When do you do risk analysis?

Risk analysis and response planning must be done during the initial planning phase of the project. Ideally, risk analysis and response planning is done during the project proposal phase and revisited on a regular basis.

"70% of a project's cost at completion is committed by the time the first 5% of the project's budget is actually spent."
The Elements of Risk

Risk is composed of TWO elements:

1.) The UNCERTAINTY (expressed as a probability (Pf) of achieving a project performance objective

   AND,

2.) The CONSEQUENCES (Cf) of a risk event

   \[ \text{Risk} = \text{Pf} \times \text{Cf} \]

Caution is needed, of course in using this approach. It is necessary to be wary of multiplying 2 pieces of information together to produce a figure which may make an account's eyes light up but be of little practical value to a project manager.

Risk Assessment Matrix

Consequences Or Impact

Probability of Failure
(1 – Probability of Success)
Characterization of Technology Risk
(utility for system development)

- Probability of failure to:
  - Reach maturity for system integration (programmatic failure)
  - And meet Technical Performance Measures goals (technical failure)

- Impact on overall system performance of failing to meet TPM goals

Measures of Probability of Failure

- The Probability of Failure is measured by the three measures used for programs or projects - cost, schedule, and performance.
Measures of Programmatic Failure

- Development difficulty
  - Technology Readiness Level Gap (Initial to TRL6)
  - Research and Development Degree of Difficulty
  - TPM gap

- Requirements, requirements flowdown, interface requirements, etc.

- Schedule
  - Defined schedule showing maturity increasing/adequate analysis and testing
  - Critical Path
  - Adequate slack
  - High risk items, work around
  - Exit criteria for every milestone

- Cost
  - Defined cost for all milestones
  - Costs include NASA and contractor

- Management and technical team (experienced)

**NASA's TECHNOLOGY READINESS LEVEL**
*(Scale for Tracking Risk Reduction)*

9 - Actual system "flight proven" on operational flight

8 - Actual system completed and "flight qualified" through test and demonstration

7 - System prototype demonstrated in flight

6 - System/Subsystem (configuration) model or prototype demonstrated/validation in a relevant environment

5 - Component (or breadboard) verification in a relevant environment

4 - Component and/or breadboard test in a laboratory environment

3 - Analytical & experimental critical function, or characteristic proof-of-concept, or completed design

2 - Technology concept and/or application formulated (candidate selected)

1 - Basic principles observed and reported

**Technology Readiness Level of 6 is usually required for Development**
NASA’s Technology Readiness Levels (Software)

**TRL 9:** Actual system "mission proven" through successful mission operations
Thoroughly debugged software readily repeatable. Fully integrated with operational hardware/software systems. All documentation completed. Successful operational experience. Sustaining software engineering support in place. **Actual system fully demonstrated.**

**TRL 8:** Actual system completed and “mission qualified” through test and demonstration in an operational environment
Thoroughly debugged software. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. V&V completed.

**TRL 7:** Initial system demonstration in high-fidelity environment (parallel or shadow mode operation)
Most functionality available for demonstration and test. Well integrated with operational hardware/software systems. Most software bugs removed. Limited documentation available.

**TRL 6:** System/subsystem prototype validated in a relevant end-to-end environment
Prototype implementations conform to target environment / interfaces. Experiments with realistic problems. Simulated interfaces to existing systems.

**TRL 5:** Module and/or subsystem qualified in relevant environment
Prototype implementations conform to target environment / interfaces. Experiments with realistic problems. Simulated interfaces to existing systems.

**TRL 4:** Module and/or subsystem qualified in laboratory environment
Standalone prototype implementations. Experiments with full scale problems or data sets.

**TRL 3:** Analytical and experimental critical function and/or characteristic proof-of-concept
Limited functionality implementations. Experiments with small representative data sets. Scientific feasibility fully demonstrated.

**TRL 2:** Technology concept and/or application formulated
Basic principles coded. Experiments with synthetic data. Mostly applied research.

**TRL 1:** Basic principles observed and reported
Basic properties of algorithms, representations & concepts. Mathematical formulations. Mix of basic and applied research.

