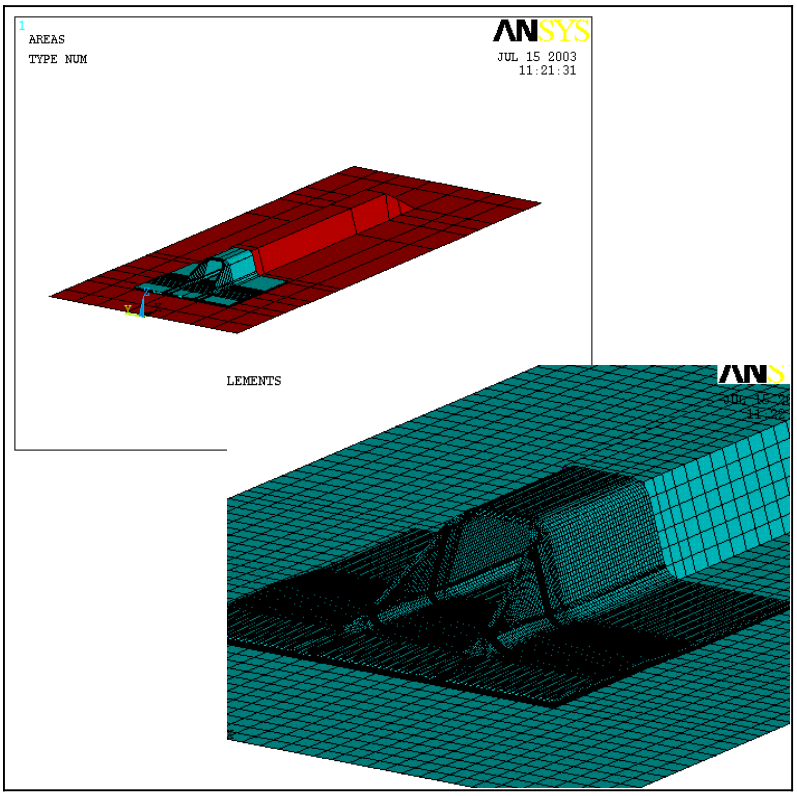

Figure 13-36 Shell Model and Detailed Solid Submodel

Why go to the effort of building the detailed solid model? Figure 13-37 shows in gray the regions of the solid model that exhibit strains that are higher than the shell model. They are, as expected, in regions where the stiffener intersects the skin. This region is not well modeled in the shell model but is in the solid model. This region also is the critical region in the assembly. It is therefore very important to perform some kind of submodeling to determine the actual state of strain in this critical region.

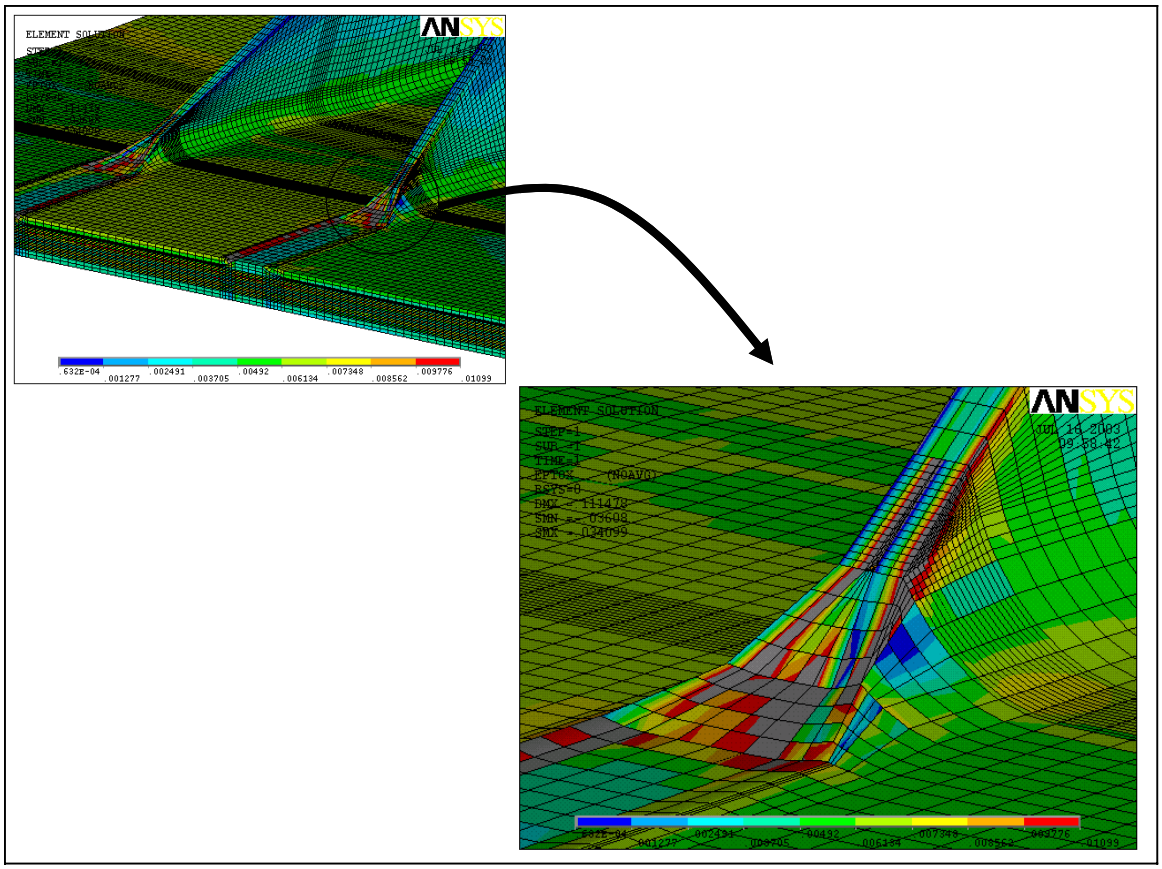

Figure 13-37 Detailed FEM Regions shown in Gray are at a Higher Strain than what was Shown in the Shell Model.

Defect Sensitivity Studies

In a manner similar to the determination of various geometrical parameters on strength studies should be performed using fracture based methods on the effect of defects in various regions of the design. Many parallels may be drawn with the final objective to be insensitive or relatively insensitive to defects in order to have a robust design.

Lessons Learned

There were a number of lessons learned encountered by the integrated technology/product team in the AIM-C Phase 1 hat stiffened panel demonstration/validation.

The AIM-C methodology and tools facilitated *integration* of the integrated technology/product team. The team *did use* existing knowledge, analyses, and test to develop the successful design. Processing and producibility assessment *were able* to keep pace with the product definition development and incorporate concerns or preferred approaches. The team repeatedly noted that this methodology/tools set greatly improved the upfront incorporation of these build improvements.

The methodology, including the IPT, multi-scale modeling, global/local solid modeling and the Strain Invariant Failure Theory *did result* in a superior design and good predictions in a projected 60% of the time of the baseline case.

Improving failure predictions on the design *early* in the development is very important. The team completed the Build-To-Package (BTP) in April. The BTP release initiates the build and test of the parts. The best available failure predictions were used. The failure predictions changed dramatically when updated analytical tools became available. In October, the predictions were coming in for tension initiation with 200% improvement over the April predictions, tension final failure 100% improvement over the April predictions, and shear final failure 12% improvement over the April predictions. This was a significant improvement over the baseline and therefore good news. Unfortunately, the test specimens and test fixtures had been built to the BTP and therefore sized to validate much lower load level predictions. Despite significant efforts to reinforce the load introduction area of the specimens and fixtures, the off-axis testing failed in the load introduction fasteners. The improved failure predictions would have allowed the team to avoid these issues.

The team decided that it would be valuable to test the same geometry specimens in similar fixtures to those used in the baseline. This would ease and improve the correlation to baseline results. Not surprisingly, the baseline definition had insufficient margin for the 200% improvement in load-carrying capability realized in October. A lesson learned is to *greatly oversize specimens and load introduction structure* to accommodate a very large change in test requirements.

Take care when planning the *thickness of frame tie-in* with the specimen to allow for modifications if doublers are needed.

Be sure to use an adequately *large margin* (like roughly 2x and not just 20%) when performing test specimen and fixture sizing.

Intec has now developed a capability to use hydraulic grips for testing. This approach is proving to be a good alternative to fastening, as was done on the baseline.

The use of third party reviews is very helpful. Uninvolved experts can often help find issues that need to be addressed.

When determining specimen configuration for off-axis testing, *consider both the configuration of the specimen and the fixture*. For example, a 10 deg off-axis test can have a fixture design to introduce the 10 deg off-axis or the specimen can be configured for 10 deg off-axis.

Methodologies and tools for *uncertainty management* are discussed in Section 9. Use of these concepts and tools was very helpful in the development of a successful design and in drawing out issues from the multifunctional team.

Conclusion

Remember that applying the tools is only part of the answer. The other part is giving adequate consideration to elimination of defects in critical regions and achieving design robustness. These considerations must be kept in mind during interpretation of results from all steps. Most important is to consider the limitations of each of the tools that are being used. For all designs where actual stress or strains are needed at any region at or near a stress concentration detailed solid finite element modeling is generally required. This process is generally time consuming and is purely a function of the software tool being used, the finite element modeler's approach and of course is subject to interpretation. The bottom line is that the exact determination of strains in anything but the simplest shape and loading condition is a difficult problem not handled well by all general purpose finite element codes.

14. Durability of Composites

Durability is the prediction of the time it takes for flaws to begin to initiate in nominal structure. Durability is primarily an economic issue affecting the inspection intervals, repair costs, and service life of a structure.

Explanation: For mechanical damage, Durability generally refers to the initiation of cracks/damage (or initial growth of damage from small undetectable flaws) in an as-manufactured structure. Also included in the definition of Durability is the initiation of irreversible material property degradation, which may result from long-term environmental exposure. The initiation of multiple small cracks (or small amounts of irreversible property degradation) is unlikely to be a safety concern until the damage progresses significantly; however, it is certainly an economic one. Once damage or degradation is detected, the structure must be repaired to restore Ultimate Load capability. Frequent and/or costly inspections may also be required to monitor the structure and assure that damage is found and repaired prior to compromising the safety of the aircraft. If such inspections and repairs prove technically or economically infeasible, the aircraft has reached the end of its service life.

To show the distinction between durability and damage tolerance, the definition of damage tolerance is provided as the prediction of damage growth (after initiation) and residual strength of structure with large cracks or other damage. Damage Tolerance is primarily a flight safety consideration – ensuring that the structure can continue to carry regulatory loads with damage or degradation due to any likely sources. Sources may include growing fatigue damage (already initiated), impacts, in-service discrete damage events (e.g., engine bursts), or any other likely source.

Note: Damage is typically localized to known locations, though interaction between multiple damage sites is possible. Regulatory load level generally depends on the level of detectability. For example, large discrete source damages are known about immediately, so usually come with a “get-home” load requirement, whereas threshold-of-visibility impact damage can’t reliably be found by visual inspection, so it typically comes with an Ultimate Load requirement (unless you inspect for it with more sensitive NDI).

14.1 Durability Methodology in General

This durability methodology augments existing practices, where an experienced designer relies on experience and intuition. The methodology provides such a designer with relevant information and a suite of software tools. The tools are available through the Durability section of the AIM-C System. These tools give an increased quantitative capability to assist in making decisions regarding design options and testing. Furthermore, the Durability tools allow the designer to extract more relevant information from a given test program once it is completed. Overall, the Durability Methodology is

comprised of four pieces: (1) a list of issues to prompt the designer on durability issues, (2) a convenient library of models and data that can be used to provide quantitative estimates of durability performance, (3) guidelines on test matrices, including the available models and methods for accelerated testing, and (4) guidelines on the interpretation of analysis and test data and its application to the target design. These four methodology components can be thought of as sequential steps in a durability program, that when taken together, will prevent many of the mistakes which can significantly hamper a materials insertion effort.

Background - The durability of composites is a broad and at times vexing topic, more so than for more homogeneous materials such as metal alloys or polymers. In contrast to these materials where typically only one or at most two mechanisms are relevant at any one time, for composites it is possible for multiple mechanisms and their interactions to affect the economic lifetime of a part. Usually only one or two load/environmental cases are really critical. The trick is to identify these critical cases at an early stage and to ensure that adequate testing is performed to ensure that there are no "surprises" awaiting the design team at a later stage in the design process. Although there are opportunities to perform accelerated testing, some level of real-time testing is always likely to be required. Given that this testing is of a long duration and therefore high cost and long lead-time, it is critical that the most relevant tests are specified at an early stage in the program and that unnecessary tests are avoided. The current procedure for accounting for durability in the design process is to entrust it to experienced designers/program managers who call on their experience and intuition to identify the most likely durability issues and to specify test programs to probe them.

The durability of composites has received considerable attention over the past 20 years and a significant number of useful models have been developed for key processes associated with durability. Examples include moisture diffusion, thermal diffusion, chemical and physical aging, creep, fatigue delamination and off-axis ply crack growth and property (usually stiffness) reduction due to damage and degradation. These models tend to have predictive capabilities that capture trends successfully, but are not capable of achieving highly accurate predictions. Furthermore, there is a general lack of models for the interaction between damage/degradation mechanisms (creation of fast moisture diffusion paths due to cracking, combined off-axis ply cracking and delamination, effects of hygrothermo-mechanical cycling). These deficiencies in the modeling capability lead to the conclusion that it is probably not worthwhile aiming for a fully integrated modeling framework. The concatenation of modeling errors once several models are combined would be likely to mask even gross trends in behavior. Furthermore, the likelihood of un-modeled interactions between damage/degradation modes within an integrated "black box" model could provide a user with a false sense of confidence, which would result in durability surprises of the type that we are aiming to avoid. Given these considerations, the most promising approach is one in which the AIM-C Durability tools augment the existing practice of an experienced designer relying on experience and intuition. The intention is to provide such a designer with an increased quantitative capability to assist him or her in making decisions regarding design choices and the associated testing.

Furthermore, the tools allow the designer to extract more relevant information from the test program once it is completed.

Approach - In order to meet these goals a fourfold approach is proposed: (1) Provision of a check list of questions to prompt the designer on durability issues, (2) A library of available models and data that can be used to provide quantitative estimates of durability performance, (3) Guidelines on the development of test matrices including the available models/methods for accelerated testing, and (4) Guidelines for the interpretation of test data and its application to the target design. These four components of the durability methodology could be thought of as four steps in a process.

A checklist: This would augment the designer's experience base and intuition regarding the likely durability limiting factors. It could be as simple as a list of questions: "have you thought about…" to a more structured decision tree directly linked into the models in step 2. Questions might be divided into several basic categories, such as "material", "geometry", "loads and environments" and then subdivided so as to identify the key features within each and then their interactions. The output of this step would be to identify possible issues whose severity could then be quantified by application of the models in step 2.

The ultimate intention of this component of the methodology is to provide a series of questions or "prompts" to a designer/durability assessor to guide her towards the appropriate literature, models and test methods (catalogued in the following sections). This information would be contained within a database, which would allow the linking of durability factors and an assessment of the durability issues and the potential means to address them. A diagram outlining the intended information flow capability is shown in Figure 14-1.

The embodiment of this check list would be either a stand alone searchable data base or a web-based linked hypertext tool. This tool will not be developed under Phase 1 of AIM-C. The appendix to this section serves as a living document cataloguing the elements contained in each of the components of the tool.

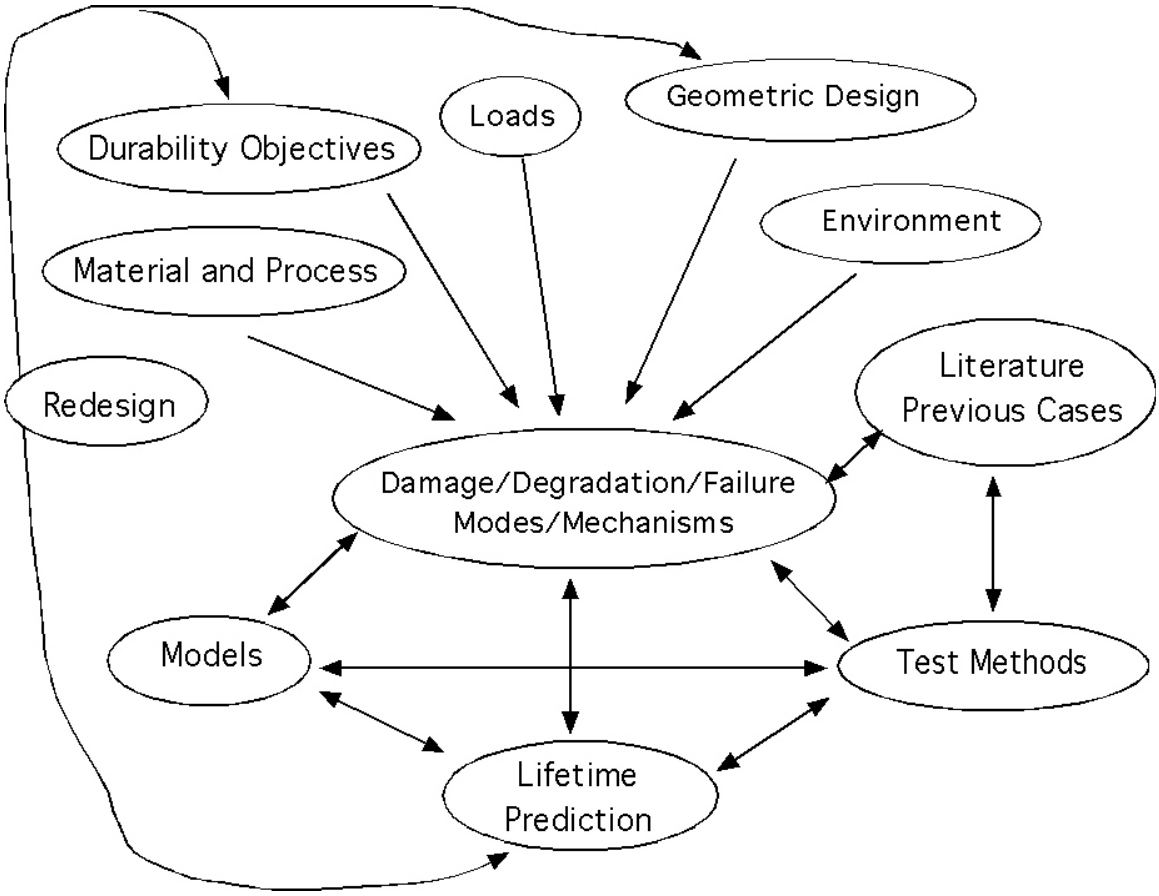

Figure 14-1. Information flow chart for the durability methodology

A library of models and data: Once the candidate durability issues have been evaluated in step 1 (or possibly in parallel with step 1), the designer would call on existing models and test data from previous programs to evaluate the likely severity of these conditions. Models that are envisioned to be used here include those physically-based models for moisture and thermal diffusion and their effect on hygrothermal stresses, fatigue crack growth models for delaminations and adhesive joints, models for physical and chemical aging, models for intralaminar cracking, models for stiffness reduction due to damage and degradation. In cases where only the raw test data is available, purely empirical models would be offered to fit the data. These models (empirical and physically-based) would allow the designer to evaluate whether there was likely to be a durability concern given the material choices, geometric design, loading and environmental conditions and the desired economic lifetime, and what the critical conditions and locations might be. This knowledge could then either be applied directly to redesign or to allow the comparison of design choices, or towards specifying the test matrix.

This will be cross-referenced from the remainder of the AIM-C durability module. Currently this consists of the following elements:

Super MicMac
Durasoft
ISAAC
HSR tools
Delamination Fatigue - supplement to Structures fracture methods

Additional models can be added as they become available, subject to validation and integration requirements.

The models should be exercised so as to identify the likely responses of the candidate design to the anticipated load and environmental factors. Key conditions or combinations of conditions that are likely to exceed or come closest to compromising the durability design objectives should be identified together with the corresponding failure modes. Factors that are predicted to have little or no affect should also be identified, so that they can be eliminated from the test matrix, or from the loading/environmental testing when spectrum loading is applied. Examples include geometric details that add manufacturing complexity but do not affect durability, low load cycles, components of hot/cold - dry/wet cycles that do not affect damage/degradation.

Guidelines for specifying a test matrix: Once steps 1) and 2) have identified the most likely key durability issues, the test matrix should be specified to probe these issues. In particular it should be targeted towards "known unknowns" i.e. conditions which are suspected of possibly determining the overall durability, but which have not been encountered in previous test programs. The model library and previous test data should be available to help guide the form of the test matrix, and in particular to identify possible accelerated test methods and to identify potential interactions between damage/degradation modes that would need to be captured by the testing. It is anticipated that the majority of the tests will consist of generic tests on generic geometries and loading conditions that capture the key features of the actual design under consideration.

The intentions behind the test matrix are twofold. Firstly, the test matrix should be guided by and be complementary to the modeling effort outlined in (2) above. The most severe loading cases predicted by the models should be applied to assess the validity of the prediction by the model and that the designed structure will indeed meet the durability design objectives. The second objective is to provide assurance against cases where there are gaps in the modeling capability, or previous experience that a particular loading or environmental factor has been problematic. Where possible accelerated testing will be used on simplified, but representative geometries. These simplifications and accelerations should be guided by the modeling in (2) above. Assuming that the test results are in reasonable agreement with the model predictions, it can generally be assumed that the remaining predictions by the models are also sufficiently accurate for design purposes.

It is anticipated that for large, primary structure a full scale fatigue test article will also be manufactured and tested and the testing of this can be guided by the modeling effort and the results fed back into the model validation.

The following test methods are currently available and documented within AIM-C. Other test methods will be added in due course.

Time-Temperature superposition
Delamination fatigue
Matrix/adhesive fracture with environmental factors
HSR accelerated test methods

Interpretation of test data: Once the testing is underway, it is important that maximum use be made of the data obtained. This is both for the particular design under consideration and also so that the data obtained can be applied to future designs, so as to expand the library of models and data in step 2. For the immediate purposes of the design under consideration, key tasks in this step include: verifying the mechanisms assumed in steps 2 and 3, tuning/calibrating the models used so that they can be applied to the actual design, developing local (ad hoc) models to capture interactions between mechanisms, and application of the models/data to the actual design. For the longer term, these results must be fed back into the modeling/data library so that they are available for future designs.

Again, it is very important that maximum use be made of the test results generated in (3) above. Durability testing is time consuming and expensive, and so it is imperative that the greatest possible benefit be derived from such tests. In addition to the macroscopic predictions of mechanical response, e.g. cycles to failure, stiffness reduction with cycles and residual strength after cycling, it is very important that the predicted damage and degradation modes be verified wherever possible. All of the models recommended in (2) base their predictions of durability response on knowledge of physical mechanisms. As shown in Figure 14-1 this is at the core of the durability methodology. In cases where a model successfully predicts the macroscopic mechanical response, it is also important that it is verified that the underlying damage/degradation processes and their extent are also correctly predicted. If this prediction is not correct, then it is likely that the model cannot be successfully transferred to other cases. Equally, in cases where a poor prediction of the test data is achieved, identification of the underlying damage modes can provide important information that can be used to refine the models.

