Skirt	Subsystem									
xxxxxx.08.03.05	TVC	Subsystem									
xxxxxx.08.03.06	Avionics	Subsystem									
xxxxxx.08.03.07	Motor	Subsystem									
xxxxxx.08.03.08	Nozzle	Subsystem									

Advanced Degree of Difficulty (AD^2)

Drivers	Schedule	Cost	Technical Readiness	Comments
Design and Analysis				
Necessary design tools	1yr to 2yr	$10M to $20M	80% Dev Risk	
Manufacturing				
Necessary mfg facilities	2yr to 3yr	$10M to $20M	30% Dev Risk	
Necessary mfg. machines	1yr to 2yr	$20M to $50M	40% Dev Risk	
Operations				
Optimized for min. annual cost	1yr to 2yr	$10M to $20M	60% Dev Risk	
Test and Verification				
Test tooling	0 to 6mo	$1M to $10M	30% Dev Risk	

WBS #	Name	Element
.		

Calculated Schedule Risk

Today's Date	1/28/2010
Milestone	CDR
CDR Date	3/1/2011
Estimated time to achieve CDR	0 months
Actual time to CDR	14 months
Current TRL	5
Historical average program time from TRL 5 to CDR	35
$Variance_H$ - Variance, Historical	7%
SR_H - Prog. Sched. Risk, Historical	150%
SR_E - Technology Sched. Risk, Estimate	0%
SR - Schedule Risk	150%

Calculated Cost Risk

Today's Date	1/28/2010
Milestone	CDR
CDR Date	3/1/2011
Estimated Δ cost to CDR	$0
Δ budget remaining to CDR	$0
Current TRL	5
CR_H - Cost Risk, Historical	47%
$Variance_H$ - Variance, Historical	35%
CR_E - Cost Risk, Estimated	0%
CR - Cost Risk	47%

Summary

- The TRL approach for assessing technologies
  - Used by NASA since the 1980's, and by the USAF since the 1990's
  - Today, both NASA and DoD utilize the TRL methodology to determine both maturity and risk
  - Depending on the maturity of the concept or system, various approaches have been used to assess technologies: Expert Opinion, Root Source Analysis/ValuStream™, Analytic Hierarchy Process (AHP), and Interview Process

- Ares chose the Interview Process for conducting the required technology assessments over the life cycle of the project.
  - Structured nature of the methodology, accuracy of the results, and acceptable manpower expenditure

- Web-based tool developed by SAIC
  - Allow collaborative assessment
  - The tool has been named, **Technology Readiness Assessment Tool (TRAT)**
  - TRAT is now considered operational

- Based on Ares' experience
  - Assessment time per subsystem ranged from 15 minutes (for reassessments) to 45 minutes (for first assessment)
  - Manpower was acceptable for conducting the assessments