---

**Measures of Programmatic Failure**

- **Development difficulty**
  - Technology Readiness Level Gap (Initial to TRL6)
  - Research and Development Degree of Difficulty
  - TPM gap

- **Requirements, requirements flowdown, interface requirements, etc.**

- **Schedule**
  - Defined schedule showing maturity increasing/adequate analysis and testing
  - Critical Path
  - Adequate slack
  - High risk items, work around
  - Exit criteria for every milestone

- **Cost**
  - Defined cost for all milestones
  - Costs include NASA and contractor

- **Management and technical team (experienced)**
### Research and Development

#### Degree of Difficulty (RD³)

<table>
<thead>
<tr>
<th>R&amp;D³</th>
<th>Description</th>
<th>Probability of Success in “Normal” R&amp;D Effort</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>A very low degree of difficulty is anticipated in achieving research and development objectives for this technology.</td>
<td>&gt; 99%</td>
</tr>
<tr>
<td>II</td>
<td>A moderate degree of difficulty should be anticipated in achieving R&amp;D objectives for this technology.</td>
<td>&gt; 90%</td>
</tr>
<tr>
<td>III</td>
<td>A high degree of difficulty anticipated in achieving R&amp;D objectives for this technology.</td>
<td>&gt; 80%</td>
</tr>
<tr>
<td>IV</td>
<td>A very high degree of difficulty anticipated in achieving R&amp;D objectives for this technology.</td>
<td>&gt; 50%</td>
</tr>
<tr>
<td>V</td>
<td>The degree of difficulty anticipated in achieving R&amp;D objectives for this technology is so high that a fundamental breakthrough is required.</td>
<td>&gt; 20%</td>
</tr>
</tbody>
</table>

### Measures of Programmatic Failure

- **Development difficulty**
  - Technology Readiness Level Gap (Initial to TRL6)
  - Research and Development Degree of Difficulty
  - TPM gap

- **Requirements, requirements flowdown, interface requirements, etc.**

- **Schedule**
  - Defined schedule showing maturity increasing/adequate analysis and testing
  - Critical Path
  - Adequate slack
  - High risk items, work around
  - Exit criteria for every milestone

- **Cost**
  - Defined cost for all milestones
  - Costs include NASA and contractor

- **Management and technical team (experienced)**
Measures of Programmatic Failure

- Development difficulty
  - Technology Readiness Level Gap (Initial to TRL6)
  - Research and Development Degree of Difficulty
  - TPM gap

- Requirements, requirements flowdown, interface requirements, etc.

- Schedule
  - Defined schedule showing maturity increasing/adequate analysis and testing
  - Critical Path
  - Adequate slack
  - High risk items, work around
  - Exit criteria for every milestone

- Cost
  - Defined cost for all milestones
  - Basis of costs (FTEs, facilities, hardware, etc.)

- Management and technical team (experienced)

Low NOx Combustor
1-Pager WorkLogic
Low NOx Combustor

1-Pager Work Logic Description

1.0.2.1 LPP Subcomponent Eval
- Many cups tested
- Feeds sector test prog
- Continues during sector test prog
- Used for sector design refinement
- Essentially complete by FY95
- GENASA

1.0.2.2 CPP Rectangular Sector Eval
- Comines components for integrated evals
- 3 configurations tested
- Primary feed to annular test program design
- Secondary feed to core combustor test program design
- Uses non EPM materials
- GENASA

1.0.2.3 LPP Curved Sector Evaluation
- Added shape fidelity over rectangular evals
- Two test series of single configuration
- Feed core combustor test program design
- GE

1.0.2.4 LPP Sector Transient Test
- Evaluation of rectangular sector configurations
- Primary feed to annular test program design

1.0.2.5 RQL Sector Combustion Rig
- 3 generation tests of progressively complex design
- Gen I tests and Gen II design from separate contract
- P&W test feed annular rig test program design
- NASA test feed core combustor test program
- Uses new EPM materials
- P&W/NASA

1.0.2.6 Enhanced Quench Zone Mixing
- Applies to RQL configuration
- P&W/NASA participation
- Feeds annular rig test program design

1.0.2.7 Quench Zone Diagnostics
- Same as 1.0.2.6
- P&W participation

1.0.2.8 Analytical Code Dev
- Feed products to test programs as developed
- NASA

1.0.2.9 Emission Minimizing Control Cost
- Feed products to test programs as developed
- NASA

1.0.2.10 Grants
- Feed products to test programs as developed
- Universities

Low NOx Combustor

1-Pager Work Schedule
Assessing Technology Risk Using AHP
(Analytical Hierarchical Process)

- The AHP is based on the hierarchical decomposition of the prioritization or forecasting criteria down to the level at which the decision or forecast alternatives can be pair-wise compared for relative strength against the criteria.

- The pair-wise comparisons are made by the participating experts and translated onto a numerical ratio scale.