Methods for observing damage/degradation can be divided into two parts:

1. In situ observations during tests. This necessitates the use of non-destructive methods. The following methods may be considered: Infra red or acoustic imaging, application of acoustic emission sensors, use of local strain gauges to measure local stiffness reduction, use of Lamb-wave sensors to triangulate damage, monitoring of overall frequency response, use of replicate techniques

where free edges are available, use of stress-sensitive paints or white coatings to help reveal the presence of cracks.

2. Post-mortem tests. Once the desired number of cycles has been applied, or failure has occurred, then more intrusive observational techniques can be applied. These include: C-Scan, X-ray inspection with penetrants, cross-sectioning and polishing and microscopy. Local micro or nano-indentation may be used to detect degradation. From large test articles, specimens may be cut out to perform local mechanical tests to assess local residual strength. Specimens can be excised for chemical analysis (SIMS, Auger, FTIR) or thermal/mechanical analysis (DMTA, DSC, TGA).

Information resulting from these observations include: presence of intraply cracks, delaminations, fiber microbuckles, tensile fracture of fibers, local chemical degradation, changes in glass transition temperature, moisture content, changes in matrix hardness, changes in other local mechanical, physical or chemical properties.

In all cases the key point is that the understanding of the failure modes be captured. Where models exist, this data can be fed back into them to improve the validation. Where models do not exist, an understanding of the relevant damage/degradation modes can be highly instrumental in allowing for the development of modeling capabilities.

Links to the rest of the AIM-C System - The durability tools and their accompanying methodology are linked to the rest of the AIM-C System. In particular, the links to the structures' module are important for the transfer of the global structural geometry, loads and environment. In addition, at a more local level, point stresses, geometrical details, and material/lay-up details will be needed by both. In addition, durability damage/degradation criteria may make direct use of analytical tools from within the structures module. These include the use of the structures' fracture mechanics methods to calculate strain energy release rates, which can then be applied to moisture/temperature modified critical strain energy release rates or to calculate fatigue crack growth rates. Similarly, the use of stress-based methods, such as SIFT, can be expanded to include effects of damage/degradation. Also, the effect of damage/degradation on local stiffness can be propagated through the structures module analysis tools in order to assess the critical levels of damage/degradation.

In addition, there will be interaction with the producibility module, particularly with regard to durability issues associated with processing-induced stresses and also the effects of defects.

Specifics - In the preceding sections, models have been reviewed that might allow progression and iteration within the design process. Models do exist, at the scales below that of the laminate (coupon), that have some utility for predicting fatigue damage propagation. Success has been achieved for individual damage modes such as bridged matrix cracking in MMC's and CMC's and off-axis ply cracking and delamination in PMC's. However, as yet these models are not sufficient to allow prediction, *a priori*, of

the fatigue response at higher structural levels that are likely to be of interest in design or maintenance applications. Even an ostensibly simple case such as the growth of damage at a notch and its effect on residual strength has only been modeled with limited success in a handful of material systems and test conditions. In particular, relatively little attention has been devoted to modeling the interactions between damage modes which typically govern the response at this level. This is chiefly because such damage is truly three-dimensional and it is often not considered worthwhile to construct a three-dimensional model, with the belief that it could evolve in parallel with the current empirical approach to fatigue in composites.

Concluding Remarks – The AIM-C durability methodology advocates the development of mechanism-based models for characterizing durability of composite structures. Many of the models currently available for individual damage mechanisms are based on fatigue crack growth relationships that can be experimentally calibrated and used to predict damage growth rates, as a function of microstructural, geometric and loading parameters. There has been less success in predicting the growth of multiple interacting damage modes that typically govern the durability at the structural level, although some models do exist, and similar modeling approaches might be applied to other materials and structural configurations. The foreseeable capability of such modeling is unlikely to be able to fully support detailed structural design, however an intelligent application of the approach may reduce the reliance on test programs to an extent that could improve the overall cost effectiveness of the design process.

14.2 AIM-C Durability Methodology Applied to Hat-Stiffened Panel Demonstration Case

The four steps of the AIM-C durability methodology are applied to the hat-stiffened panel demonstration problem below. The listings under each step are included as examples but are not necessarily definitive design guidelines.

1. Checklist of durability issues
   - What are the locations where mechanically induced (*i.e.* fatigue) damage is most likely to initiate?
     - Free edges
     - Plank/skin interface
     - Skin/hat interface (including adhesive)
     - Noodle
     - Fasteners
   - What are acceptable levels of damage at these locations?
     - None
     - Microcracking initiation
     - Microcracking initiation that creates a delamination, but no delamination propagation
     - Microcracking initiation that creates a delamination with subcritical delamination propagation

- What are the effects of temperature and moisture on the development of damage at these locations?
  - Accelerated or delayed microcrack initiation
  - Accelerated or delayed delamination propagation
- How does damage affect structural behavior?
  - Decreased stiffness
  - Failure
- How do temperature, moisture, and aging affect structural behavior (assuming no damage)?
  - Accelerate decrease in stiffness and onset of failure

2. Library of models and data
   - Data
     - Properties as a function of temperature and moisture
     - Fatigue behavior of structural details at various temperature and moisture levels
     - Aging behavior
   - Models
     - SIFT durability
     - Moisture diffusion
     - Microcracking in off-axis plies
     - Fatigue crack initiation and propagation
     - Physical or chemical aging
     - Stiffness reduction from damage and degradation
   - Analysis methodology for skin/hat interface
     - Choose acceptable level of damage to determine cumulative fatigue life
     - Determine cycles to microcracking initiation
       - Calculated maximum principal transverse tensile stress compared with transverse tension fatigue life (Minguet and O'Brien)
     - Determine cycles to delamination onset
       - Compare strain energy release rate with threshold fatigue data
     - Predict delamination propagation and examine effect on structural behavior
       - Use crack growth law and determine structural stiffness based on propagated crack
     - Examine effect of temperature and moisture on damage development
       - Use modified crack growth law based on environmental conditions

3. Guidelines for specifying a test matrix
   - General tests
     - Stringer flange/skin tests
     - Material characterization at various temperature and moisture conditions
   - Model Calibration Tests
     - Fatigue crack growth of delaminations
     - Transverse tensile fatigue testing
   - Accelerated Testing
     - Viscoelastic resin tests

- Validation Tests
  - Hat stiffened panel fatigue test

4. Interpretation of test data
   - Verify assumed mechanisms/behavior
     - Crack initiation locations and propagation behavior
   - Tuning/calibrating models
     - Crack growth laws
     - Modified crack growth laws for environmental conditions
   - Develop local models to capture interactions between mechanisms
     - Interaction of damage at several locations
     -

14.3 AIM-C Durability Methodology Example

The problem statement is: "I have a new application that takes an existing "AIM" material into a different environment. How does one generate a carpet plot that takes into account all the durability issues of interest for a particular application? In other words, the structures carpet plot is for a RTD, pristine material. How would that carpet plot change after exposure to environments including temperature, cyclic loading, moisture, etc? See Figure 14-2.

- Methodology for the determination of carpet plots that include durability effects
- Four step durability methodology would be implemented in the AIM-C system
  - Checklist of questions/issues
  - Library of models and data
  - Guidelines for specifying a test matrix (including accelerated testing)
  - Interpretation of analysis and test data
- Methodology is generic such that it can be applied to fracture results, etc.
  - Same process would be used, but different input data and models required
- Multiple "tools" available. The one used depends on the answers to the questions along the way

Figure 14-2. AIM-C Durability Methodology Example

Figure 14-3 shows the AIM-C Main Menu/Home. There are a few different ways to reach the durability page from this location. The most obvious way is to select the word durability and/or the picture of the open-hole test coupons. Another way to reach the durability page is through the analysis template pull down menu as shown in Figure 14-4. A third way is through the process guidelines pull down menu.

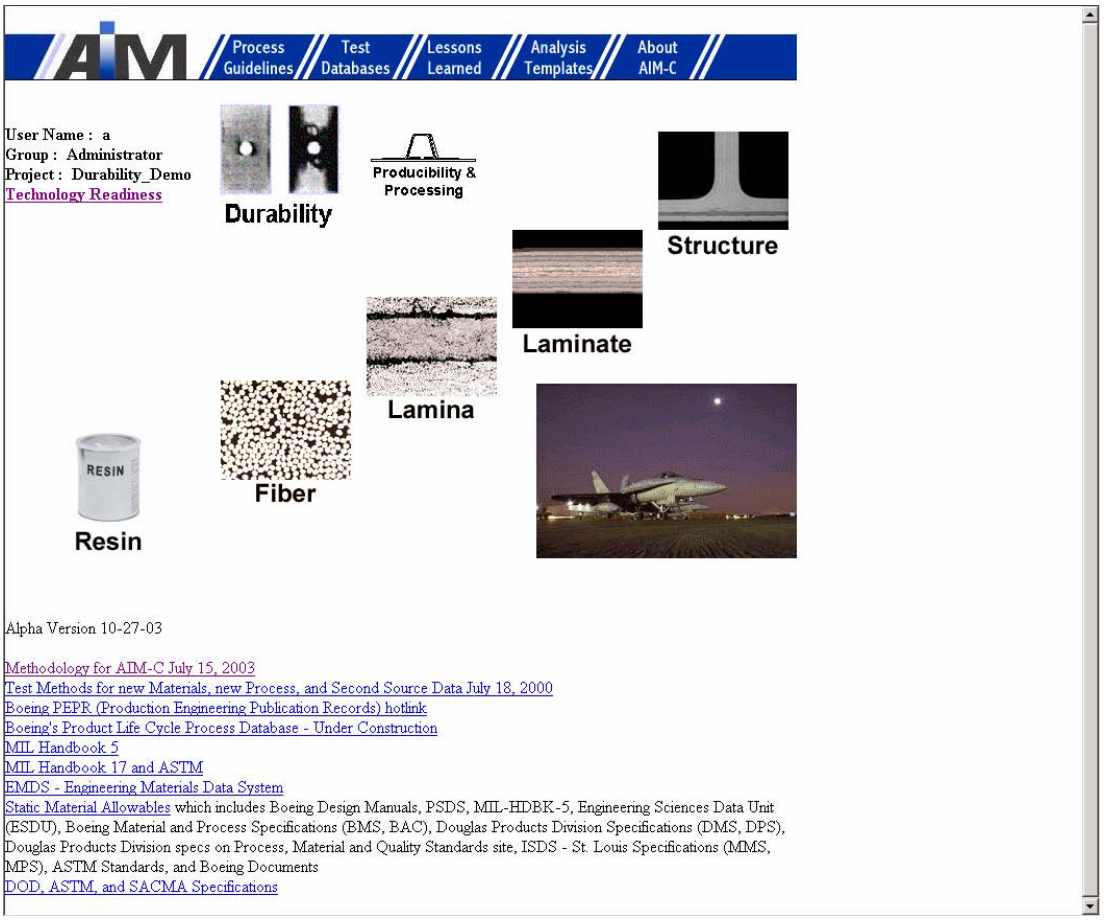

Figure 14-3. The AIM-C System Home Page

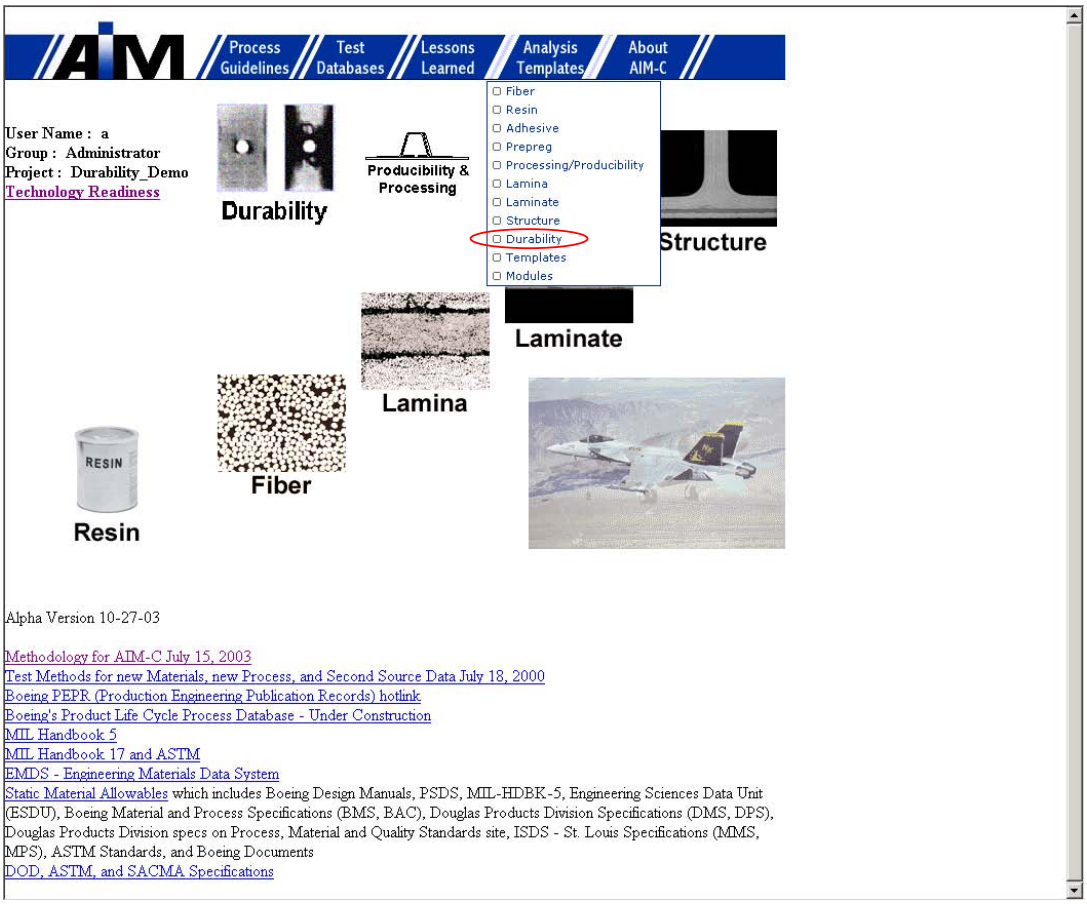

Figure 14-4. The AIM-C System Analysis Template Menu

The overall AIM-C methodology follows a process that begins at the technology readiness level (TRL) and proceeds to the XRL and down to the worksheet level. This path is illustrated by this example problem. Figure 14-5 shows the top-level technology readiness level of the system software. The next level down can be reached by selecting any of the items in the first column of the TRL chart. If the user selects application maturity, he is taken to the menu shown in Figure 14-6. Similar menus exist for each of the remaining items in this column, such as structures maturity, materials maturity, etc. As the user progresses further down into the system, specific answers to questions related to the application would indicate what types of durability issues might be of interest. For example, the application requirements might specify the upper and lower use temperatures, etc. The answers to these questions should prompt the user to go to the durability assessment page.

AIM | Process Guidelines | Test Databases | Lessons Learned | Analysis Templates | About AIM-C

AIM-C Technology Readiness Summary

Codes :	YES (done)	NO (not done)	In-Work	Problem	N/A

Technology	Readiness	Level	-	-	-	-	-	-	-	-
TRL	1	2	3	4	5	6	7	8	9	10
Application Maturity	****	****	****	****	****	****	****	****	****	****
Certification	****	****	****	****	****	****	****	****	****	****
Design	****	****	****	****	****	****	****	****	****	****
Assembly	****	****	****	****	****	****	****	****	****	****
Structures Maturity	****	****	****	****	****	****	****	****	****	****
Materials Maturity	****	****	****	****	****	****	****	****	****	****
Fabrication Maturity	****	****	****	****	****	****	****	****	****	****
Cost Benefits Maturity	****	****	****	****	****	****	****	****	****	****
Supportability	****	****	****	****	****	****	****	****	****	****
Intellectual Rights	****	****	****	****	****	****	****	****	****	****

Save and Continue

Figure 14-5. AIM-C Technology Readiness Summary Page

AIM | Process Guidelines | Test Databases | Lessons Learned | Analysis Templates | About AIM-C

AIM-C Application Maturity

Do you have estimated properties?	⦿ YES	○ InWork	○ Problem	○ NO	○ N/A
Do you have mechanical properties?	⦿ YES	○ InWork	○ Problem	○ NO	○ N/A
Are you documenting manufactuing processes?	⦿ YES	○ InWork	○ Problem	○ NO	○ N/A
Are you developing allowables?	⦿ YES	○ InWork	○ Problem	○ NO	○ N/A
Are you testing subcomponent assemblies?	○ YES	○ InWork	○ Problem	⦿ NO	○ N/A
Are you testing full scale components?	○ YES	○ InWork	○ Problem	⦿ NO	○ N/A
Is this product in full scale ground test?	○ YES	○ InWork	○ Problem	⦿ NO	○ N/A
Is this product in flight test?	○ YES	○ InWork	○ Problem	⦿ NO	○ N/A
Is this product in production?	○ YES	○ InWork	○ Problem	⦿ NO	○ N/A
Is this product out of production?	○ YES	○ InWork	○ Problem	⦿ NO	○ N/A

Figure 14-6. The AIM-C System Application Maturity Page

Figure 14-7 shows the durability home page, aligned with the four-step durability methodology process. Also on this page is a direct link to the Durability xRL conformance planning check sheet and a link to an example showing the durability methodology applied to the hat stiffened panel design problem. Each of the items on the durability home page allow further interrogation, as will be demonstrated by the current carpet plot example.

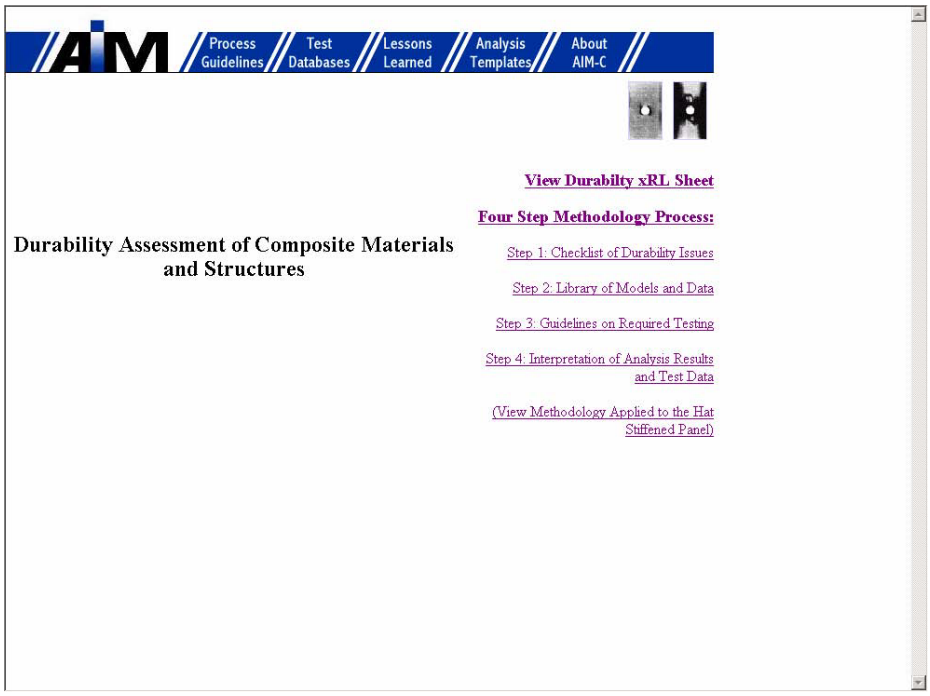

Figure 14-7. The AIM-C System Durability Assessment "Home Page"

Figure 14-8 illustrates step 1 of the durability methodology – the checklist of issues. After the durability issues are identified, the user proceeds to step 2 of the methodology via the link at the bottom of the page (see Figure 14-8). The page for step 2 is shown in Figure 14-9. This provides a list and description of all the durability analysis tools available in the system. For this carpet plot example, the user selects the link to the Super Mic-Mac spreadsheets and manuals. Selecting this link brings the user to the page shown in Figure 14-10.

AIM Process Guidelines | Test Databases | Lessons Learned | Analysis Templates | About AIM-C

Step 1.Checklist of Durability Issues

The IPT will determine durability checklist based on critical structural requirements and expected service environment.

Consult Durability Conformance Planning Checksheets (XRL's) for durability issues

Following is an example checklist based on a hat-stiffened fuselage panel from a military aircraft:

A. What are the locations where mechanically induced (i.e. fatigue) damage is most likely to initiate?
- Free edges
- Plank/skin interface
- Skin/hat interface (including adhesive)
- Noodle
- Fasteners

B. What are acceptable levels of damage at these locations?
- None
- Microcracking initiation
- Microcracking initiation that creates a delamination, but no delamination propagation
- Microcracking initiation that creates a delamination with subcritical delamination propagation

C. What are the effects of temperature and moisture on the development of damage at these locations?
- Accelerated or delayed microcrack initiation
- Accelerated or delayed delamination propagation

D. How does damage affect structural behavior?
- Decreased stiffness
- Failure

E. How do temperature, moisture, and aging affect structural behavior (assuming no damage)?
- Accelerate decrease in stiffness and onset of failure

On to Step 2 Library of Durability Models and Data

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Figure 14-8. Durability Methodology Step 1 - Checklist

AIM | Process Guidelines | Test Databases | Lessons Learned | Analysis Templates | About AIM-C

Durability

Step 2. Library of Durability Models and Data

Consult Durability Conformance Planning Checksheets (XRL's) for durability issues

These Spreadsheets are not controlled databases. They will not be saved by this system software.

Thermal Degradation SpreadSheet V_1.0.0 3-07-03
Degradation Theory Manual
Thermal Degradation Data Set
This will select, implement, and develop models that relate the effects of environmental exposure to the change in structural performance. This includes determining the life of the product to first detectable damage that can affect the strength of the part if usage continues or alternately the residual strength at the end of the service life. Beyond this, a methodology for implementation of the modules and the application of heuristics are also being developed in support of the AIM vision of reducing the time to insert materials. The thermal degradation of polymer systems is highly temperature dependent and involves many different chemical reactions. The type of chemical reaction depends on environmental factors, such as pressure, concentration of oxygen, moisture, and diffusion characteristics. The environmental factors will govern not only the rate of reaction, but the type of reactions that happen. Our work thus far has focused on thermal effects; without oxygen or moisture, thus temperature is the only accelerating factor. The approach taken here builds on methods and analysis taken from the HSCT program and from the literature.

SuperMicMac SpreadSheets and Manuals (Stanford University) V_1.0.1 7-31-03
The program runs on Microsoft Excel and is composed of several worksheets some shown and some hidden. Most of the calculation is real-time, meaning the calculation is performed instantly every time any input is changed. Additional features such as the interactive guide, analysis of multiple and spectrum load cases, parameter study, and carpet plot can be performed by pressing appropriate buttons on the worksheet. The purpose of this program is to provide the engineers and designers an integrated durability analysis tool that can predict the long-term stiffness and strength of composite laminates at wide ranges of temperature and moisture conditions. These predictions will facilitate the material selection, ply orientation optimization, and reduction of time-consuming durability tests.

Delamination Tool Spreadsheet (MIT) V_1.1.0 9-01-03
Delamination Tool Manual
The Delamination Durability Tool allows for durability analyses of composite structures that are likely to develop delaminations in critical locations. It takes tables of information from the structures module model and material data and calculates the number of cycles to the initiation of matrix cracking, delamination onset (beginning of crack propagation from a delamination), and propagation of a crack to a specified length. While it is not expected that the predictions will exactly predict the number of cycles to a specific event, the Tool is extremely useful at determining which mechanisms dominate under particular loading regimes and the magnitude of the time that these mechanisms can be expected to occur.

DURASOFT Download (MIT) V_1.0.0 8-01-03
DURASOFT Manual (MIT)
MicroCracking Data Set
Durability software for cyclic hygro-thermo-mechanical loading predicts number of flight cycles until microcracking and reduced mechanical properties at end of design life. It allows prediction of incidence and effects of microcracking, a key durability damage mode, thereby reducing long duration testing. It will help designer determine sensitivity of laminate to hygral, thermal, and cyclic mechanical loading to minimize testing.

These Spreadsheets are not controlled databases. They will not be saved by this system software.

See also Structures Analysis Tools

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Figure 14-9. Library of Durability Models and Data

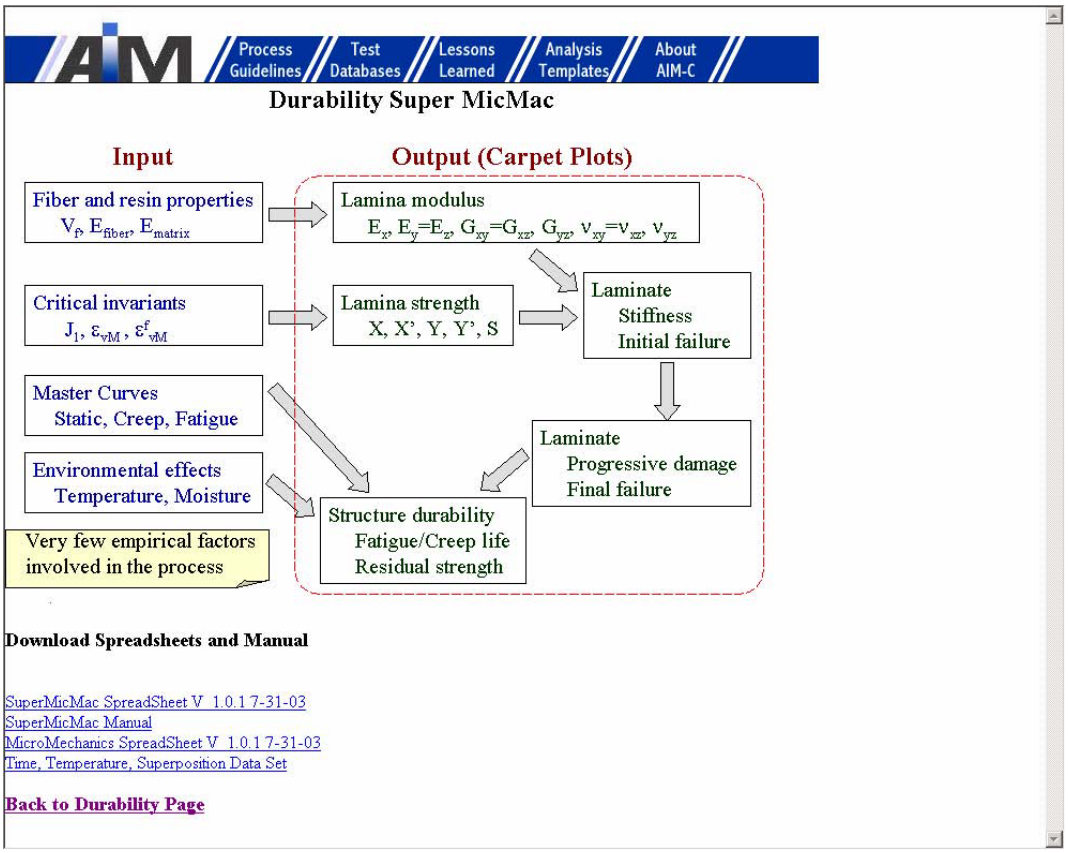
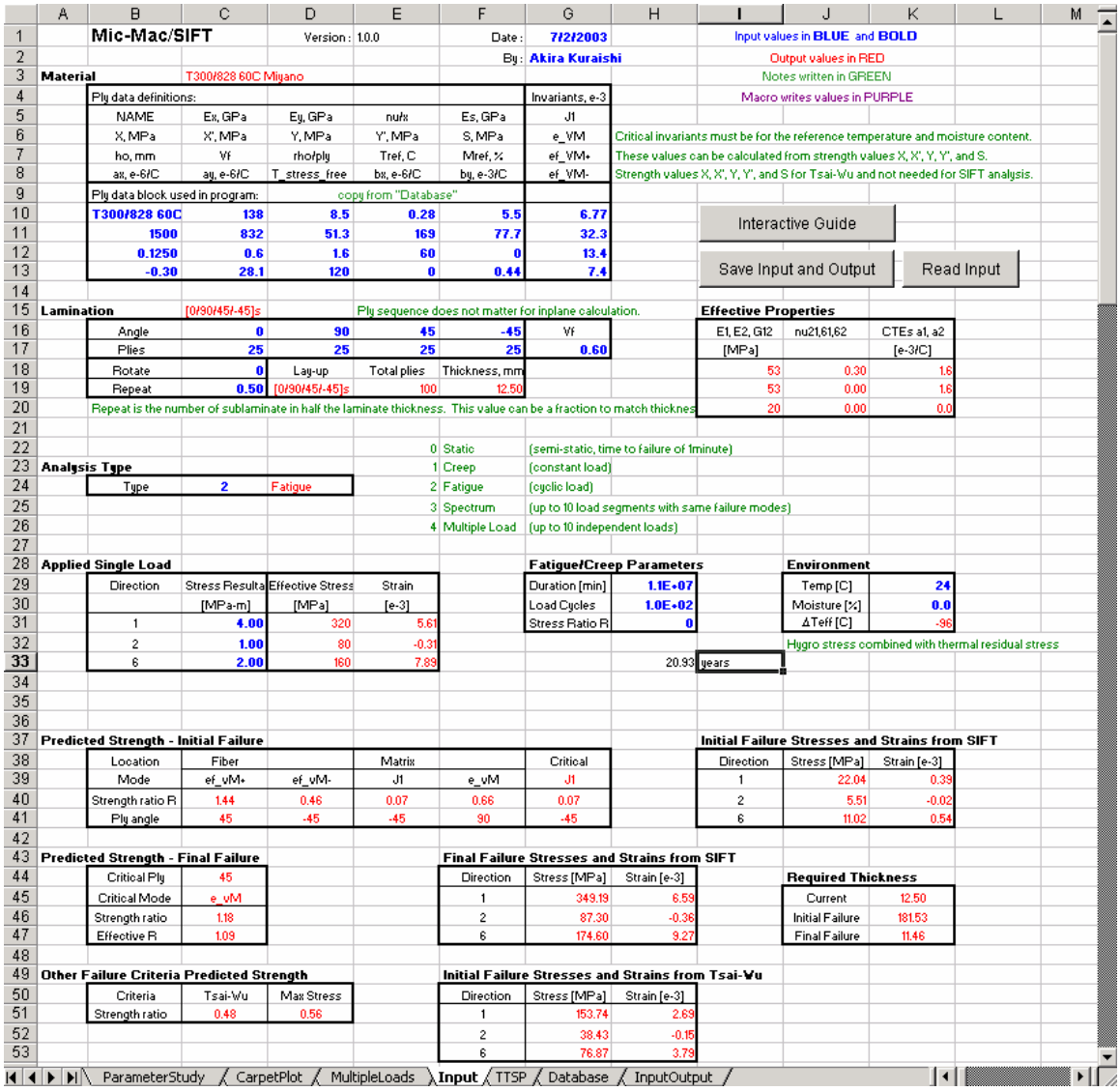


Figure 14-10. Super Mic-Mac Durability Analysis Tool Home Page

Figure 14-11 shows the SIFT Durability Spreadsheet developed by Stanford. The input sheet is where the material properties are entered, along with the laminate layup, the applied loads, the environmental conditions, and the type of analysis that will be conducted. Eventually, we would like for most of this information to be automatically entered from other regions of the system software or from answers to questions up to this point.



	A	B	C	D	E	F	G	H	I	J	K	L	M
1		Mic-Mac/SIFT		Version :	1.0.0	Date :	7/2/2003		Input values in BLUE and BOLD				
2						By :	Akira Kuraishi		Output values in RED				
3	Material		T300/828 60C Miyano						Notes written in GREEN				
4		Ply data definitions:					Invariants, e-3		Macro writes values in PURPLE				
5		NAME	Ex, GPa	Ey, GPa	nuxy	Es, GPa	J1						
6		X, MPa	X', MPa	Y, MPa	Y', MPa	S, MPa	e_VM	Critical invariants must be for the reference temperature and moisture content.					
7		ho, mm	Vf	rho/ply	Tref, C	Mref, %	ef_VM+	These values can be calculated from strength values X, X', Y, Y', and S.					
8		ax, e-6/C	ay, e-6/C	T_stress_free	bx, e-6/C	by, e-3/C	ef_VM-	Strength values X, X', Y, Y', and S for Tsai-Wu and not needed for SIFT analysis.					
9		Ply data block used in program:			copy from "Database"								
10		T300/828 60C	138	8.5	0.28	5.5	6.77		Interactive Guide				
11		1500	832	51.3	169	77.7	32.3						
12		0.1250	0.6	1.6	60	0	13.4		Save Input and Output		Read Input		
13		-0.30	28.1	120	0	0.44	7.4						
14													
15	Lamination		[0/90/45/-45]s		Ply sequence does not matter for inplane calculation.				Effective Properties				
16		Angle	0	90	45	-45	Vf		E1, E2, G12	nu21,61,62	CTEs a1, a2		
17		Plies	25	25	25	25	0.60		[MPa]		[e-3/C]		
18		Rotate	0	Lay-up	Total plies	Thickness, mm			53	0.30	1.6		
19		Repeat	0.50	[0/90/45/-45]s	100	12.50			53	0.00	1.6		
20		Repeat is the number of sublaminate in half the laminate thickness. This value can be a fraction to match thicknes							20	0.00	0.0		
21													
22					0	Static	(semi-static, time to failure of 1minute)						
23	Analysis Type				1	Creep	(constant load)						
24		Type	2	Fatigue	2	Fatigue	(cyclic load)						
25					3	Spectrum	(up to 10 load segments with same failure modes)						
26					4	Multiple Load	(up to 10 independent loads)						
27													
28	Applied Single Load						Fatigue/Creep Parameters			Environment			
29		Direction	Stress Resulta	Effective Stress	Strain		Duration [min]	1.1E+07		Temp [C]	24		
30			[MPa-m]	[MPa]	[e-3]		Load Cycles	1.0E+02		Moisture [%]	0.0		
31		1	4.00	320	5.61		Stress Ratio R	0		ΔTeff [C]	-96		
32		2	1.00	80	-0.31					Hygro stress combined with thermal residual stress			
33		6	2.00	160	7.89			20.93	years				
34													
35													
36													
37	Predicted Strength - Initial Failure								Initial Failure Stresses and Strains from SIFT				
38		Location	Fiber		Matrix		Critical		Direction	Stress [MPa]	Strain [e-3]		
39		Mode	ef_vM+	ef_vM-	J1	e_vM	J1		1	22.04	0.39		
40		Strength ratio R	1.44	0.46	0.07	0.66	0.07		2	5.51	-0.02		
41		Ply angle	45	-45	-45	90	-45		6	11.02	0.54		
42													
43	Predicted Strength - Final Failure					Final Failure Stresses and Strains from SIFT							
44		Critical Ply	45			Direction	Stress [MPa]	Strain [e-3]		Required Thickness			
45		Critical Mode	e_vM			1	349.19	6.59		Current	12.50		
46		Strength ratio	1.18			2	87.30	-0.36		Initial Failure	181.53		
47		Effective R	1.09			6	174.60	9.27		Final Failure	11.46		
48													
49	Other Failure Criteria Predicted Strength					Initial Failure Stresses and Strains from Tsai-Wu							
50		Criteria	Tsai-Wu	Max Stress		Direction	Stress [MPa]	Strain [e-3]					
51		Strength ratio	0.48	0.56		1	153.74	2.69					
52						2	38.43	-0.15					
53						6	76.87	3.79					

ParameterStudy / CarpetPlot / MultipleLoads / Input / TTSP / Database / InputOutput

Figure 14-11. SIFT Durability Spreadsheet (Super Mic Mac by Stanford University)

FiFigure 14-12 shows that the carpet plot tab is one of two output tabs, the other being the parameter study. The carpet plot tab is where the user selects what results to plot in the carpet plot. As one can see, there are numerous choices.

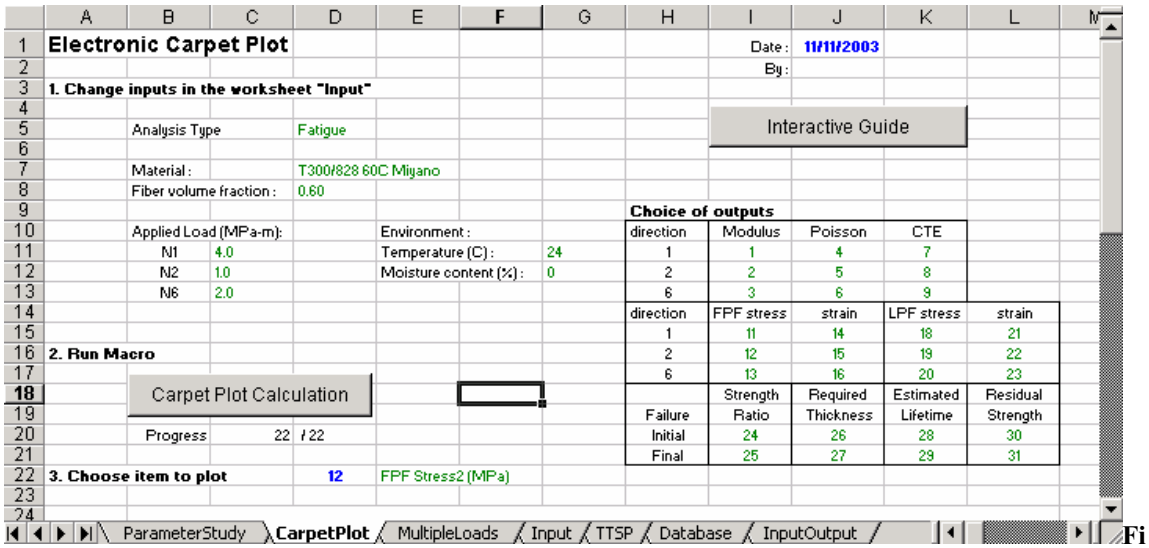


Figure 14-12. Super Mic-Mac Carpet Plot Output Selection

Figure 14-13 shows an example carpet plot for the first ply failure transverse stress (item #12 from the list). This type of plot could be generated for several "what if" scenarios where the user would go back to the input sheet and change loads, temperatures, material properties, etc. and see what effect that would have on the first ply failure stress.

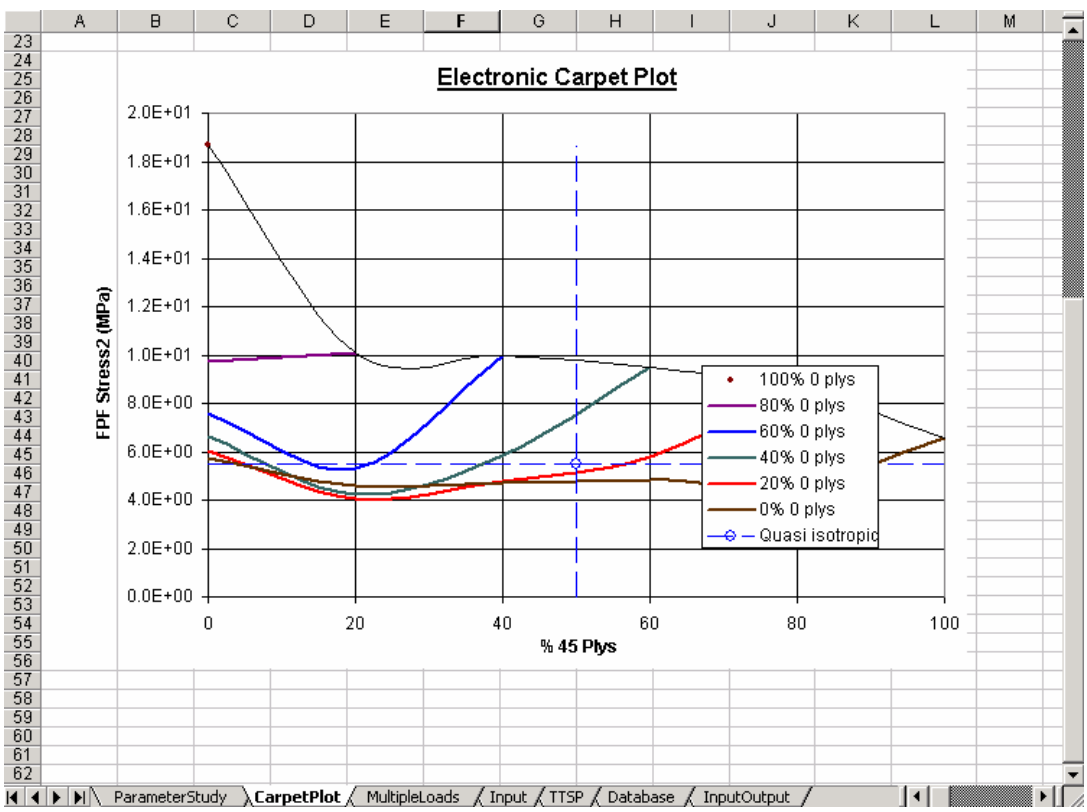


Figure 14-13. Carpet Plot Output

Appendix

Working list of Categories/Questions/Prompts in each section of the durability methodology tool

A. Material:

Listing of material types

Either straight list of materials for which data/experience exists, perhaps subdivided into sub-categories:
graphite/epoxies, glass epoxies, graphite thermoplastics…)
or
listing by constituents: epoxy matrices, graphite fibers, fiber architectures

- Constituents
  - Graphite fibers
    - T300
    - IM7
    - AS4
  - Glass Fibers
  - Aramid Fibers
  - Thermoset Resins
    - 977-3
    - 934
    - 3501-6
  - Thermoplastic resins
    - PEEK
- Material Architecture
  - Unidirectional plies
  - Woven
  - Stitched
  - Braided
- Manufacturing Route
  - Prepreg/Autoclave
  - VARTM
  - Pultruded
  - Filament wound
- Coatings
  - Paints
  - Sealants
  - Sacrificial layers
- Hybrid Materials
  - Fiber metal laminates
    - TiGr
    - GLARE

ARALL
Glass/Carbon Hybrids

B. Loads

1. Phasing with environmental factors?

2. Monotonically increasing
   - Tension
   - Compression
   - Shear
   - Biaxial
   - Triaxial

3. Cyclic
   - Constant amplitude
   - Spectrum loading
   - Tension
   - Tension-Compression
   - Compression-Compression
   - Fretting loads?
   - Biaxial
   - Triaxial

4. Constant
   - Tension
   - Compression
   - Biaxial
   - Triaxial

5. Impact
   - Low velocity
     - Max force
     - Energy
   - High velocity
     - Velocity
     - Max force
     - Energy

6. Contact loads
   - Sliding contacts
   - Rolling contacts
   - Repeated normal contacts

C. Environmental factors

Phasing with load conditions?
Temperature
    Steady
    Cyclic
Moisture
    Constant exposure (e.g. immersion)
    Cyclic
    Freezing possible?
Solvents
Gaseous reagents
Plasmas
Atomic Oxygen

D. Geometric Details

Constant cross-section
Varying cross-section
Curved plates (shells)
Cut outs
Principally in-plane loading
3-Dimensional loading
T joints
Mechanical fasteners
    Bolts
        Clamping force
    Rivets
Bimaterial Joints
    Composite-composite
    Composite-metal
    Etc.

Durability Design Objectives
    Nominal mission cycle (i.e. ground air ground)
    Number of intended missions
        Single mission
        Multiple mission cycles
    Total expected lifetime
    Target inspection frequency
    Target repair frequency

Outputs
    Degradation/Damage Mechanisms

- Fiber debonding
- Delamination
- Fiber failure
  - Tensile failure
  - Fiber Microbuckling (compression)
- Off-axis ply cracking
- Creep
- Physical aging
- Chemical Aging
- Erosion
- Wear
- Exceeds glass transition
- General tensile failure
- General fatigue failure
- General compressive failure
- Etc.

Modeling options
- See section 2

Test options
- See section 3

Literature
- Research papers in journals, conferences
- Reports from previous test programs

15 Assembly

Assembly is a primary area associated with material qualification and certification. The identification and evaluations of application assembly concepts and approaches is integrally tied to the element, subcomponent and component joints that have to be evaluated for application requirements and conformance. This section on assembly includes definitions, requirements and conformance but is lacks detail information below the top technology readiness level. This detail is on assembly processes along with their associated quality and tooling.

For purposes of the AIM-C program, assembly is composed of three primary items. First is the assembly processes of which there are several kinds. Second is quality associated with each assembly process. Third is assembly tooling associated with the assembly processes.

There are four primary types of assembly processes for connecting individual parts, subassemblies or assemblies together. First is secondary attachment by fasteners inserted into holes. Second is bonding by adhesives creating a "bonded structure" (this can be with either metallic or composite components/pieces). Third is composite cobonding where a cured detail/part/feature is attached to an uncured detail/part/feature during an autoclave cure to yield a completed structure. Fourth is composite cocure where individual details/parts/features are cured together at the same time to yield a completed structure.

15.1 REQUIREMENTS

The requirements for assembly are broken down into readiness level criteria going from the initial assembly concept through production and disassembly for disposal. This approach for assembly is the same as the other disciplines or areas associated with material qualification and certification and allows for coordinated maturity evaluations according to the maturity levels. The next section goes into the details of these top level requirements for assembly.

15.1.1 Technology Readiness Level (TRL) Chart

A technology readiness level chart was generated in order to identify specific exit criteria associated with assembly with maturity going from 1 to 10. This chart is shown in Figure 15-1.

TRL	1	2	3	4	5	6	7	8	9	10
Assembly/ Quality	Assembly Concept	Assembly Plan Definition	Key Assembly Detail Definitions	Key Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled	Production	Disassembly for Disposal

Figure 15-14 Assembly Technology Readiness Chart

The exit criteria and what they mean are shown below.