- The AHP mathematical model then uses the input pair-wise comparisons data to compute priorities or forecast distributions as appropriate.
Technology Risk Assessment – Phase 3
Summary Of Airframe Risk Assessments

<table>
<thead>
<tr>
<th>TA</th>
<th>TECHNOLOGY PROJECT</th>
<th>COST</th>
<th>SCHED</th>
<th>TECH</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>STRUCTURAL HEALTH MONITORING – NORTHROP GRUMMAN</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>METALLIC CRYOTANK - BOEING</td>
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<td></td>
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<tr>
<td>2</td>
<td>CERAMIC MATRIX HOT STRUCTURES - MRD</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>DURABLE ACREAGE CERAMIC TPS - BOEING</td>
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<tr>
<td>2</td>
<td>DURABLE ACREAGE METALLIC TPS - OCEANEERING</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>INTEGRATED AERO-THERMAL &amp; STRUCTURAL THERMAL ANALYSIS - NASA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>STRUCTURAL &amp; MATERIALS/TANK/TPS INTEGRATION - NASA</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>STAGE SEP &amp; ASCENT AERO-THERMODYNAMICS - NASA</td>
<td>No Data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>MATERIALS &amp; ADVANCED MANUFACTURING: PERMEABILITY RESISTANCE - NASA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>LIGHTWEIGHT INFORMED MICRO-METEOROID RESISTANT TPS - NASA</td>
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<td></td>
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<tr>
<td>2</td>
<td>ULTRA HIGH TEMPERATURE SHARP EDGE TPS - LMC</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>CERAMIC MATRIX COMPOSITE – SOUTHERN RESEARCH</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Technology Risk Assessment – Phase 3
Structural Health Monitoring (Shm)

TA-2 Airframe

Northrop Grumman

MAJOR RISKS

☐ Cost – Cost of 8,000 sensors for full scale SHM could be very high, but is understood.

☐ Schedule – Critical schedule issue is availability of Composite Cryo-tank for testing. SHM starting at TRL 4 in 2002. No development issues affecting schedule.

☐ Technical
  ➢ Reliability – Integration of 8,000 sensors into one reliable SHM is a risk
  ➢ Testability - Availability of Full Scale Composite Cryo-tank for testing to achieve TRL 6

CONTINGENCY PLAN SUGGESTION

Use a subscale tank (18 to 20 ft diameter) to test SHM system

NOTE: Only new or updated comments are contained in this report. Refer to Phase 2 report for complete evaluation. No significant change in evaluation from Phase 2.

Show Stopper – Lack of Funding for Composite Cryo-tank for Testing

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Structural Health Monitoring (Northrop Grumman)

Development Schedule

1. They should meet this goal based on present information.

2. NGC is starting with the SHM technology at a TRL level of 4 in 2002. They have plans to develop a structural health monitoring system and integrate it into a full-scale composite cryotank and complete test in 2009 timeframe. So the critical element of this is really having available a full-scale composite tank with this system integrated into it in 2009. That's the biggest concern because the funding level could get cut on the full-scale development of a composite tank that is in a separate technology development fund under GEN2. So, there are no major issues with respect to developing the SHM system that NGC is proposing here. The issue is with respect to the availability of a full-scale composite cryotanks in 2009/2010 which could face some serious funding issues given that GEN2 is probably not going to carry two tanks to TRL = 6 (metallic and composite).

5. If funding is maintained for the duration of the project, it is probable that it will come in on schedule.

7. There is a trade-off that should be made between the amount of health monitoring and robustness of design analysis. As the vehicle is used for repeated flights some of the health monitoring sensors will become inoperable and others will produce data that has increasing errors. At some point a decision will need to be made relative to how many flights can be achieved before the health monitoring system itself must be inspected and checked out for adequate performance. The cost of maintaining the health monitoring system should be weighed against the cost of increasing the robustness of design thereby reducing the need for health monitoring. The viability of the health monitoring system must consider the sensors, the data system and everything that is needed to transfer the data from the sensor to the data system. The lowest reliability part of the system may be the vehicle installed data transmission lines (and a rest of lines) which must pass through the vehicle requiring compromises to be made in other disciplines of the vehicle design.

Technology Success Data

<table>
<thead>
<tr>
<th>Technology Area: Airframe Technologies</th>
<th>Technology Development: Composite Cryotank (Northrop Grumman)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metric</td>
<td>Probability of Success</td>
</tr>
<tr>
<td>Development Cost</td>
<td>0.50  2005  225  2007  215  137  19%  12%  50%</td>
</tr>
<tr>
<td>Development Schedule</td>
<td>0.50  2005  2007  2006  2008  9%  50%</td>
</tr>
<tr>
<td>External Inspection Interval missions</td>
<td>0.09  0.1  0.2  0.3  0.4  0.5  31%  50%</td>
</tr>
<tr>
<td>Flight Mission Life missions</td>
<td>0.13  0.2  0.3  0.4  0.5  0.6  32%  25%</td>
</tr>
<tr>
<td>Internal Inspection Interval missions</td>
<td>0.05  0.1  0.2  0.3  0.4  0.5  30%  25%</td>
</tr>
<tr>
<td>Leak Rate SCIM</td>
<td>0.13  0.2  0.3  0.4  0.5  0.6  30%  25%</td>
</tr>
<tr>
<td>Operating Pressure PSI</td>
<td>0.01  0.2  0.4  0.6  0.8  1.0  31%  50%</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.13  0.2  0.3  0.4  0.5  0.6  32%  25%</td>
</tr>
<tr>
<td>Weight/Volume fbt/ft^3</td>
<td>0.13  0.2  0.3  0.4  0.5  0.6  31%  50%</td>
</tr>
</tbody>
</table>

Assumption: The Low to High range contains 100% of the possible values of the metric.