1. **Assembly Concept –** Identification of assembly concept or concepts to be used on the application

2. **Assembly Plan Definition –** The overall assembly plan for the application is established and high risk areas identified.
3. **Key Assembly Detail Definitions –** Key details are defined and fabricated for assembly process evaluations of the joints
4. **Key Assembly Details Tested –** The key details assembled in TRL 3 are tested to verify joint capability for the application
5. **Subcomponents Tested –** Subcomponents are assembled and tested to validate the joint approaches
6. **Components Tested –** Components are assembled and tested to validate the joint approaches
7. **Airframe Assembled –** Assembly processes and methods are used to assemble the completed air frames for testing.
8. **Flight Vehicles Assembled –** Assembly processes and methods are used to assemble the flight vehicles.
9. **Production –** Assembly processes and methods are used in production
10. **Disassembly for Disposal –** Methods and processes have been identified for disassembly of production units for disposal.

The exit criteria shown in Figure 1 are relative to an application and associated items for application maturity. Details of what may be involved with the individual assembly processes and their maturity would be found in the XRL charts covering the specific process.

15.1.2 XRL Charts

Detailed XRL charts would be generated for each of the assembly processes covering the process itself, quality associated with the process, and tooling associated with the process. These XRL charts would utilize the generic materials/processing/producibility guide that covers both technical requirements definition and production readiness.

16. Supportability

The following describes the methodology and process definition for the Technology Readiness Levels (TRL) for the Supportability discipline related to the structural system of a vehicle. Included are the associated elements and their criteria for each readiness level, as well as a description of how the methodology is implemented.

16.1 Supportability TRLs – At the technology readiness level, it is difficult to distinguish the technology readiness level of supportability for just structural components as the supportability discipline is really focused at the system level. There are many elements of supportability; however, not all of the elements apply to the vehicle's structural system or components. Those elements that do apply have somewhat distinct attributes that make it difficult to describe in total at this high level. Therefore, in order to describe the Supportability TRLs in a succinct way (common for the other TRL definitions), reference to the specific elements of the discipline are not possible. Consequently, the TRLs are labeled, Figure 16-1, using descriptions appropriate for the "Support System" level, where the "support system" is comprised of the primary elements that contribute to a vehicle's supportability attribute.

	1	2	3	4	5	6	7	8	9	10
Supportability (TRL)	Support System Concepts Formulated	Support System Methodologies Selected	Support System Requirements Specified	Support System Elements Applied	Support System Element Details Mature	Support System Defined	Initial Support System Ready	Support System Finalized	Support System Operational	Support System Deactivated

Figure 16-1 Supportability TRL Definitions

The criterion that is used to determine compliance or maturity to each of these ten Supportability TRL levels is contained in the Supportability Readiness Level (the XRL for the supportability discipline if you will). It is not intended that one would be able to determine the status of a technology's maturity simply by evaluating it at the TRL level. The elements of the XRL must be evaluated and rated for compliance. Each element can also be given different importance to the overall system by assigning weights to it. However, the premise of the AIM-C program has been that all elements are equally important to the maturation of the system. Ignoring any one of the primary elements results in a system not fully qualified and an application not fully certified. The results from this analysis are then rolled-up to constitute a TRL rating for the structural supportability readiness level. The next section defines the Supportability XRL for the vehicle's structural system.

16.2 Supportability XRL Elements - The supportability discipline within Boeing has defined eight (8) primary elements for airframe structures. Each element contributes to the readiness level of structural supportability. The eight elements are listed below.

1. Damage Assessment and Characterization
2. Structural Repair Data
3. Repair Concepts
4. Support Materials and Maintenance Processes
5. Repair Design and Analysis
6. Maintenance Documentation
7. Supplier Management Procurement
8. Maintenance Training

Each element has a unique set of criteria defined for each of the maturity levels, where each criterion builds upon its lower level elements as the maturity level increases. A technology is evaluated to see if it meets or exceeds the criteria defined at each maturity level. If it does, it is then considered ready at least at that level for that element. For example, the "Repair Concepts" element is considered to be at the readiness level of 5 if it has met the criteria defined for levels one through five, but has not met the criteria for level six. Figures 16-2 through 16-9 contain the criterion that has been defined for each level for each element.

	1	2	3	4	5
Damage Assessment and Characterization	Qualitative damage/failure assessment provided	Comparable historical maintenance data collected and assessed; types, location, and degradation rates determined	Damage types, impact energy levels, frequencies, and typical locations determined	Damage characterization data applied to preliminary design configurations; damage zones identified	Specific damage zones with modes, frequency, projected effects defined for each component
	6	**7**	**8**	**9**	**10**
	Damage zone and detailed definition and criteria refined for final designs	Damage zone and detailed definition and criteria updated based on ground tests	Damage zone and detailed definition and criteria finalized based on flight tests	Service damage data collection system in place; initial damage data and assessment documented	Damage characteristic data over vehicle life assessed, compiled, documented, and archived

Figure 16-2. Element Criteria: Damage Assessment and Characterization

	1	2	3	4	5
Structural Repair Data	Applicability of standard repair methods identified	Existing data collected from previous testing/ experienced; data shortfalls, inconsistencies, and incompatibilities identified	Structural repair element, subcomponent, and full-scale demonstration and test data requirements defined; repair test plan established	Repair joint configuration tests conducted and data documented	Subcomponent repair test data, as applicable and necessary, documented
	6	**7**	**8**	**9**	**10**
	Selected (critical) component tests completed and results documented	Structural repair test program fully documented, including lessons learned	Structural repair and maintenance experience from flight test documented	Repair and maintenance supporting data available to support maintenance and service life extension assessment	Repair and maintenance data collected over vehicle life documented/archived

Figure 16-3. Element Criteria: Structural Repair Data

Repair Concepts	**1**	**2**	**3**	**4**	**5**
	Draft operations and maintenance plan available and repair concept/methods explored and documented	Repair concepts/methods defined, including configuration, MTTR, limitations, risks involved, and any R&D needed	Existing repair method details quantified; new repair methods required undergoing R&D; repair/NDI criteria defined	Repair concept R&D complete and documented; repair concepts applied to structural components and repair level analysis performed	Repair method mature; repair and NDI methods demonstrated on subcomponents
	6	**7**	**8**	**9**	**10**
	Repair and NDI methods updated as required	Repair and NDI methods refined/updated as required	Repair and NDI methods updated as required, finalized, and documented	Repair and NDI methods/capability updated and documented as required	N/A

Figure 16-4. Element Criteria: Repair Concepts

Support Materials and Maintenance Processes	**1**	**2**	**3**	**4**	**5**
	Support infrastructure, repair, and NDI options, including material and fabrication methods, identified	Repair and NDI methods selected; repair materials and processes dowselected	Repair materials and processes sufficiently characterized; repair material, process, and field NDI requirements defined	Preliminary repair and NDI process procedures selected and outlined	Repair and NDI process procedures and associated limitations defined; repair material specifications finalized
	6	**7**	**8**	**9**	**10**
	Repair and NDI process procedures updated; repair materials qualified and associated specifications updated	Repair and NDI process procedures refined and validated	Repair and NDI process procedures certified for use	Repair and NDI process procedures updated as required based on operational use requirements	N/A

Figure 16-5. Element Criteria: Support Materials and Maintenance Processes

Repair Design and Analysis	**1**	**2**	**3**	**4**	**5**
	Repair design and analysis (RD&A) methodology identified	RD&A method determined for each component based on its configuration/classification (SSI, primary/secondary, nonstructural, FC, DC, SOF etc.) defined.	RD&A criteria defined and incorporated into overall structural design methodology	Preliminary structural assessment of "damaged" components performed; preliminary allowable damage limits (ADL) determined	Repair methods applied to "damaged" subcomponents and analyzed; repair design guidelines established
	6	**7**	**8**	**9**	**10**
	Repair damage limits (RDLs) defined and repair designs available	Repair damage limits (RDLs) refined and repair designs finalized	Structural repair analysis documentation updated from flight test data; sustaining engineering in place	Sustaining engineering/service life extension analysis support personnel, processes, and tools available	Sustaining engineering as-built drawings nad analysis packaged documented, archived, and personnel disbanded

Figure 16-6. Element Criteria: Repair Design and Analysis

Maintenance Documentation	**1**	**2**	**3**	**4**	**5**
	Draft strategic plan for maintenance documentation outlined	Comparable documentation gathered and assessed for applicability	Scope/purpose, statement of work, and plan for building structural repair manual (SRM) defined	Data requirements for SRM build established and in-place; SRM/IETM outlined; support process plans determined	Preliminary SRM materials and process procedures documented
	6	**7**	**8**	**9**	**10**
	Initial draft of SRM/IETM documentation available for review and trial use	SRM/IETM data updated and initial release ready to support flight test	SRM/IETM updated, certified for operational use, and released to operational units	SRM/IETM available for use; maintenance/updates as required	SRM/IETM data and associated documentation archived and de-activated

Figure 16-7. Element Criteria: Maintenance Documentation

Supplier Management Procurement	**1**	**2**	**3**	**4**	**5**
	Possible procurement concepts and methods identified	Procurement concept(s) and method(s) selected and approved	Contractual methods for procurement identified	Contractual processes for supplier procurement defined	Procurement contract methodology mature and initial contracts pursued
	6	**7**	**8**	**9**	**10**
	Procurement contract methodology for suppliers implemented	Capability to readily supply needed spares and materials for maintenance and repair established	Materiel suppliers all on board and initial deliveries in place	Supplier management process in place	Supplier management process deactivated

Figure 16-8. Element Criteria: Supplier Management Procurement

Maintenance Training	**1**	**2**	**3**	**4**	**5**
	Training methodology considered and documented	Training requirements defined and implementation plan established	Training methods determined and courses selected and outlined	Preliminary training courses built; beta tests underway	Training courses updated based on beta testing; training methods mature
	6	**7**	**8**	**9**	**10**
	Initial training on NDI and composite repairs provided to customers (supports full-scale repairs on test articles)	Flight test maintenance engineers and technicians possess ability to efficiently accomplish maintenance and repair procedures	Operational maintenance engineers and technicians fully trained to effectively support vehicle structures	Periodic maintenance team training in place; updates to processes provided; lessons learned documented	Maintenance training discontinued

Figure 16-9. Element Criteria: Maintenance Training

The meaning and criteria definition for the TRL levels is illustrated in the following. The TRL level of 6, "Support System Defined", is defined by the following criteria that must be met (from each of the 8 elements) for that level.

- Damage zone and detailed definition and criteria refined for final designs
- Selected (critical) component tests completed and results documented
- Repair and NDI methods updated as required
- Repair and NDI process procedures updated; repair materials qualified and associated specifications updated
- Repair damage limits (RDLs) defined and repair designs available
- Initial draft of SRM/IETM documentation available for review and trial use
- Procurement contract methodology for suppliers implemented
- Initial training on NDI and composite repairs provided to customers (supports full-scale repairs on test articles)

Note that all of the criteria for the lower levels (1 – 5) must also have been met. Once all of the elements have been evaluated and a readiness level has been defined for each, they can be rolled up to determine the overall structural supportability readiness level. In addition, weighting factors can be assigned to each element, based on its overall importance to the supportability system, to obtain a more refined readiness level assessment. These weights could be program driven; however, consistency in sharing data across programs favors the establishment of a standardized system. The following

example illustrates the use of these elements in assessing the readiness level for structural supportability.

16.3 Use of the Supportability XRL Definitions

Figure 16-10 shows the results of an artificial assessment of each element where the columns are filled in with the maturity level criteria that has been met to date. Totaling the results yields an overall Supportability Technology Readiness Level (TRL) of 3, which correlates to the definition of the TRL 3 of "Support System Elements Applied." Obviously some elements are being pursued beyond the TRL 3 level and those beyond TRL level of 5 are at risk should data not support the maturity levels of the current concepts at TRL = 4.

	1	2	3	4	5	6	7	8	9	10
Damage Assesment and Characterization	Qualitative damage / failure assessment provided	Comparable historical maintenance data collected and assessed; types, location, and degradation rates determined	Damage types, impact energy levels, frequencies, and typical locations determined	Damage characterization data applied to preliminary design configurations; damage zones identified	Specific damage zones with modes, frequency, projected effects defined for each component	Damage zone and detailed definition and criteria refined for final designs				
Structural Repair Data	Applicability of standard repair methods identified	Existing Data collected from previous testing / experience, data shortfalls, inconsistencies, and incompatibilities identified	Structural repair element, subcomponent, and full-scale demonstration and test data requirements defined; repair test plan established	Joint repair configuration tests conducted and data documented						
Repair Concepts	Draft operations and maintenance plan available and repair concepts / methods explored and documented	Repair concepts / methods defined, including configuration, MTTR, limitations, risks involved, and any R&D needed	Existing repair method details quantified; new repair methods undergoing R&D; NDI requirements defined							
Support Materials and Maintenance Processes	Support infrastructure, repair, and NDI options, including material and fabrication methods, identified	Repair and NDI methods selected; repair materials and processes downselected	Repair materials and processes sufficiently characterized; repair material, processes, and field NDI requirements defined	Preliminary repair and NDI process procedures selected and outlined	Repair and NDI process procedures and associated limitations defined; repair material specifications finalized					
Repair Design and Analysis	Repair design and analysis (RD&A) methodology identified	RD&A determined for each component based on its configuration / classification (BB, primary / secondary, nonstructural FC, DC, SFO, etc) defined	RD&A criteria defined and incorporated into overall desing methodology	Preliminary structural assessment of "damaged" components performed; preliminary allowable damage limits (ADL) determined						
Maintenance Documentation	Draft strategic plan for maintenance documentation outlined	Comparable documentation gathered and assessed for applicability	Scope / purpose, statement of work, and plan for building structural repair manual (SRM) defined	Data requirements for SRM build established and in-place; SRM/ETM outlined; support process plans determined						
Supplier Management and Procurement	Possible procurement concepts and methods identified	Procurement concept(s) and method(s) selected and approved	Contractual methods for procurement identified	Contractural processes for supplier procurement defined						
Maintenance Training	Training methodology considered and documented	Training requirements identified and implementation plan established	Training methods determined / courses selected and outlined							

Figure 16-10. Example of Readiness Level Assessment

APPENDIX A - REQUIREMENTS DEVELOPMENT

Introduction

The overall AIM-C methodology for accelerated materials and/or processes insertion is composed of four primary steps shown in Figure A-1. Requirements identification is incorporated as part of the problem statement according to objectives, applications and customers. Establishing these requirements has been an issue historically because they mean different things to different disciplines/people and they tend to shift or creep during qualification and certification.

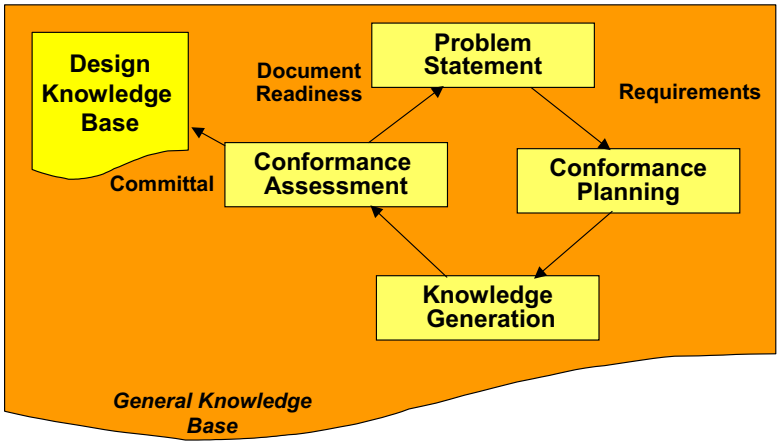


Figure A-1 Overall Methodology

The objective of the AIM-C process for requirements definition is to provide a disciplined framework for the insertion of a new material that captures the designers' application/problem statement. The methodology or process is intended to provide guidance at all levels and by all disciplines in the certification process. This methodology process is robust with flexibility so that change and customer perspective requirements can be easily addressed while maintaining full trace ability of information and data.

Requirements identification are a very important piece of the overall AIM-C methodology that has been overlooked in other approaches such as the Building Block, TRL, 2nd Source, and AGATE. The WHY of material qualification and certification is that requirements have to be met acceptably to the customers and certification agency.

One of the key problems encountered in accelerating the insertion of materials into products is that requirements are defined at the System or Vehicle levels, but the materials' decisions are made at the part level. Figure A-2 shows a schematic of how the system level requirements link to the part or component level decisions through a Systems Engineering approach known as the House of Quality. This can be considered as requirements flow down from the system level to airframe and component levels.

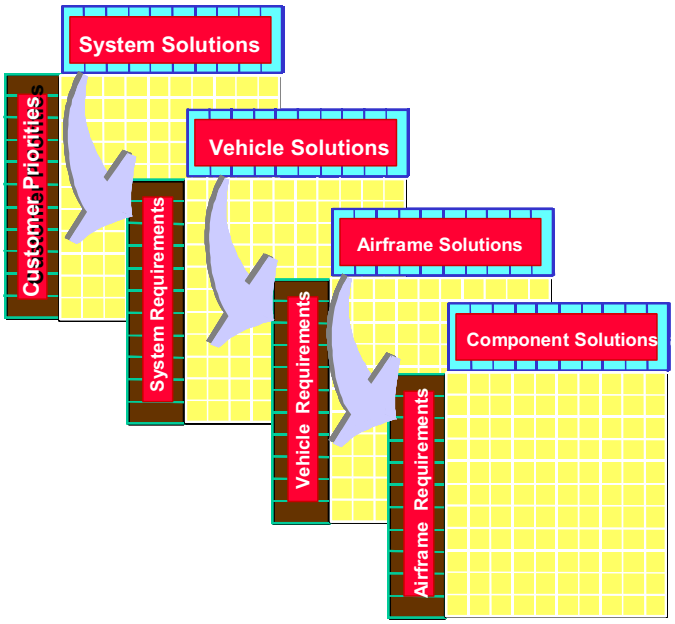


Figure A-2. Requirements Flow Down to the Component Level for Qualification and Certification

Satisfying the airframe and component requirements has been historically conducted through a building block process such as used for the F/A-18E/F qualification and certification. Figure A-1 illustrates the traditional steps in the building block insertion process.

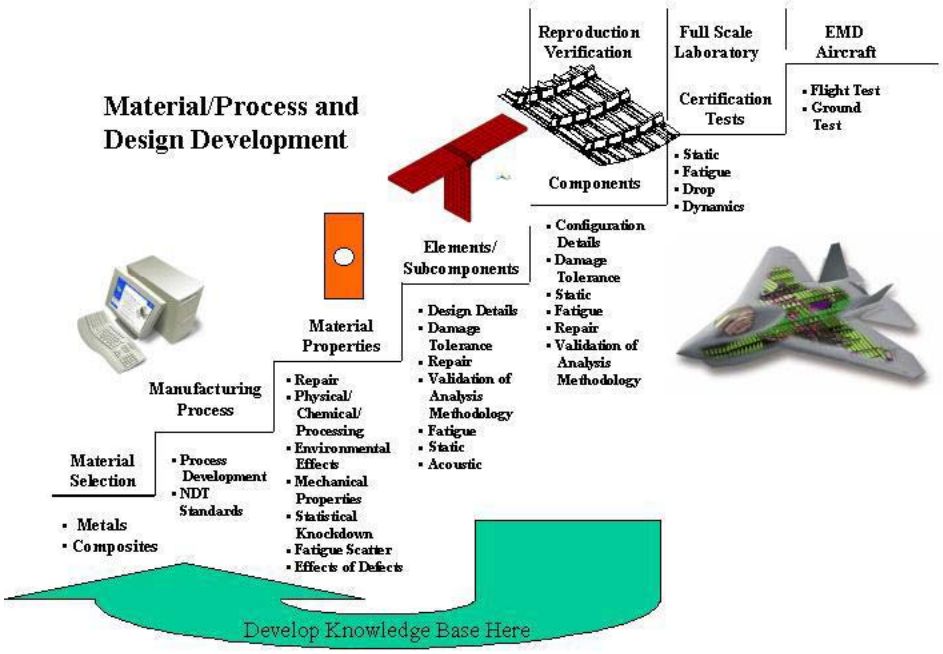


Figure A-1 Methodology Approach With Early Knowledge Base Development.

This AIM-C approach is presented in Figure A-2 in comparison to the conventional Building Block Approach and shows hen activity groups are conducted. The primary differences between the AIM-C approach and the Building Block Approach is the focus on addressing scale-up and design details (two recognized historical show-stoppers) before any allowables development begins. The AIM-C approach does this by focusing efforts on defining, producing, and testing a Key Features Article that represents the scale of the largest part to be fabricated, the most critical design detail features, and the most difficult tooling considerations included in it. This article could be a pre-production proof test article, or it might be an artificial article designed to include the most critical issues contained in a number of parts. The primary purpose of the article is to demonstrate that the material, processes, and fabrication capabilities are defined and stable enough to produce such parts consistently. This article also serves through destructive tests to guide the development of allowables toward those elements of the design that control certification. There are three stages to the AIM-C approach going from quick look assessments to mid depth assessments and then to detailed assessments. Each stage builds on previous stages with early risk reduction thereby minimizing the potential for showstopper issues.

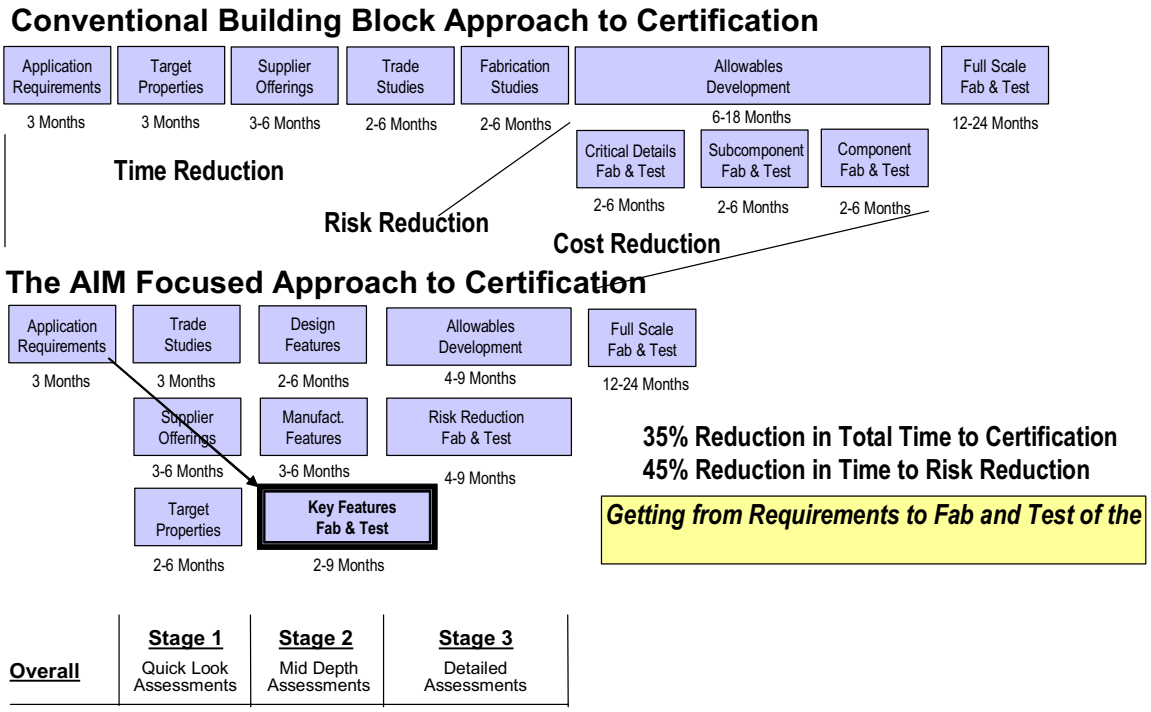


Figure A-2. The AIM-C Process use IPT Lessons Learned to Drive Rapid Insertion

The approach defined in Figure A-2 starts to establish a framework for an IPT effort toward accelerated insertion. This means that every test and every analysis performed and every bit of knowledge brought to the effort is available to speed the satisfaction of the requirements for certification of the material on a particular application being proposed. Moreover, the

purpose is to ensure that every piece of data or knowledge obtained is used to the greatest extent possible and that no data or knowledge developed which has no relevance to the application being proposed.

Key to this accelerated insertion is understanding of what the requirements are and understanding what has been satisfied and what needs to be satisfied. The AIM-C program decided to utilize a technology readiness level concept similar to those defined by NASA and the Air Force. By linking the approach to an appropriate technology readiness level, the maturity of the product development cycle can be established from test tube materials development to qualification and certification in the application.

Technology readiness levels (TRL) were originally established to grade the maturity level of a system application and went from concept exploration of a 1 to production at a 9. This is shown in Figure A-3 for NASA's approach to TRL's. Usage of this numbered maturity level allows breaking requirements up into more understandable steps.

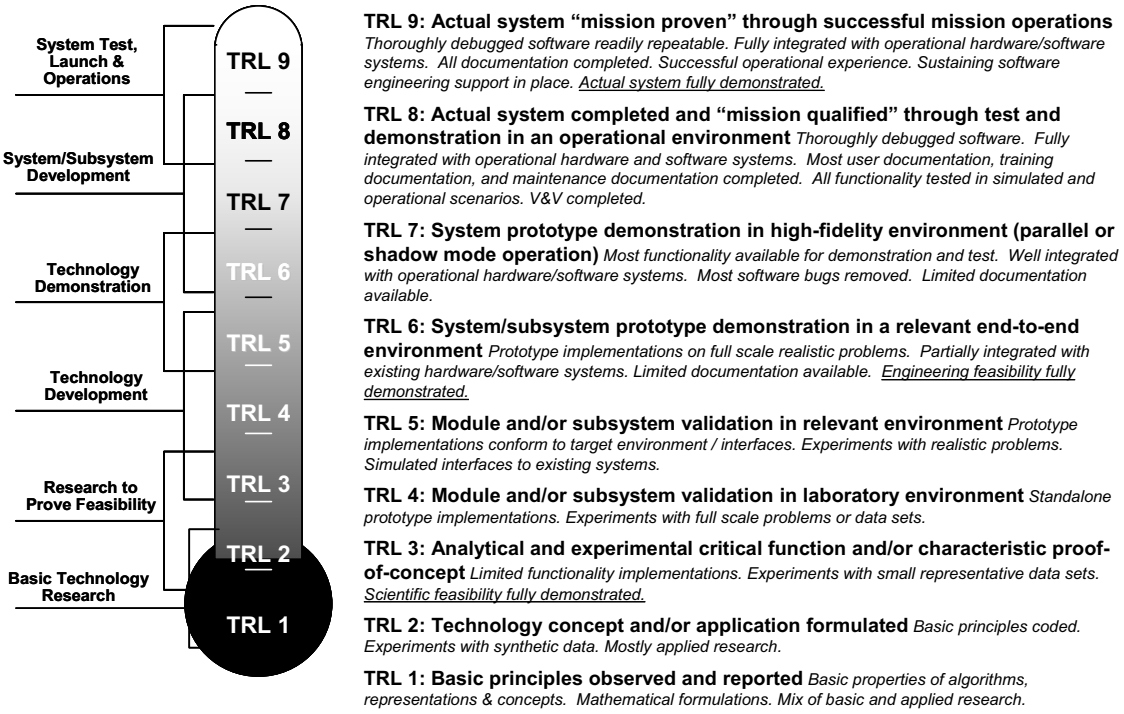


Figure A-3 NASA TRL Scale

For the AIM-C methodology process, concept exploration starts at a 1 but it goes to 10 and covers recycle or disposal. This TRL application maturity ranking for the AIM-C program is shown in Figure A-4 for application maturity. Also shown are what could be primary activities or exit criteria for each of the application maturity levels.

TRL	0	1	2	3	4	5	6	7	8	9	10
Certification	Qualification Plan Assessment	Certification Elements Documented	Certification Plan Documented	Certification Plan Approved	Elements	Subcomponent Testing	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test	Production Approval	Disposal Plan Approval

Figure A-4. AIM-C Technology Readiness Levels 1 to 10 for Certification Maturity.

The link between the AIM-C approach and the Technology Readiness Levels for each is shown schematically in Figure A-5. Stage 1 is early activities for concepts, approaches and material/process trade studies and/or down selection. The second stage covers TRLs 2 and 3 simultaneously as the material, process, fabrication, and structures elements are all addressed by concurrent or synergistic evaluations. Stage 3 is detailed assessment of design allowables and specific application certification at element and subcomponent levels.

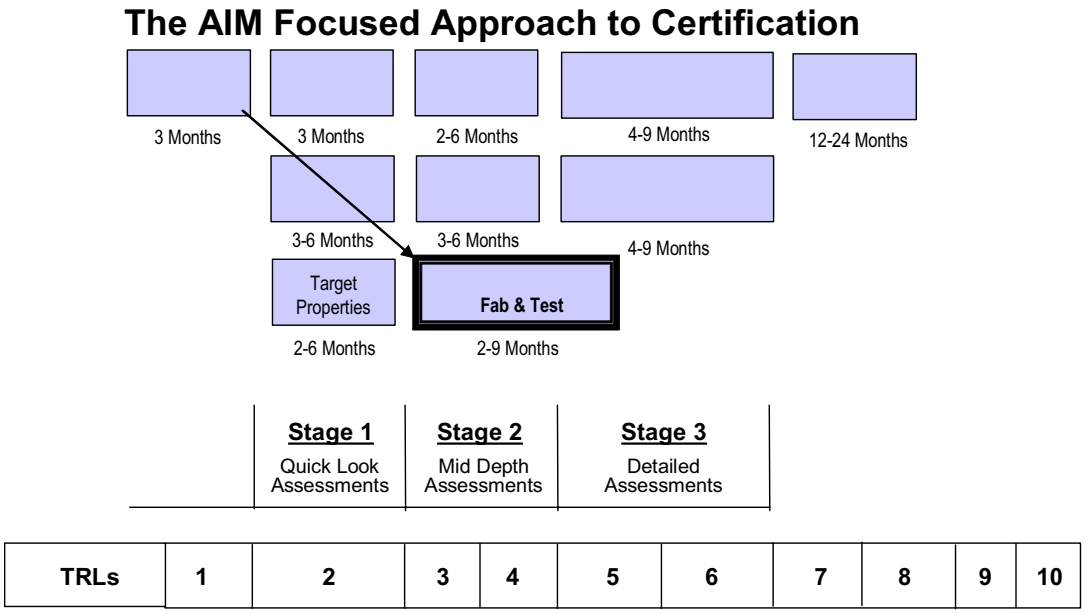


Figure A-5 The AIM-C Methodology Links the AIM-C Process to Technology Readiness

There are a number of engineering disciplines involved with qualification and certification requirements. For aircraft applications, the primary disciplines include design, structures/strength, materials, manufacturing/producibility, and supportability plus others as needed for specialty areas. The trend today is towards forming teams composed of the primary disciplines that work together on an application from initial material screening through final product qualification. These teams are called an integrated product team (IPT). Customers, suppliers, subcontractors, technical leads and management are also involved with qualification and certification as members of the IPT. The multiple disciplined IPT establishes objectives and requirements for qualification and certification data.

Requirements can be viewed as to what is needed for acceptance of a new material and/or process on an application from this multiple discipline perspective. A summary of the overall multiple discipline needs is shown in Figure A-6. These needs can be considered the overall designer knowledge base (DKB).

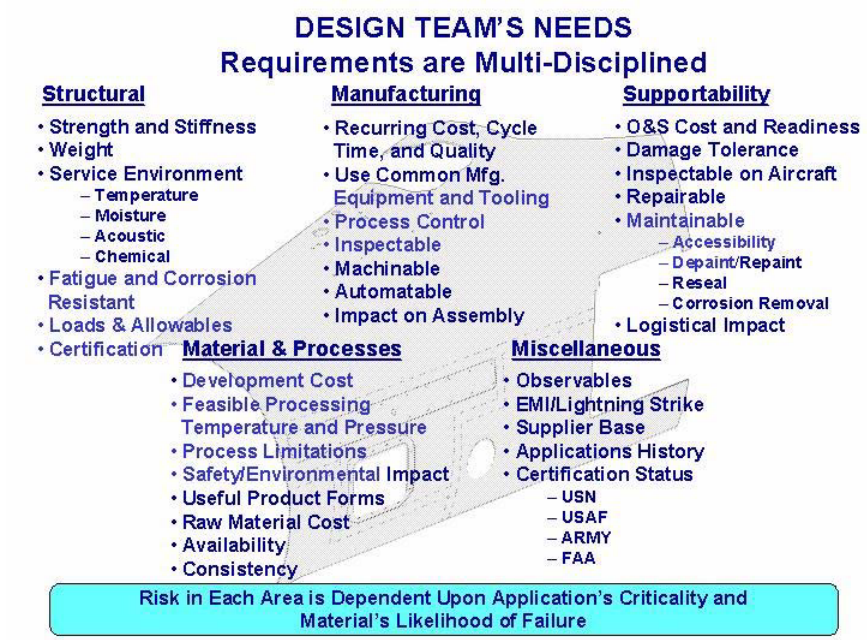


Figure A-6 The Overall Design Knowledge Base

The overall DKB provides the broad, all inclusive definition of knowledge required for application design. It goes beyond what is absolutely necessary to obtain certification of the product to include those supportability and survivability. The AIM-C DKB definition is the information for the certification agent. This agent or person has a defined series of criteria to make sure that the material system meets the requirements of the application and will not prove ineffective during the use of the product.

The next section provides background information and definitions for the TRL numbers used in the AIM-C program.

Maturity Level Scale Background and Definitions

Technology maturity measurement approaches have been established by several government agencies and incorporated into DoD acquisition regulations. The left side of FIGXX shows a designer perspective for technology maturity on applications going from 1 of concept exploration through 10 for disposal. This is very similar to the NASA numbering and activity definitions leading to certification on an application. There are positives and negatives associated with this Technology Readiness Level (TRL) approach that are also shown in Figure A-7.

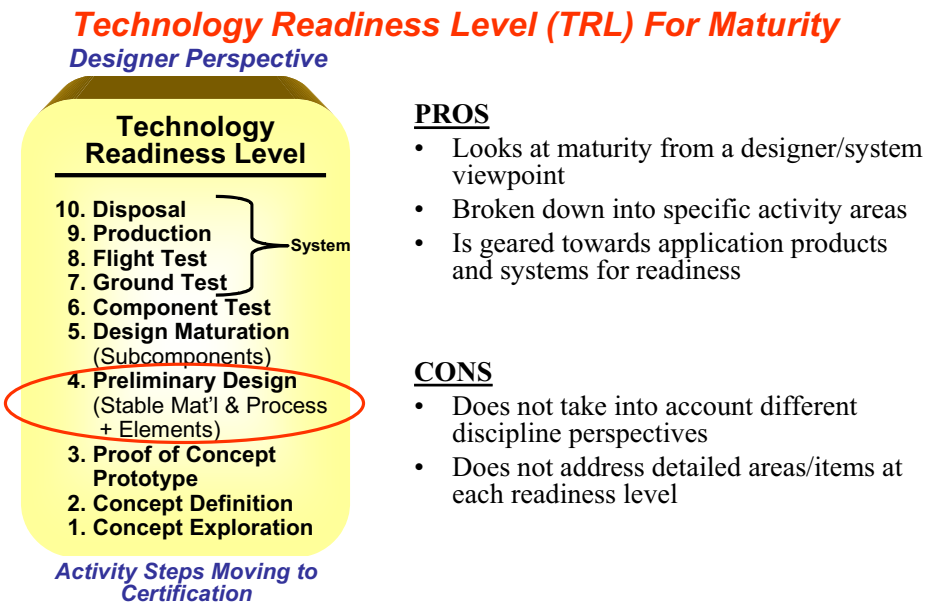


Figure A-7 Designer Perspective of Application TRL Maturity Leading to Certification

Another issue with this designer/application perspective is the difficulty of interpretation for technologists who work with materials, processes or producibility/manufacturing. If a technologist view is used, there would be different definitions for the maturity levels that move from concept exploration at TRL of 1 to qualified material/process at 7 and industry standard at 9. This technologist view is shown in Figure A-8 along with positives and negatives of this perspective.

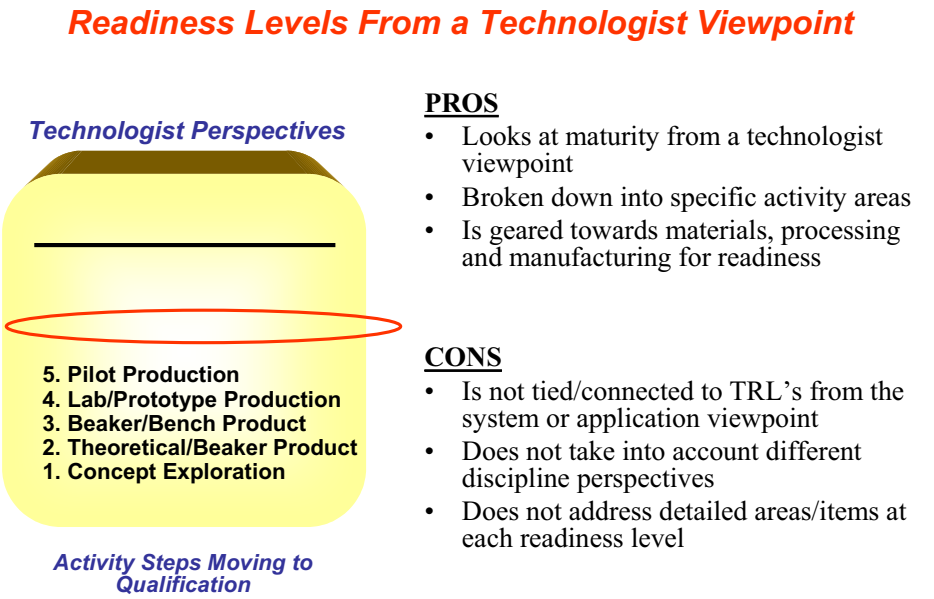


Figure A-8 Technologist Perspective of TRL Maturity Leading to Qualification

To take care of the connection of TRL's between the two viewpoints, the charts can be connected at two common denominators (Figure A-9). One is the designer/application TRL of 4 with a stable materials and process which correlates to the technologist readiness level of 7 with a qualified material and process. The second connection point is production at a designer/application TRL of 9 and a technologist readiness level of 8. Another distinction was made between the application and technologist views. Application readiness was described as Technology Readiness Levels or TRL. Technologist readiness was described as XRL or (x)RL where X was fill in the blank for the technology area. Example areas would be resin, fiber, prepreg, etc.

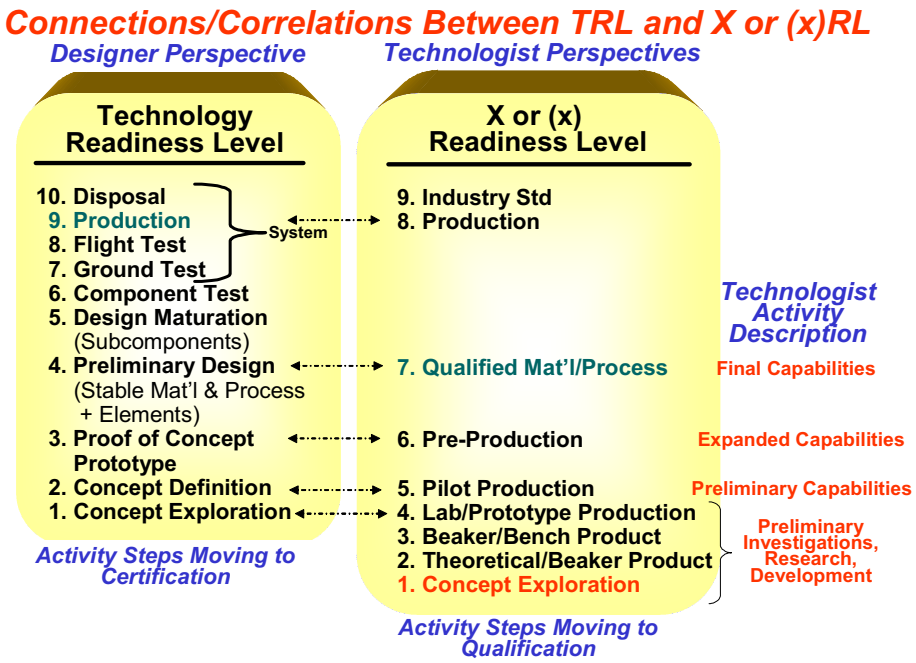


Figure A-9 Connection of Common Application and Technologist Readiness Levels

Another way of presenting this double scale is shown in Figure A-10. This was developed for use on technology transition onto the C-17 and was established independent of AIM-C activities. This indicates that this duality of measurements between application maturity and technology maturity is more typical in industry than originally thought.

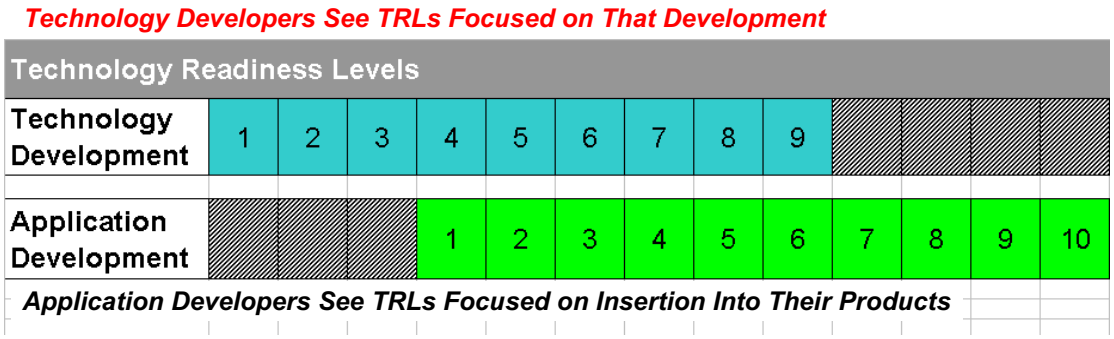


Figure A-10 C-17 Technology Readiness Metric Approach

These two measurement scales were used in the AIM-C program for a period of time but it tended to be confusing with the conversions that were happening between applications and technologies for their different numbers and what they meant. These measurement scales were modified based on inputs from the team and from customer groups. This modification consisted of putting both the application/designer perspective and the technologist perspective onto a single scale of 1 to 10. This updated numbering scheme is shown in Figure A-11 and will enable a common view of maturity regardless of individual perspectives to qualification and certification.

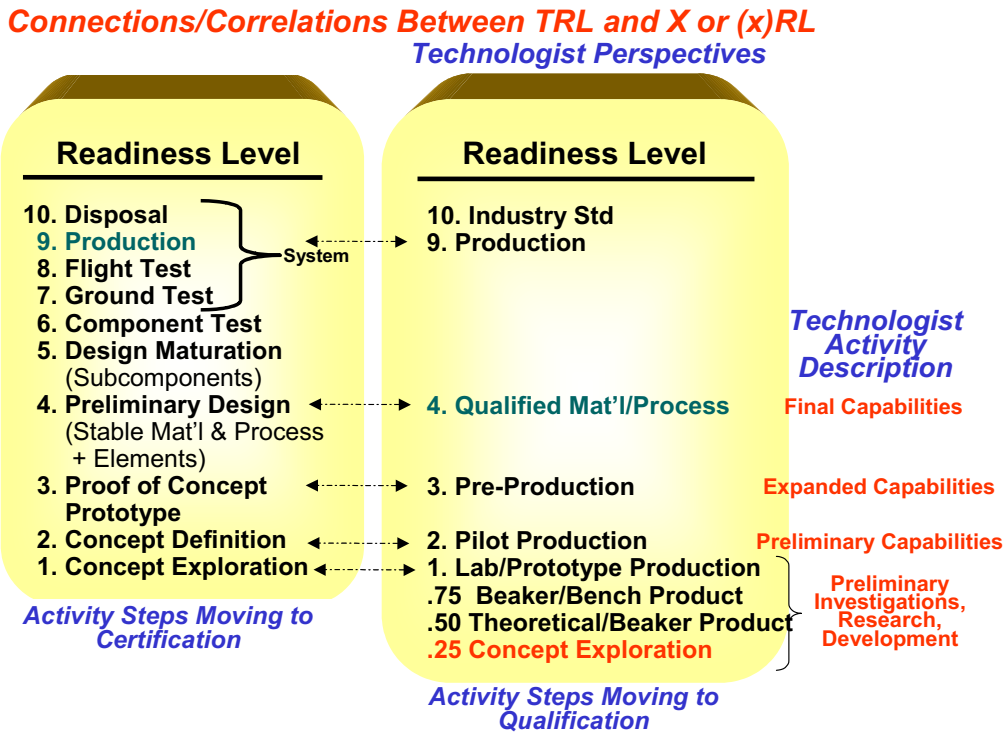


Figure A-11 Connection of Common Application and Technologist Readiness Levels

Another way of presenting this common number approach is shown in Figure A-12. It enables viewing the qualification and certification process as a whole with integrated product teams (IPT) working together for common goals and objectives.

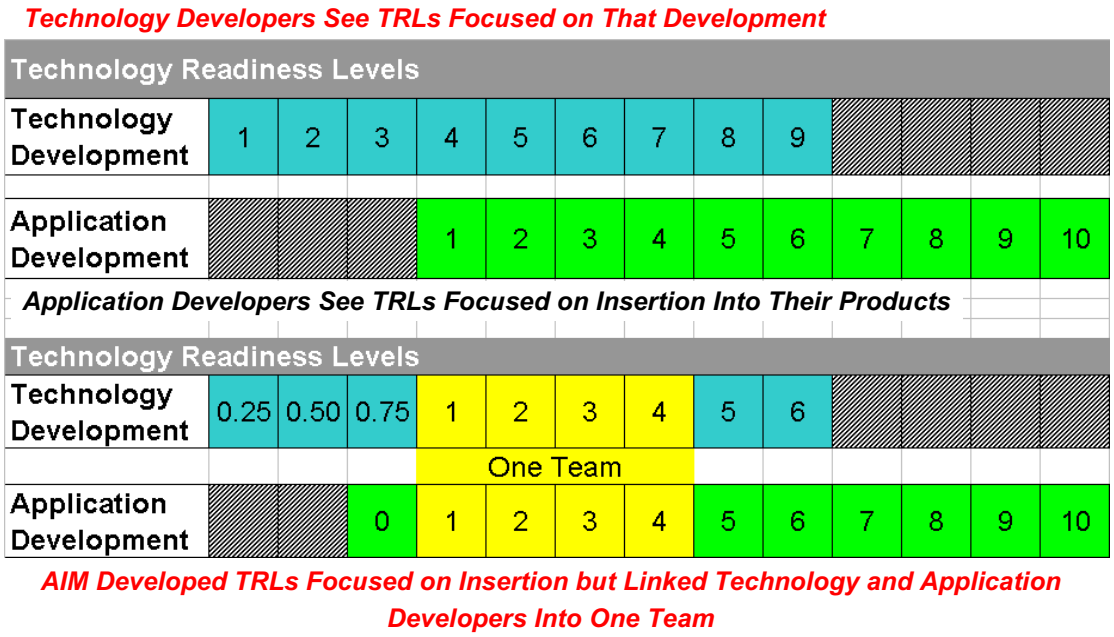


Figure A-12 Alternate Presentation of Common Number Metrics

Requirements Definition Process

The requirement definition process follows after the requirement flow down to the airframe and component levels. The AIM-C requirement definition process is comprised of two primary steps with associated tool sets to use with the steps. Figure A-13 depicts the requirement flow down through the two primary steps for specific requirement definition for areas/items/groups associated with meeting requirements.