1. Combined Weighted Success: 31%

Expected Value – Mean or average value of the estimated probability distribution. It is the value of the metric expected by the evaluators.

Expected Value Deviation – Deviation of the EV from the goal, calculated as follows:

Absolute Value: EV - Goal

Goal

A minus sign in front of the calculated value indicates that the EV is worse than the goal.

EV Deviation show by how much the EV misses the goal. It is zero for certain metrics.
Risk Assessment Matrix

Probability of Failure
(1 – Probability of Success)

Launch Vehicle Propulsion Technology Selection

<table>
<thead>
<tr>
<th>Technology</th>
<th>Delta Isp, sec</th>
<th>Cost</th>
<th>Delta Isp/Cost</th>
<th>TRL</th>
<th>RD(^3)</th>
<th>Probability of Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metalized Hydrogen</td>
<td>15</td>
<td>200</td>
<td>0.075</td>
<td>2</td>
<td>5</td>
<td>25</td>
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<tr>
<td>Advanced Materials</td>
<td>10</td>
<td>150</td>
<td>0.067</td>
<td>3</td>
<td>4</td>
<td>16</td>
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<tr>
<td>Chamber Pressure</td>
<td>8</td>
<td>100</td>
<td>0.080</td>
<td>3</td>
<td>4</td>
<td>16</td>
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<tr>
<td>Combustion Efficiency</td>
<td>6</td>
<td>90</td>
<td>0.067</td>
<td>4</td>
<td>3</td>
<td>9</td>
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<tr>
<td>Nozzle Efficiency</td>
<td>4</td>
<td>50</td>
<td>0.080</td>
<td>4</td>
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<td>6</td>
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<tr>
<td>O/F Ratio</td>
<td>2</td>
<td>65</td>
<td>0.031</td>
<td>5</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

What is the your investment order?
Weighted Technology Impact Ranking
(Quantitative assessment after tech portfolio selected and funded)

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Safety (45%)</th>
<th>Loss of Crew</th>
<th>Loss of Vehicle</th>
<th>Loss of Mission</th>
<th>Loss of Payload</th>
<th>$/lb (35%)</th>
<th>Launch Availability</th>
<th>DDT&amp;E - Average</th>
<th>1st Unit Prod. Cos</th>
<th>Annual Ops Cost</th>
<th>Facilities Cost</th>
<th>Technical (20%)</th>
<th>Vehicle Empty We</th>
<th>Vehicle GLOW</th>
<th>Total Weighted Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.45</td>
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</tbody>
</table>

Impact Assessment

High | Medium | Low

Comments on Investment Strategy and Impact Assessment Method

- Very poor choice of technology portfolio (~two-thirds of technologies have low or negative impact)
- Wrong requirements were developed
- Systems analysis did not model the technologies correctly
High impact (enabling) technologies can have low ROI.

Competing Main Propulsion Systems (see next chart)

Technology Risk Assessment

Impact on Requirements (weighted value functions)

Engine Technologies

& Should be considered for funding based on cost and expert opinion

Probability of Failure (TRL, RD^3, Cost, Schedule)
**Technology Agency Impact Model**

- **Requirements Flowdown**
  - Enterprise Strategic
    - Priority of missions within an Enterprise
  - Missions / Program
    - Percentage of total missions that architectures are utilized
  - Architecture
    - Percentage of proposed architectures that capability impacts
  - Capability
    - Indexed technology impact on capabilities computed by systems analysis (not yet available for all Architectures) or by expert opinion

- **Technology Needs**

Technology Impact = Capability * Architecture * Mission * Enterprise Impact

**Summary**

**Technology Risk Assessment**

- Technology risk is based on the probability of technology development success versus the impact of the technology on the system.

- Technology development probability of failure is similar to any project. Should have defined WBS, requirements, schedule, cost, etc.

- Expert opinion is used for assessment; AHP is one method to obtain and integrate the opinions.

- Expert opinion or systems analysis can be used to define the impact of the technology on the system.

- For total Agency impact, future enterprise missions need to be prioritized to assess technology global impact and risk.