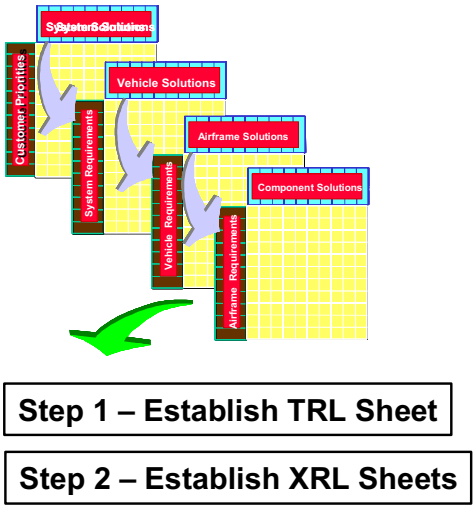


Figure A-13 Requirement Definition Primary Process Steps

Step 1 activities focus on establishing graduated maturity level metrics for each of the primary areas identified with requirements in the problem statement. The metrics could be considered exit criteria to move from one maturity level to the next. These areas would make up the TRL sheet for maturity metric identification. Example areas would be Application/Design, Certification, Structures, Materials and Fabrication/Producibility plus others.

Step 2 activities focus on establishing detailed graduated maturity level metrics concentrating on items associated with each area on the TRL sheet. These detailed area requirement sheets are called XRL sheets where X stands for a specific area. For example, structures would have a detailed XRL sheet covering durability and properties. Material would have detailed XRL sheets covering resin, fibers and prepreg.

In the AIM-C program, two guides were developed to assist in establishing the XRL sheets. These guides are for structures and a generic guide that can be used for materials, processing and fabrication/producibility. The structures guide encompasses typical big picture requirements for component failure mode, property and durability requirements from which a tailored and specific XRL sheet for structures can be established. The material, process and fabrication/producibility guide looks at requirements for these areas from a production readiness perspective to ensure that all item requirements are established for successful transition to production through qualification and into certification. Figure A-14 shows an overview of this requirements definition process with the different tool sets and personnel conducting the activities. These activities could be considered assessments for requirements definition.

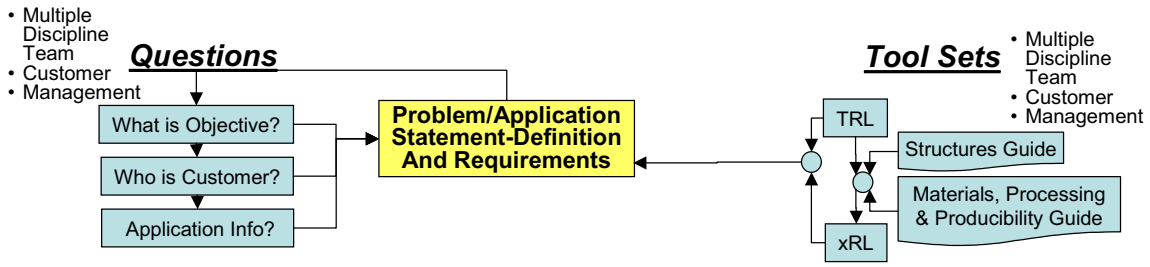


Figure A-14 Requirement Definition Process Overview

If the process steps and assessments are broken down further, a series of process flow steps could be shown. Figure A-15 and Figure A-16 show these process steps in a flow chart form.

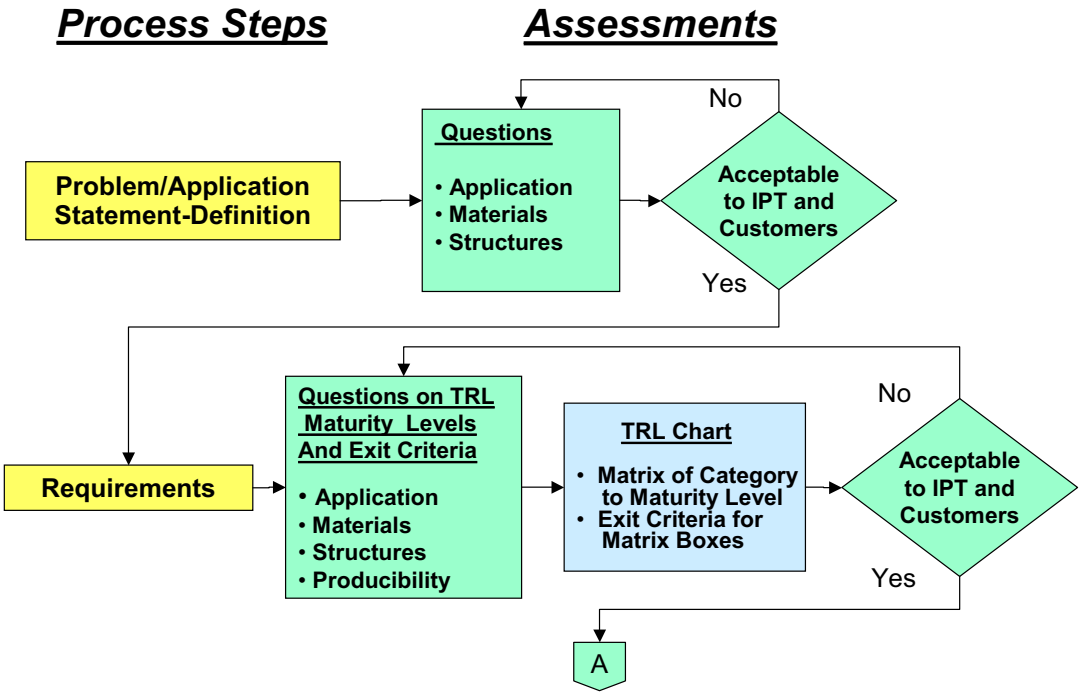


Figure A-15 Process Flow for Requirements Definition

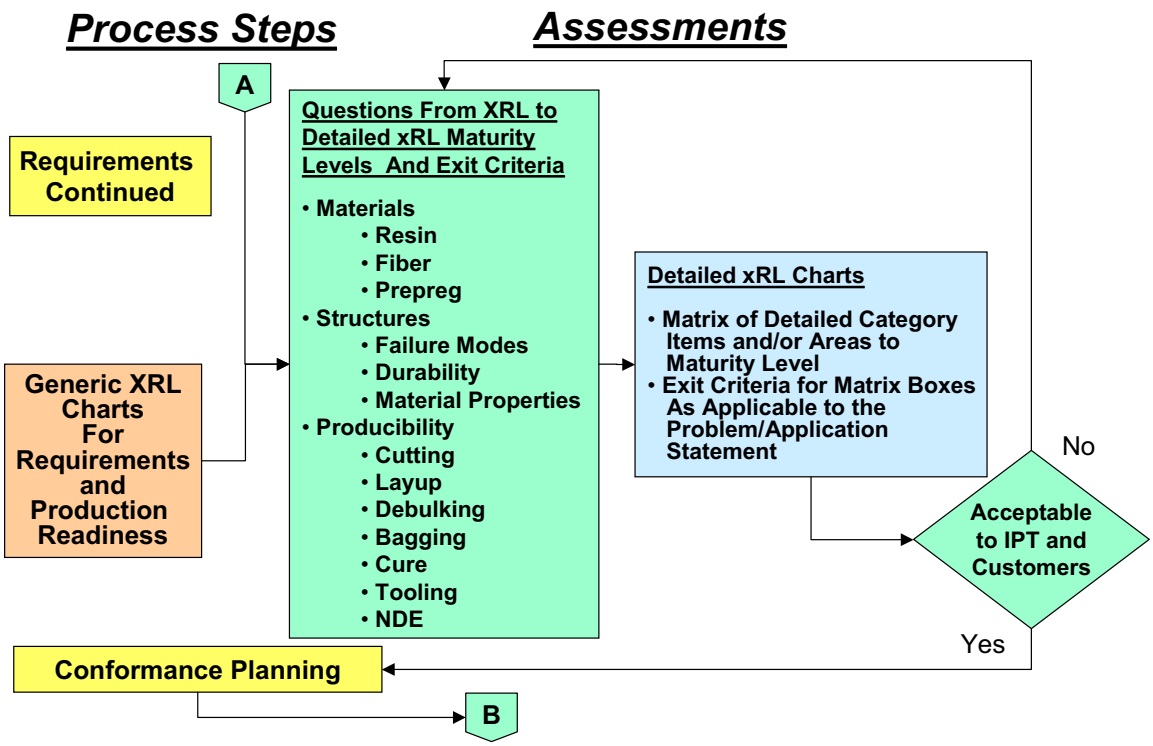


Figure A-16 Process Flow for Requirements Definition, Continued

An overview of the TRL sheet process flow is shown in Figure A-17. Also identified are inputs, outputs and metrics from this process.

TRL Process Flow

1. **Identify Primary Areas Involved with Objective**
2. **Identify high level, sequential step-wise criteria going from conceptualization through disposal for each area**

INPUTS: Objective, Needs, and Customer
OUTPUTS: Technology Readiness Level Matrix Chart
METRICS: Increased Data and/or confidence and/or increased application complexity

Figure A-17 TRL Sheet Process Flow

An overview of the XRL sheet process flow is shown in Figure A-18. Also identified are inputs, outputs and metrics from this process along with references to be used as needed in establishing the XRL sheets.

XRL Process Flow

1. **Identify Items Associated with Each Primary Area Involved in Objective**
   - **Include variability as an item for each primary area**
   - **Include quality characteristics relative to application or acceptance criteria as an item for each primary area**
   - **If applicable, address production readiness areas with the items**
2. **Identify sequential step-wise criteria going from conceptualization through disposal for each item**

INPUTS: Objective, Needs, and Customer plus TRL Matrix Chart
OUTPUTS: xRL Matrix Chart
METRICS: Increased Data and/or confidence and/or increased application complexity
REFERENCES: XRL Guides for Structures, Materials, Processing and Producibility/Fabrication

Figure A-18 XRL Sheet Process Flow

Obviously a key element in enabling AIM-C Process to be effective is to have a Methodology that links the process to the toolset that supports it and that allows accelerated technology insertion. We have chosen to do this by linking the requirements for certification of a material on an application to the technology readiness levels required for insertion of a technology into a product. Then, by tying the technology readiness levels to the readiness levels determined by each discipline required to support that level of readiness, we can roll down the requirements to the exit criteria required for a given application. This provides a roll up of the satisfaction of those requirements to the product technology readiness level so that the team can see the readiness, or the show stoppers for application of the technology to the product at any time. A design/development integrated product team (IPT) knows where to focus its resources or what expertise needs to be brought to bear in order to continue the accelerated insertion of that technology. In the worst case, the Methodology may allow the IPT to know when to curtail efforts to insert the technology because the show stoppers or schedule requirements simply cannot be met. But even in that case, the IPT has the information required to make that decision as early as it can be rationally made.

In summary, the requirements definition is conducted along with the problem statement and objective definition to identify the "Whys" of all qualification and certification activities that most programs focus on. These definitions take into account application aspects and certification agency aspects by bring them together in a systematic approach for requirements.

- **Application Aspects -** A definition has to be established for the application that the new material will be applied to. This forms the high level requirements in a complete problem statement with objectives that materials will have to meet for acceptance and insertion. Typical application information that has to be identified is working organization, program, component, manufacturing processes of interest, material systems of interest, operating environment, etc. Additional specific information is added such as associated part features and desired characteristics of prepreg ply thickness, fiber volume, resin content, dimensional accuracy, void content plus others.

- **Certification Agency Aspects -** Identification of the certification agency establishes a set of requirements that will have to be met in order to insert a new material. Items included are such things as the Joint Services Specification that establishes requirements for a full aircraft system. Areas that are included are detailed design, general parameters, specific design, structural loading, strength, durability, aeroelasticity, areoacoustic durability, survivability, plus a number of others. The intent is to develop a way of tying the certification agency requirements in to the overall methodology for new material insertion.
- **Systematic Requirements Definition Approach -** A key aspect of the AIM-C methodology is the systematic functional approach to identify requirements for what needs answering to insert a new material while simultaneously evaluating portions of risk and their consequences relative to what has to be answered. This approach is based on combining Technology Readiness Levels (TRL's) with building block segments, individual material insertion disciplines, and production readiness to establish what has been done from an exit criteria requirements standpoint. This is called a TRL sheet or tool set along with the XRL sheets or tool sets.

The requirement definition and problem/application statement activities are part of the overall AIM-C process for accelerated insertion of materials and/or processes. This total picture summary is shown in Figure A-19.

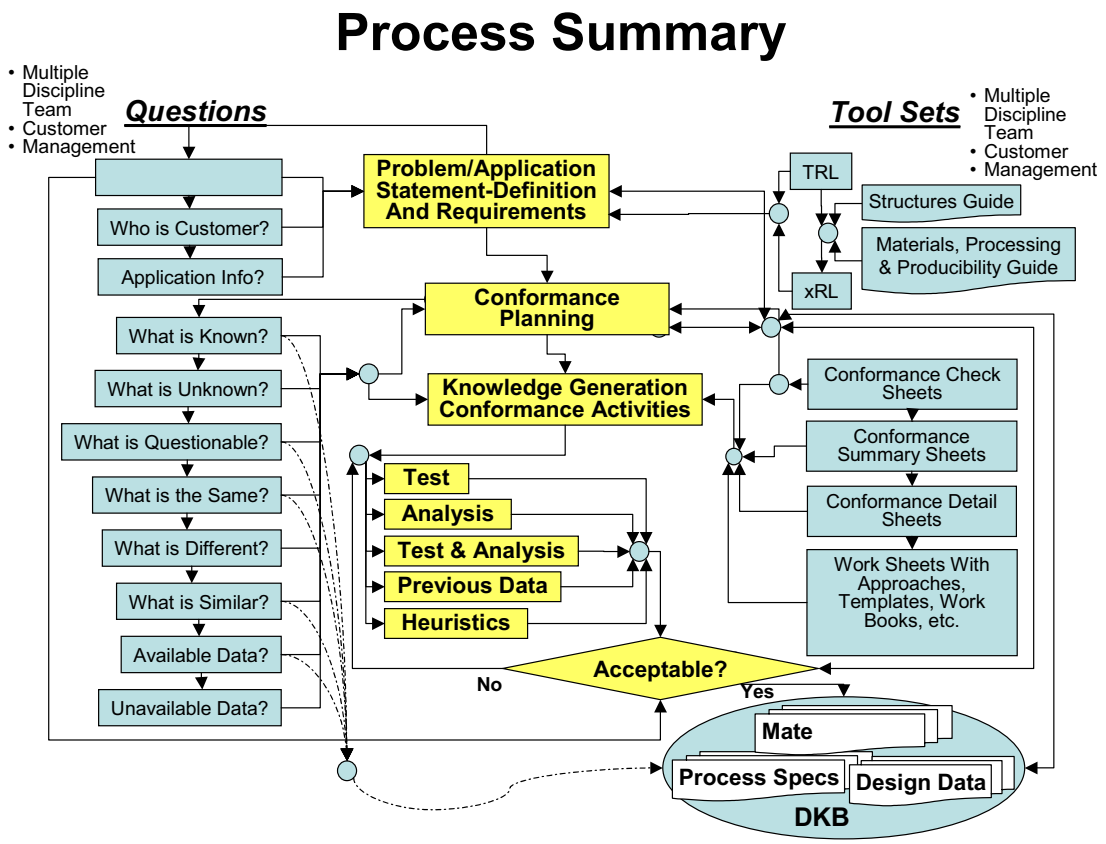


Figure A-19 Overall AIM-C Process Summary

In this big picture, activities are conducted simultaneously in multiple disciplines. The next series of figures shows example activities at TRL's of 2, 3, 4 and 5.

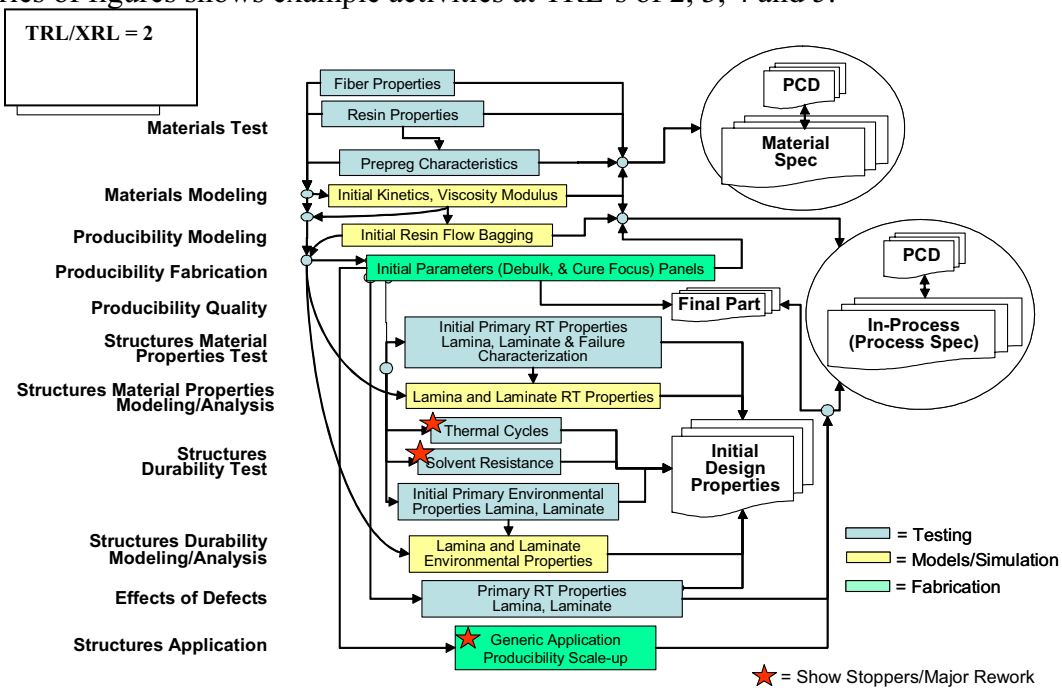


Figure A-20 Example Common Activities at TRL 2

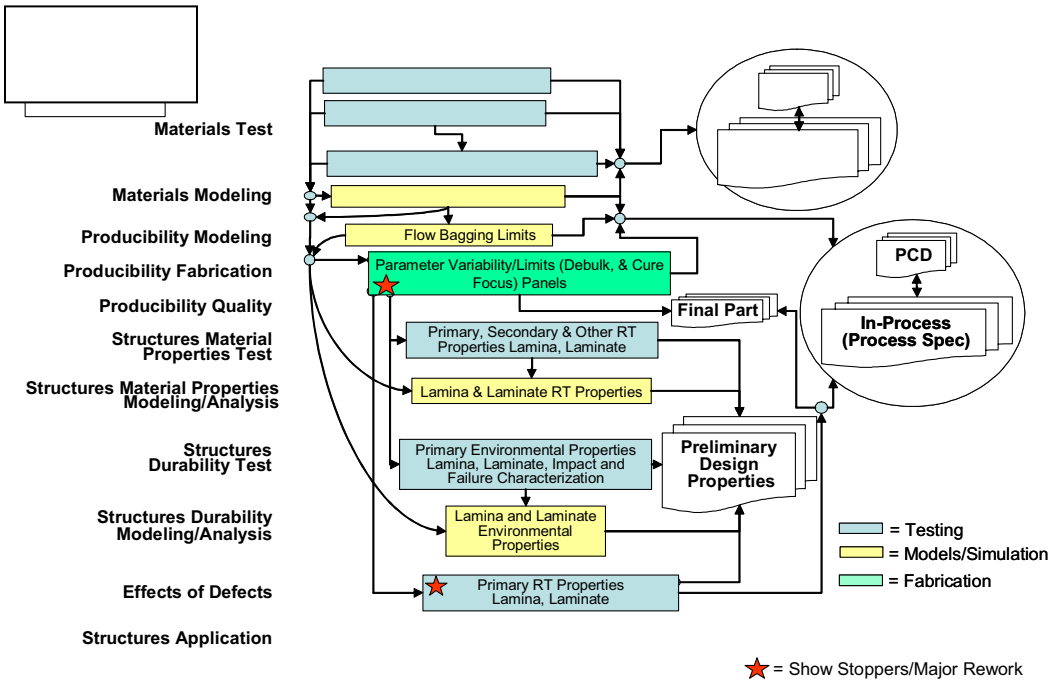


Figure A-21 Common Activities at TRL 3

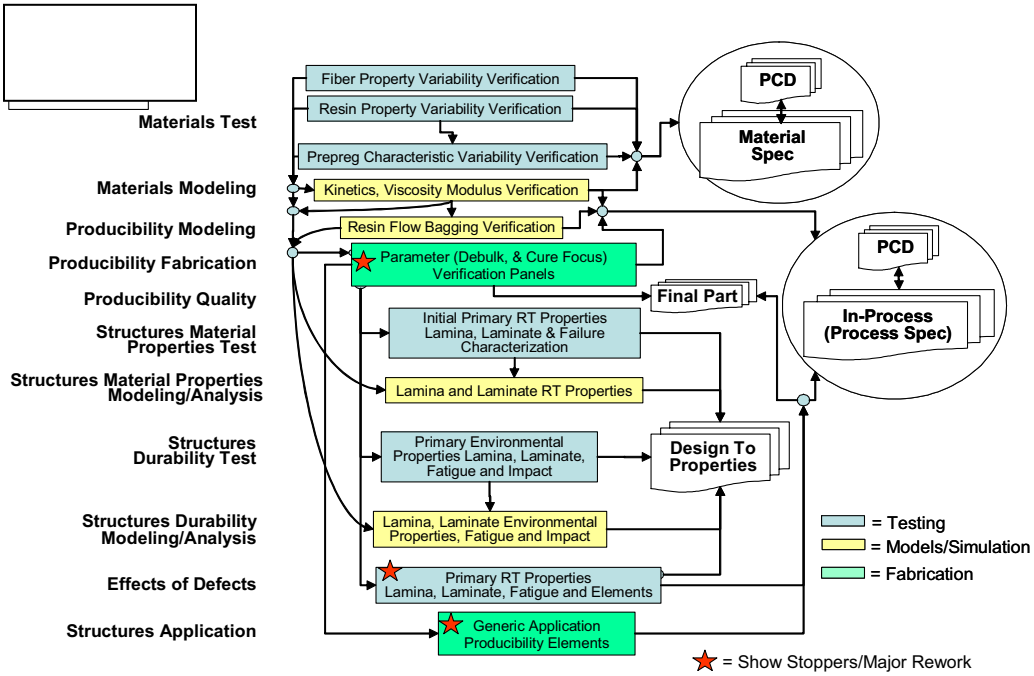


Figure A-22 Common Activities at TRL 4

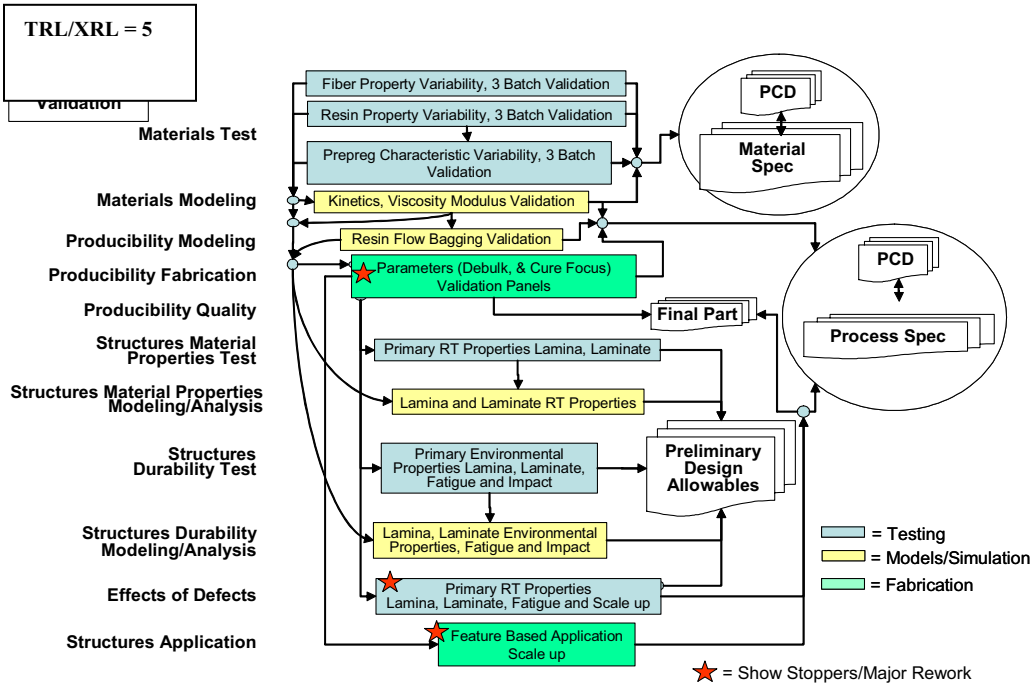


Figure A-23 Common Activities at TRL 5

Technology Readiness Level (TRL) Sheets

The qualification, certification and insertion of a material is a multi-disciplined process and encompasses requirements from each of their viewpoints. This requirements methodology approach addresses each of the primary discipline and areas that have inputs to the process. These primary disciplines and areas material and/or process requirements identification are *Certification, Design, Assembly, Structures, Materials, Fabrication, Cost Benefits, Supportability, and Intellectual Property*.

To establish a TRL chart, these primary multiple discipline areas and/or items associated with the problem/application statement and requirements are listed on the left side of a sheet. An example of this is shown in Figure A-24 for a new material qualification and certification.

Figure A-24 Primary Discipline/Areas Associated with Qualification and Certification

The next step would be to add maturity numbers across the top of the sheet going from 1 to 10 relative to technology maturity numbering. This would form a matrix sheet as shown in Figure A-25.

TRL	1	2	3	4	5	6	7	8	9	10
Application/ Design										
Certification										
Assembly/ Quality										
Structures & Durability										
Materials										
Fabrication/ Quality										
Supportability										
Survivability										
Cost/Schedule/ Benefits										
Intellectual Rights										

Figure A-25 Example Blank Matrix TRL Sheet

The TRL numbered blocks are filled in from a multi-disciplined perspective with specific exit criteria requirements. An example of this approach is shown for composites in Figure A-26. It was intended that each discipline would evaluate what requirements would have to be satisfied for a material insertion maturity assessment using this TRL chart with specific exit criteria.

TRL	1	2	3	4	5	6	7	8	9	10
Application/ Design	Concept Exploration	Concept Definition	Proof of Concept	Preliminary Design (Elements)	Design Maturation (Revised by Subcomponent Testing)	Revised by Component Testing	Revised by Ground Testing	Revised by Flight Test	Production Support	Recycle or Dispose
Certification	Certification Elements Documented	Certification Plan Documented	Certification Plan Approved	Elements	Subcomponent Testing	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test	Production Approval	Disposal Plan Approval
Assembly/ Quality	Assembly Concept	Assembly Plan Definition	Key Assembly Detail Definitions	Key Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled	Production	Disassembly for Disposal
Structures & Durability	Preliminary Properties-Characteristics	Initial Screening Properties (Lamina Data)	Design To Properties Developed (Laminate Data)	Preliminary Design Values	Final Design Allowables	Allowables for Critical Design Features	Production and Test Support	Certified Allowables	Flight Tracking/ Production Support/ Fleet Support	Retirement for Cause
Materials	Lab-Prototype Materials	Pilot Production Materials	Pre-Production Materials	Production Sacleability Validated	EMD Material Supplied	EMD Material Supplied	EMD Material Supplied	LRIP Material Supplied	Production Material Supplied	Support for Recycle or Disposal Decisions
Fabrication/ Quality	Unfeatured-Panel Fabrication	Feature Based Generic Small/Subscale Parts Fabricated	Property-Fab Relationships Tested/ Target Application Pilot Production of Generic Full Size Parts	Process Specs/ Effects of Fab Variations Tested/ Elements Fab'd/ Production Representative Parts Fab'd	Subcomponents Fab'd	Full Scale Components Fabricated	EMD Fabrication	Low Rate Initial Production (LRIP)	Production	Recycle or Disposal
Supportability	Repair Items/Areas Identified	Repair Materials & Processes Identified	Repair Materials & Processes Documented	Fab Repairs Identified	Fab Repair Trials/ Subcomponent Repairs	Component Repairs	Production Repairs Identified	Flight Qualified Repairs Documented	Repair-Replace Decisions	Support for Recycle or Disposal Decisions
Survivability	Requirements Definition	Concept Definition	Proof of Concept	Preliminary Design Data and Guidelines	Design Allowables and Guidelines Defined	Critical Details Testing	Ground Test	Flight Test	Production Support	Operations Support & Disposal
Cost/Schedule/ Benefits	Cost Benefit Elements ID'd & Projected	ROM Cost Benefit Analysis	Cost Benefit Analysis Reflect Size Lessons Learned	Cost Benefit Analysis Reflect Element and Production Representative Part Lessons Learned	Cost Benefit Analysis Reflect Subcomponent Fab & Assembly Lessons Learned	Cost Benefit Analysis Reflect Component Fab & Assembly Lessons Learned	Cost Benefit Analysis Reflect EMD Lessons Learned	Cost Benefit Analysis Reflect LRIP Lessons Learned	Cost Benefit Analysis Reflect Production Lessons Learned	Cost Benefit Analysis Reflect Disposal Lessons Learned
Intellectual Rights	Concept Documentation	Patent Disclosure Filed	Proprietary Rights Agreements	Data Sharing Rights	Vendor Agreements	Material and Fabrication Contracts	Production Rate Contracts	Vendor Requal Agreements	Post-Production Agreements	Liability Termination Agreements

Figure A-26 Example TRL Sheet with Exit Criteria

In summary, the process steps to create a TRL matrix sheet are highlighted below. This information then leads into more detailed requirements definition sheets for each of the primary areas, items or disciplines shown in the left had column.

<u>Create Technology Readiness Level (TRL) Matrix Sheet</u>

Purpose: Identify the multiple disciplines and areas involved with the problem statement and identify top level graduated maturity exit criteria for each

- In column 1, list the areas and/or disciplines involved with problem statement
- For columns 2 through 11, use a maturity scale of 1 to 10 for matrix column headings
- For each line area/discipline box going from 1 to 10, identify specific top level exit criteria requirements

X Readiness Level (XRL) Guides

When using this TRL table in a multi-disciplined team environment, it was found lacking as a tool to assess what had been completed for material insertion maturity for several disciplines. For example, materials could actually be divided into resin, fiber, prepreg, and adhesive which was not reflected in this chart. Another example was that fabrication could be broken down into the different methods and the methods relative to the materials. To get an accurate picture of the maturity level of materials and fabrication, other areas had to be taken into account such as equipment, tooling auxiliary processes, variability, etc. A number of these items were previously considered to be part of a production readiness assessment but really needed integration with the technical requirements and associated exit criteria. Additionally, the perspective of a system and technology readiness levels associated with the system created difficulties in communications with multiple disciplines because of semantics and multiple meanings to the same terminology. An alternative approach needed to be found to integrate disciplines into the top level TRL concepts to accommodate details from their perspectives.
The solution was establishing generic guides that could be used to generate specific XRL sheets for the different areas. These areas included structures, materials and fabrication/producibility. Details on these guides are in the next sections.

Structures XRL Guide

The structures guide was difficult to generate because of the large areas covered. The final form generated for the AIM-C Phase I program focused on various failure mode examinations for applicability along with property generation for materials and for durability investigations. This guide is shown in the following Figure A-27.

STRUCTURAL CHARATERISTIC **Date: 10/6/2003**

xRL	0	1	2	3	4	5	6	7	8	9
In-plane Ultimate Strength -- Unnotched Compression	Approximate design values based on at least 3 evaluation results at RT	Approximate design values based on at least 3 evaluation results at RT	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial Effects of defects analyses performed.	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods for off-design points.	Repair methods and approaches established and verified.
In-plane Ultimate Strength -- Unnotched Tension	Approximate design values based on at least 3 evaluation results at RT	Approximate design values based on at least 3 evaluation results at RT								
Ultimate Strength -- Combined Loads	N/A	N/A	Approximate bending and shear interaction from experience/past data		Bending and shear interaction from analysis using current data	Bending and shear interaction by validated analysis or data from similar concepts		Bending and shear interaction validated by element tests	Customer sign-off on data and methods. Component and Full-scale static test validation.	
In-plane Ultimate Strength -- Open Hole Compression	Approximate design values based on at least 3 evaluation results at RT, ET, and ET Wet	Approximate design values based on at least 3 evaluation results at RT, ET, and ET Wet	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
In-plane Ultimate Strength -- Open Hole Tension	Approximate design values based on at least 3 evaluation results at RT and low temp	Approximate design values based on at least 3 evaluation results at RT and low temp								
Ultimate Strength -- Open Hole, Combined Loads	N/A	N/A	Approximate bending and shear interaction from experience/past data		Bending and shear interaction from analysis using current data	Bending and shear interaction by validated analysis or data from similar concepts Initial effects of defects analyses performed		Bending and shear interaction validated by element tests	Customer sign-off on data and methods. Component and Full-scale static test validation.	
Stability - Global/Panel	Data (modulus) from similar system	Data (modulus) from similar system	Typical lamina vendor data. Laminate data by approx. analysis (e.g., CLPT). Layup, environmental, and statistical corrections from similar systems.	Typical lamina vendor data. Laminate data by approx. analysis (e.g., CLPT). Layup, environmental, and statistical corrections from similar systems.	Lamina modulus data sufficient to establish environmental and statistical corrections. Laminate data by approx. analysis (e.g., CLPT).	Laminate data sufficient to establish B-Basis values at all relevant environments. Analysis of typical areas (e.g., Eigenvalue buckling) Initial effects of defects analyses performed.	Laminate data sufficient to establish A-Basis values. Detailed Analysis of complex/ critical areas (e.g., NL FEA)	Critical areas validated by subcomponent test. Effects of manufacturing variations and defects analyzed.	Customer sign-off on data and methods. Component and Full-scale static test validation.	Repair methods and approaches established and verified.
Stability - Skin Buckling	Data (modulus) from similar system	Data (modulus) from similar system	Typical lamina vendor data. Laminate data by approx. analysis (e.g., CLPT). Layup, environmental, boundary conditions, and statistical corrections from similar systems.	Typical lamina vendor data tailored to available data. Laminate data by approx. analysis (e.g., CLPT). Layup, environmental, boundary conditions, and statistical corrections from similar systems.	Lamina modulus data sufficient to establish environmental and statistical corrections. Analysis uses more rigorous methods (FEM, Eigenvalue Extraction, etc)	Analysis of typical areas (e.g., Non-linear FEA, Eigenvalue buckling) verified by key features test. Initial effects of defects analyses performed.	Laminate data sufficient to establish A-Basis values if necessary. Detailed Analysis of complex/ critical areas (e.g., NL FEA)	Critical areas validated by subcomponent test. Effects of manufacturing variations and defects analyzed.	Customer sign-off on data and methods. Component and Full-scale static test validation.	Repair methods and approaches established and verified.
Stability - Stringer Crippling	Data (modulus) from similar system	Data (modulus) from similar system	Typical lamina vendor data. Laminate data by approx. analysis (e.g., CRIP). Layup, environmental, boundary conditions, and statistical corrections from similar systems.	Typical lamina vendor data tailored to available data. Crippling analysis by approx. methods (e.g., EBMCOL). Layup, environmental, boundary conditions, and statistical corrections from similar systems.	Lamina modulus data sufficient to establish environmental and statistical corrections. Analysis uses more rigorous methods (Eigenvalue Extraction, Non-Linear FEM, etc)	Analysis of typical areas (e.g., Non-linear FEA, Eigenvalue buckling) verified by key features test. Initial effects of defects analyses performed.	Laminate data sufficient to establish A-Basis values if necessary. Detailed Analysis of complex/ critical areas (e.g., NL FEA)	Critical areas validated by subcomponent test. Effects of manufacturing variations and defects analyzed.	Customer sign-off on data and methods. Component and Full-scale static test validation.	Repair methods and approaches established and verified.
Stability - Stringer Column Buckling	Data (modulus) from similar system	Data (modulus) from similar system	Typical lamina vendor data. Laminate data by approx. analysis (e.g., CRIP). Layup, environmental, boundary conditions, and statistical corrections from similar systems.	Typical lamina vendor data tailored to available data. Crippling analysis by approx. methods (e.g., EBMCOL). Layup, environmental, boundary conditions, and statistical corrections from similar systems.	Lamina modulus data sufficient to establish environmental and statistical corrections. Analysis uses more rigorous methods (Eigenvalue Extraction, Non-Linear FEM, etc)	Analysis of typical areas (e.g., Non-linear FEA, Eigenvalue buckling) verified by key features test. Initial effects of defects analyses performed.	Laminate data sufficient to establish A-Basis values if necessary. Detailed Analysis of complex/ critical areas (e.g., NL FEA)	Critical areas validated by subcomponent test. Effects of manufacturing variations and defects analyzed.	Customer sign-off on data and methods. Component and Full-scale static test validation.	Repair methods and approaches established and verified.
Bond/Interlaminar Joint Strength - Damage Initiation	Approximate design values based on experience. Data from similar system.	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Bond/Interlaminar Joint Strength - Final Failure	Approximate design values based on experience. Data from similar system.	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Bolted Joint - Bearing/Bypass	Approximate design values based on experience. Data from similar system.	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Maximum Deflection	Data (modulus) from similar system	Data (modulus) from similar system	Typical lamina vendor data. Laminate data by approx. analysis (e.g., CRIP). Layup, environmental, boundary conditions, and statistical corrections from similar systems.	Typical lamina vendor data tailored to available data. Crippling analysis by approx. methods (e.g., EBMCOL). Layup, environmental, boundary conditions, and statistical corrections from similar systems.	Lamina modulus data sufficient to establish environmental and statistical corrections. Analysis uses more rigorous methods (Eigenvalue Extraction, Non-Linear FEM, etc)	Analysis of typical areas (e.g., Non-linear FEA, Eigenvalue buckling) verified by key features test. Initial effects of defects analyses performed.	Laminate data sufficient to establish A-Basis values if necessary. Detailed Analysis of complex/ critical areas (e.g., NL FEA)	Critical areas validated by subcomponent test. Effects of manufacturing variations and defects analyzed.	Customer sign-off on data and methods. Component and Full-scale static test validation.	Repair methods and approaches established and verified.
Residual Strength -- BVID, Compression	Approximate design values based on experience. Data from similar system.	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Typical vendor data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Residual Strength -- Penetrations, Tension	Approximate design values based on experience. Data from similar system.	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Typical vendor data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Residual Strength -- Penetrations, Compression										
Residual Strength -- Penetrations, Combined Loads	N/A	N/A	Approximate bending and shear interaction from experience/past data		Bending and shear interaction from analysis using current data	Bending and shear interaction by validated analysis or data from similar concepts Initial effects of defects analyses performed		Bending and shear interaction validated by element tests	Customer sign-off on data and methods. Component and Full-scale static test validation.	
Local Stability - Face wrinkling (Sandwich Only)	Approximate design values based on experience. Data from similar system.	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Typical vendor data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Local Stability - Intracell Buckling (Sandwich Only)	Approximate design values based on experience. Data from similar system.	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Local Stability - Shear Crimping (Sandwich Only)	Approximate design values based on experience. Data from similar system.	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.

DURABILITY

STRUCTURAL CHARATERISTIC **Date: 10/6/2003**

xRL	0	1	2	3	4	5	6	7	8	9
Durability/Life - Microcracking	N/A	Approximate design values based on evaluations	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Durability/Life - Delamination Growth	N/A	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Durability/Life - Stiffness Degradation	N/A	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Durability/Life - Bearing Strength Degradation	N/A	Approximate design values based on experience. Data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environmental factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at critical design environment. Statistical basis from similar data	Data for 3 laminates, 3 batches. Layup, environmental, and statistical corrections from actual system.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method. Initial effects of defects analyses performed	Test data sufficient to establish A-Basis values where needed. Fully validated Analysis Method.	Effects of defects covering items such as oversized holes and short e/D. Fully validated Analysis Method.	Customer sign-off on open hole allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.

MATERIAL FAMILY PROPERTIES AND MATERIAL DURABILITY (Material Allowables, Coupon Level Evaluations)

STRUCTURAL CHARATERISTIC **Date: 10/6/2003**

xRL	0				4	5	6	7	8	9
Material Mechanical Properties - Primary (Tension, Compression, Shear, Bearing By-pass)	Approximate values based on experience/data from similar system.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	fo values based on initia c inate data at RT. Lay s initiated. Statistical similar systems.		s, 3 Layup and ns f al material cts ts analyses mer on lamina wabl	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Mechanical Properties - Secondary (CTE, Poisson's, Fracture Toughness,)	Approximate design values based on experience/data from similar system.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	App values based on initia fo inate data at RT. Lay c s initiated. Statistical similar systems.		s, 3 Layup and ns f al material cts ts analyses orm	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Mechanical Properties - Other ()	Approximate design values based on experience/data from similar system.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	A values based on initia f inate data at RT. Lay s initiated. Statistical similar systems.		s, 3 Layup and ns f al material cts ts analyses orm	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Environmental Impact on Properties	Approximate design values based on experience/data from similar system.	Approximate values based on at least 3 evaluation results at possibly low temp, ET and/or ET Wet plus data from similar systems. Other durability investigations initiated.	A values based on initia f inate data at environm La correlation activities in rom other similar syste		s, 3 batches. Layup and ns from actual material cts of defects analyses mer sign off on lamina wables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Impact Resistance and Fatigue	N/A	Approximate values based on experience/data from similar system.	sign values based on i Layup, environmental tions from similar syste		s, 3 batches. Layup and ns from actual material cts of defects analyses ormed.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Solvent Resistance	N/A	Approximate values based on evaluation results of solvent investigations	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Figure A-27 Generic Structures XRL Guide

Materials, Processing and Producibility XRL Guide

The guide for materials, processes and fabrication/producibility detailed requirements came about because of shortcomings in the requirements area for production readiness leading to qualification. The AIM-C program established a generic guide that could be used in defining specific exit criteria for different material, processing and fabrication/producibility areas.

Production readiness is normally associated with manufacturing/production equipment, tooling, and processes or methods. This definition has been expanded in the AIM-C program to cover all technology elements and would better be titled "Insertion" readiness because of this. A more detailed definition of production/insertion readiness is given in Figure A-28 and correlates with previous definitions of production readiness except with a larger perspective.

Definition

- The ability to adhere to appropriately documented processes/delineated procedures and to adequately record all pertinent information on what actually occurred for traceability.
- Paperwork includes procurement documents, specifications, process instructions (planning/work orders, travellers, quality techniques, etc.).
- Capital equipment needs and calibration/certification, tooling, personnel training, and process flow are typical elements.
- ISO 9000 methodologies should be used throughout the qualification process.
- It is important to establish a product dependability plan along the lines of ISO 9000-4.

Figure A-28 Production/Insertion Readiness Definition

By the previous definition, production/insertion readiness encompasses multiple areas besides production/manufacturing. Specific areas for the AIM-C program are shown in Figure A-29 and cover materials, analytical tools, design, manufacturing steps and repairs. These areas are expanded over the normal connotation of what production readiness covers. In practice, these areas are assessed for readiness but not usually under production readiness.

Assessment Areas

- **Primary Materials**
  - Resin
  - Fiber
  - Prepreg
- **Secondary Materials**
  - Adhesive
  - Core
  - Other
- **Analysis Tools**
- **Design**
  - Joints/Assembly
  - Features
  - Configuration
  - Application
- **Manufacturing Steps/ Operations**
  - Tooling
  - Cutting
  - Layup
  - Bagging
  - Cure
  - NDE
- **Repairs**

Figure A-29 Production/Insertion Readiness Assessment Areas

For each of the areas, there are a number of items that have to be addressed to give a complete picture of the readiness of a technology or area for insertion and usage. Figure A-30 shows representative items that are covered in an assessment of a technology area. These items cover most of the key aspects that have to be understood, evaluated or the metrics of for an assessment of where it is in a maturity or risk level.

Assessment Items

- **Production Processes**
- **Equipment**
- **Tooling**
- **Quality**
- **Variability**
- **Cost/Benefit Analysis**
- **Application Maturity**
- **Supportability**
- **Regulatory**
- **Intellectual Property**

Figure A-30 Requirement Readiness Assessment Items

These requirement assessment items were then incorporated into a generic maturity level matrix with example exit criteria to establish a guide. The guide can be used to develop specific XRL sheets for multiple areas in material, processing and fabrication/producibility. The generic sheet is shown in Figure A-31.

Material and Producibility xRL Guide

Date: 10/6/2003

(x)RL Rating	0			1	2		3		4	5	6 - 7	8 - 9	10
					2.1 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9					
MATERIAL	Material ingredients/ combinations never used previously.. No industrial base capability available. Constituent properties and compatibility issues unknown.	Material ingredients/combinations made in a laboratory environment. No industrial base capability available. Constituent properties and compatibility issues identified.	Key material ingredient characteristics identified for processing, quality, and application. Potential approaches identified to remedy incompatibilities.	Critical functions/ characteristics of material/ ingredients demonstrated. New material within state-of-the-art. Indirect material requirements identified. Facility requirements identified.	Proof-of-concept completed for production, properties, and scale-up of material under relevant conditions achieved (including resolving of material incompatibilities).	Material requirements/outputs OK based on models and/or prototypes and/or pilot plant in relavent environment. Marginal capacity (e.g., single source, offshore only, pilot plant, etc).	Material requirements tested in relevant environment. Scale-up and cost issues addressed. Adequate capacity for ingedients/material available in-house or in an industrial base (vendors). Certification requirements identified.	Material is repeatable, stable and storage requirements evaluated. Technical data packages and associated material proof tests completed. Materials and controls verified as sufficient to support scale-up, rate, cost, quality, and regulatory requirements.	Production readiness review accepts production material. All documentation is complete and training program for personnel complete for certification.	Successful prototype or low rate production of material achieved. Production readiness review accepts production material. Documentation/data package and training complete.	Successful production of less than 30 batches achieved.	Successful production of greater than 30 batches achieved.	Considered an industry standard.
PROCESSES	Requires technology never used previously. No industrial base capability available. Constituent properties and compatibility issues unknown.	Requires yields/tolerances/ throughput/scale not previously achieved. New process needed requiring state-of-the-art advance. Critical facility or vendor not available. Process compatibility issues identified.	Key characteristics identified for process, quality, and application. Potential approaches identified to remedy incompatibilities.	Critical functions/characteristics of processing demonstrated. New process operates within state-of-the-art. Facility requirements identified. Indirect materials or process steps identified.	Proof-of-concept completed for production, properties, and scale-up of process achieved under relevant conditions (including resolving of material incompatibilities). One or more requirements only marginally achievable.	Process requirements/outputs OK based on models and/or prototypes and/or pilot plant. Marginal capacity (e.g., single source, offshore only, etc).	Processing requirements tested in relevant environment including scale-up issues. Yields/tolerances/process controls meet needs and blessed by all functions. Process limits defined and tested. Production capability verified in operational environment (possibly for similar operational product). Qualification/certification requirements identified.	Yields/tolerances/process controls meet needs and blessed by all functions. Process limits defined and tested. Production capability verified in operational environment (possibly for similar operational product). Qualification/certification requirements identified.	Adequate capacity available in-house or in an industrial base (vendors). Processes and controls verified as sufficient to support scale-up, rate, cost, quality, and regulatory requirements.	Production readiness review accepts production processes. Documentation/data package and training complete.	Associated process proof tests completed. Successful use of process for less than 30 times achieved.	Successful use of process for greater than 30 times achieved.	Considered an industry standard
EQUIPMENT	Appropriate equipment does not exist and/or requirements are not known.	Necessary equipment requirements identified including key technology areas.	Key characteristics identified for process, quality, and application. Characteristics applicable to technology areas and individual equipment pieces.	Critical functions/ characteristics of individual equipment pieces demonstrated. Indirect materials and facility requirements identified. Equipment accuracy requirements defined.	Initial proof-of-concept testing completed including critical scale-up issues.	Integration of equipment parts/systems demonstrated.	Capabilities of integrated equipment tested in relevant environment including scale-up issues. Certification requirements identified.	Equipment accuracy and consistency verified for operational environment (possibly on similar operational product). Demonstrated integration of equipment into the users systems/facility.	Verified as sufficient to support scale-up, rate, cost, quality, and regulatory requirements. Successful production of test articles.	Production readiness review accepts equipment. Documentation, training and certification complete.	Associated process proof tests completed. Successful use of equipment for less than 30 times and/or less than 30 pieces of equipment achieved.	Sucessful use of equipment for greater than 30 times and/or greater than 30 pieces of equipment achieved.	Considered an industry standard
TOOLING	Appropriate tooling does not exist or requirements are not known.	Necessary tooling requirements identified and includes key technology areas.	Key characteristics identified for process, quality, and application. Characteristics applicable to technology areas and individual equipment pieces.	Critical functions/ characteristics of individual tooling pieces demonstrated. Indirect materials and facility requirements identified. Tooling accuracy requirements defined.	Initial proof-of-concept testing completed including scale-up issues.	Integration of tooling parts/details/systems demonstrated.	Capabilities of integrated tooling tested in relevant environment including scale-up issues. Certification requirements identified.	Tooling accuracy and consistency verified for operational environment (possibly on similar operational product). Integration of tooling into the users systems/facility demonstrated.	Verified as sufficient to support scale-up, rate, cost, quality, and regulatory requirements. Successful production of test articles.	Production readiness review accepts tooling. Documentation, training and certification complete.	Associated process proof tests completed. Successful use of tooling for less than 30 times and/or less than 30 tools achieved.	Sucessful use of tooling for greater than 30 times and/or greater than 30 tools achieved.	Considered an industry standard
VARIABILITY	Drivers of variability unknown or not understood.	Some items of variability identified.	Key drivers of variability identified. Methods of measuring identified.	Variabilities roughly characterized.	Variabilities measured with tests on representative samples/items and used as baseline capabilities. Proof-of-concept for scale-up variability issues identified.	Variability requirements OK based on models and/or prototypes and/or pilot plant.	Variabilities measured in relevant environment and includes scale-up issues.	Variabilities measured in operational environment and consistent with projections.	Verified as sufficient to support scale-up, rate, cost, quality, and regulatory requirements.	Production readiness review accepts procedures and capabilities for variability management. Variability control plan accepted and documentation complete.	Variability measured on less than 30 parts/items.	Variability measured on greater than 30 parts/items.	Considered an industry standard
QUALITY - IN-PROCESS	Requires technology never used in manufacturing previously. No industrial base capability available	Requires Q/A capability levels not previously achieved.	Key quality characteristics identified.	Critical quality functions/characteristics demonstrated. Indirect material and/or process steps identified. Facility requirements identified. Defects identified	Proof-of-concept for quality practices/procedures/techniques successfully demonstrated including scale-up issues.	Quality requirements/outputs OK based on models and/or prototypes. Defects evaluated.	Inspection and Q/C techniques defined and tested in relevant environment including scale-up issues. Results are blessed by all functions. Capability for use in production verified (possibly for similar operational product).	Quality, accuracy and consistency verified for an operational environment. Demonstrated integration of the quality functions into user systems/facility. Defect limits established	Quality procedures and techniques verified as sufficient to support scale-up, rate, cost, requirements, and regulatory requirements. Successful use on test articles.	Verified as sufficient to support scale-up, rate, cost, and regulatory requirements. Production readiness review accepts procedures and capabilities for final product quality assurance/control. Documentation, training, certification complete. Effects of defects known.	Quality techniques and procedures used for less than 30 final parts and quality acceptance.	Quality techniques and procedures used for greater than 30 final parts and quality acceptance.	Considered an industry standard.
QUALITY - FINAL PRODUCT	Requires technology never used in manufacturing previously. No industrial base capability available	Requires Q/A capability levels not previously achieved.	Key quality characteristics identified.	Critical quality functions/characteristics demonstrated. Indirect material and/or process steps identified. Facility requirements identified. Defects identified.	Proof-of-concept for quality practices/procedures/techniques successfully demonstrated including scale-up issues.	Quality requirements/outputs OK based on models and/or prototypes. Defects evaluated.	Inspection and Q/C techniques defined and tested in relevant environment including scale-up issues. Results are blessed by all functions. Capability for use in production verified (possibly for similar operational product). Generic sub-scale parts evaluated.	Quality, accuracy and consistency verified for an operational environment. Demonstrated integration of the quality functions into user systems/facility. Defect Limits established.	Quality procedures and techniques verified as sufficient to support scale-up, rate, cost, and regulatory requirements. Successful use on test articles. Production representative parts evaluated	Verified as sufficient to support scale-up, rate, cost, and regulatory requirements. Production readiness review accepts procedures and capabilities for final product quality assurance/control. Documentation, training, certification complete. Effects of defects known.	Quality techniques and procedures used for less than 30 final parts and quality acceptance.	Quality techniques and procedures used for greater than 30 final parts and quality acceptance.	Considered an industry standard.
APPLICATION MATURITY	New technology required; state-of-the art advance. One or more requirements may be unachievable.	Relevant unit problems identified, technologies understood and tested at unit level.	Primary functions/characteristics understood and demonstrated.	Critical functions/characteristics demonstrated; physical phenomena understood.	Component/breadboard successfully tested in relevant environments,OR, existing item requiring major modification tested. One or more requirements only marginally achievable.	Generic small-subscale prototype parts or engineering models successfully tested in relevant environments, OR, existing item requiring significant modification tested.	Prototype or engineering model successfully tested in relevant environments, OR, existing item requiring minor modification.	Uses individually qualified items which require integration, OR, successfully tested in an operational enviroment, OR, uses existing item, but qualification needed.	Qualification testing initiated.	Qualification testing successfully completed.	Design uses only fully qualified existing items. No added development/integration.	Developmental/initial operational testing successfully completed.	Physical and functional audits successfully completed
COST/BENEFIT ANALYSIS	Cost/benifits not known.	High level costs/benefits identified.	Costs/benefits defined.	Key costs/benifits have had a preliminary assessment for quantification.	Key costs/benifits have been shown in a relevant environment with scale-up.	Key costs/benifits have been shown with models and/or prototypes.	All cost benefits elements have been shown in a relavent environment.	All cost benefits elements have been validated in a representative environment.	All cost benefits elements verified in actual usage environment.	Cost/benefit analysis accepted by users for production readiness reviews.	Costs/benefits validated on less than 30 items.	Costs/benefits validated on greater than 30 items.	Costs/benefits understood at an industry level.
SUPPORTABILITY	Requires repair technology never used before. No capability available.	New repair processes requiring state-of-the-art advanced.	Key characteristics identified for repair processes.	Critical repair functions and characteristics demonstrated.	Proof-of-concept completed for repair procedures under relevant conditions including scale-up issues, OR, major modification of proven repair procedure completed.	Repair requirements OK based on models and prototypes, OR, significant modification of proven repair procedures completed.	Repair requirements tested in relevant environment including cost and scale-up issues, OR, minor modification of proven repair procedures.	Repair processes meet need (possibly based on experience on similar product), and blessed by all functions.		Repair procedures verified as sufficient to support operations.	Supportability readiness review accepts repair procedures.		
REGULATORY	Potential problems unknown.	Potential regulatory issues identified.	Federal, state, and local applicable regulations identified (i.e. OSHA, NIOSH, EPA, air, water, building, shipping, etc.).	Regulatory issues understood.	Potential approaches identified to eliminate regulatory concerns.	Initial proof-of-concept tests of potential approaches successfully completed.	Approaches to remedy regulatory problems successfully tested in a relevant environment.	Approaches to remedy regulatory problems successfully tested in a representative environment.	Approaches to remedy regulatory problems successfully tested in operational environment.	Qual tests (or equivalent) demonstrate satisfaction of regulatory requirements.	Meets all company SOP's, and accepted by regulatory agencies.		Considered an industry standard.
Intellectual Property		Proprietary material and process concepts identified.	Patent disclosures based on data drafted. Trademark and potential trade secret issues identified.	Reduction to practice in progress. Strategy to issue patents or preserve technology as trade secret accepted.	Patent Applications drafted. Trade secret practices in place.	Reduction to practice verified.	Patent applications completed and submitted with project approval.	Applications under review by patent office.	Applications updated after receiving remarks by the patent office.	Applications accepted by the patent office.		Patents issued.	Considered an industry standard.

Figure A-31 Generic Material, Processing and Fabrication/Producibility Guide

Activities for using the guides to establish specific XRL exit requirements are shown in Figure A-32.

3.0 xRL Flow

1. **Identify Items Associated with Each Primary Areas Involved with Objective**
   - **Include variability as an item for each primary area**
   - **Include quality characteristics relative to application or acceptance criteria as an item for each primary area**
2. **Identify sequential step-wise criteria going from conceptualization through disposal for each item**

INPUTS: Objective, Needs, and Customer plus TRL Matrix Chart
OUTPUTS: xRL Matrix Chart
METRICS: Increased Data and/or confidence and/or increased application complexity

Figure A-32 XRL Sheet Process Flow

Example Multiple Disciplined XRL Sheets

Example structures XRL sheets have been generated. Also, the following material, processing and fabrication/producibility technology items could each have an example XRL sheet generated for maturity tracking.

- Resin
- Fiber
- Prepreg
- Cutting
- Layup
- Bagging
- Cure

The steps for creation of these sheets are as follows.

- Create X Readiness Level (XRL) Matrix Chart (Where X represents an area/discipline in the TRL chart)
- Purpose: Establish detailed, graduated maturity exit criteria for each discipline/area identified in the TRL chart
- In column 1, list areas/items involved with each requirement area/discipline
- For columns 2 through 11, use a maturity scale of 1 to 10 for matrix column headings
- Identify specific exit criteria conformance to requirements for each area/item line box going from 1 to 10 in the matrix
- Utilize generic guides for structures, materials, processing, and producibility to identify specific exit criteria tailored for the problem/application statement-definition
- The structures guide is based on failure modes, durability, and material characteristics/properties
- The materials, processing and producibility guide is based on technical requirements and production readiness
- Utilize an approach of asking questions of whether the guide items apply to the problem/application statement-definition and if so, how for the individual line boxes
- Could be viewed from standpoint of increased information/data or fidelity or increased size or scale as maturity increases.

Example sheets are listed in the next sections.

TRL

TRL	1	2	3	4	5	6	7	8	9	10
Application/ Design	Concept Exploration	Concept Definition	Proof of Concept	Preliminary Design (Elements)	Design Maturation (Revised by Subcomponent Testing)	Revised by Component Testing	Revised by Ground Testing	Revised by Flight Test	Production Support	Recycle or Dispose
Certification	Certification Elements Documented	Certification Plan Documented	Certification Plan Approved	Elements	Subcomponent Testing	Full Scale Component Testing	Full Scale Airframe Tests	Flight Test	Production Approval	Disposal Plan Approval
Assembly/ Quality	Assembly Concept	Assembly Plan Definition	Key Assembly Detail Definitions	Key Assembly Details Tested	Subcomponents Assembled	Components Assembled	Airframe Assembled	Flight Vehicles Assembled	Production	Disassembly for Disposal
Structures & Durability	Preliminary Properties-Characteristics	Initial Screening Properties (Lamina Data)	Design To Properties Developed (Laminate Data)	Preliminary Design Values	Final Design Allowables	Allowables for Critical Design Features	Production and Test Support	Certified Allowables	Flight Tracking/ Production Support/ Fleet Support	Retirement for Cause
Materials	Lab-Prototype Materials	Pilot Production Materials	Pre-Production Materials	Production Sacleability Validated	EMD Material Supplied	EMD Material Supplied	EMD Material Supplied	LRIP Material Supplied	Production Material Supplied	Support for Recycle or Disposal Decisions
Fabrication/ Quality	Unfeatured-Panel Fabrication	Feature Based Generic Small/Subscale Parts Fabricated	Property-Fab Relationships Tested/ Target Application Pilot Production of Generic Full Size Parts	Process Specs/ Effects of Fab Variations Tested/ Elements Fab'd/ Production Representative Parts Fab'd	Subcomponents Fab'd	Full Scale Components Fabricated	EMD Fabrication	Low Rate Initial Production (LRIP)	Production	Recycle or Disposal
Supportability	Repair Items/Areas Identified	Repair Materials & Processes Identified	Repair Materials & Processes Documented	Fab Repairs Identified	Fab Repair Trials/ Subcomponent Repairs	Component Repairs	Production Repairs Identified	Flight Qualified Repairs Documented	Repair-Replace Decisions	Support for Recycle or Disposal Decisions
Survivability	Requirements Definition	Concept Definition	Proof of Concept	Preliminary Design Data and Guidelines	Design Allowables and Guidelines Defined	Critical Details Testing	Ground Test	Flight Test	Production Support	Operations Support & Disposal
Cost/Schedule/ Benefits	Cost Benefit Elements ID'd & Projected	ROM Cost Benefit Analysis	Cost Benefit Analysis Reflect Size Lessons Learned	Cost Benefit Analysis Reflect Element and Production Representative Part Lessons Learned	Cost Benefit Analysis Reflect Subcomponent Fab & Assembly Lessons Learned	Cost Benefit Analysis Reflect Component Fab & Assembly Lessons Learned	Cost Benefit Analysis Reflect EMD Lessons Learned	Cost Benefit Analysis Reflect LRIP Lessons Learned	Cost Benefit Analysis Reflect Production Lessons Learned	Cost Benefit Analysis Reflect Disposal Lessons Learned
Intellectual Rights	Concept Documentation	Patent Disclosure Filed	Proprietary Rights Agreements	Data Sharing Rights	Vendor Agreements	Material and Fabrication Contracts	Production Rate Contracts	Vendor Requal Agreements	Post-Production Agreements	Liability Termination Agreements

Figure A-35 Example TRL Sheet

XRL

Structures

MATERIAL FAMILY PROPERTIES AND MATERIAL DURABILITY (Material Allowables, Coupon Level Evaluations)

Date: 10/6/2003

xRL	0	1	2	3	4	5	6	7	8	9
Primary Mechanical Property - Tension (strength, modulus, strain to failure)	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for lamina and laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at a RT design environment. Statistical basis from similar material data	st ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Primary Mechanical Property - Compression (strength, modulus, strain to failure)	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for lamina and laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at a RT design environment. Statistical basis from similar material data	st ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Primary Mechanical Property - Shear (strength, modulus, strain to failure)	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for lamina and laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at a RT design environment. Statistical basis from similar material data	st Initial Cu ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Primary Mechanical Property - Bearing Bypass (strength, strain to failure)	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at a RT design environment. Statistical basis from similar material data	Data statistic Initial Cu ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Secondary Mechanical Property - CTE	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for lamina and laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at a RT design environment. Statistical basis from similar material data	Data statistic Initial Cu ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Secondary Mechanical Property - Poissons 1	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for lamina and laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at a RT design environment. Statistical basis from similar material data	Data statistic Initial Cu ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Secondary Mechanical Property - Fracture Toughness	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for lamina and laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at a RT design environment. Statistical basis from similar material data	Data statistic Initial Cu ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Secondary Mechanical Property - CME	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for lamina and laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at a RT design environment. Statistical basis from similar material data	Data statistic Initial Cu ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Mechanical Properties - Other ()	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at RT plus data from similar systems	Approximate design values based on initial tests of 3 panels for lamina and laminate data at RT. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates at a RT design environment. Statistical basis from similar material data	Data statistic Initial Cu ates, 3 batches. Layup and s from actual material system. efects analyses performed. off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.

Figure A-36 Example Structures XRL Sheet

MATERIAL FAMILY PROPERTIES AND MATERIAL DURABILITY (Material Allowables, Coupon Level Evaluations)

Date: 10/6/2003

xRL	0	1	2	3	4	5	6	7	8	9
Material Durability/Life Properties - Enviromental (Temperature and Humditiy) Impact - Tension (strength, modulus, strain to failure)	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at possibly low temp, ET and/or ET Wet plus data from similar systems.	Approximate design values based on initial tests of 3 panels for lamina and laminate data at environmental conditions. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at environmental conditions. Statistical basis from similar material data	Data for 3 laminates, 3 batches. Layup and statistical corrections from actual material system. Initial effects of defects analyses performed. Customer sign off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Enviromental (Temperature and Humditiy) Impact - Compression (strength, modulus, strain to failure)	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at possibly low temp, ET and/or ET Wet plus data from similar systems.	Approximate design values based on initial tests of 3 panels for lamina and laminate data at environmental conditions. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at environmental conditions. Statistical basis from similar material data	Data for 3 laminates, 3 batches. Layup and statistical corrections from actual material system. Initial effects of defects analyses performed. Customer sign off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Enviromental (Temperature and Humditiy) Impact - Shear (strength, modulus, strain to failure)	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at possibly low temp, ET and/or ET Wet plus data from similar systems.	Approximate design values based on initial tests of 3 panels for lamina and laminate data at environmental conditions. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at environmental conditions. Statistical basis from similar material data	Data for 3 laminates, 3 batches. Layup and statistical corrections from actual material system. Initial effects of defects analyses performed. Customer sign off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Enviromental (Temperature and Humditiy) Impact - Bearing By-pass (strength, strain to failure)	Approximate values based on experience/data from similar systems.	Approximate values based on at least 3 evaluation results at possibly low temp, ET and/or ET Wet plus data from similar systems.	Approximate design values based on initial tests of 3 panels for lamina and laminate data at environmental conditions. Layup and statistical correlation activities initiated. Statistical basis from other similar systems.	Data for at least 3 laminates, 3 replicates, and 3 layups at environmental conditions. Statistical basis from similar material data	Data for 3 laminates, 3 batches. Layup and statistical corrections from actual material system. Initial effects of defects analyses performed. Customer sign off on lamina allowables.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Thermal Cycle Evaluations	Approximate design values based on experience/data from similar systems.	Approximate design values based on at least 3 evaluation results of thermal aging times, temperatures, and/or cycles	Approximate design values based on initial tests of 3 panels for lamina and laminate data at environmental conditions. Layup and statistical correlation activities initiated. Statistical basis form other similar systems.	Data for at least 3 laminates, 3 replicates at environmental conditions. Statistical basis from similar material data	Data for 3 laminates, 3 batches. Layup and statistical corrections from actual material system. Initial effects of defects analyses performed.	Effects of defects covering items such as oversized holes and short e/D. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Impact Resistance	N/A	Approximate design values based on experience/data from similar system.	Approximate design values based on initial tests of 3 laminates at RT. Environemntal factors and statistical factors based on data from similar systems. Layup, environmental, and statistical corrections from similar systems.	Data for at least 3 laminates, 3 replicates at environmental conditions. Statistical basis from similar material data	Data for 3 laminates, 3 batches. Layup and statistical corrections from actual material system. Initial effects of defects analyses performed.	Effects of defects. Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.		Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties Coupon Fatigue	N/A	N/A	Approximate design values based on initial tests of 3 panels for lamina and laminate data at environmental conditions. Layup and statistical correlation activities initiated. Statistical basis form other similar systems.	Data for at least 3 laminates, 3 replicates at environmental conditions. Statistical basis from similar material data	Data for 3 laminates, 3 batches. Layup and statistical corrections from actual material system.	Effects of defects covering items such as oversized holes and short e/D. Initial effects of defects analyses performed.	Test data sufficient to establish B-Basis values. Fully validated Analysis Method.	Test data sufficient to establish A-Basis values where needed.	Customer sign-off on all allowables and relevant analysis methods and numerical models.	Repair methods and approaches established and verified.
Material Durability/Life Properties - Solvent Resistance	N/A	Approximate design values based on at least 3 evaluation results of solvent investigations	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Figure A-37 Example Structures XRL Sheet, Continued

Materials – Resin

RESIN READINESS LEVEL (xRL) **Date: 10/6/2003**

	LABORATORY PRODUCT				PILOT PLANT PRODUCT		PRE-PRODUCTION PRODUCT		PRODUCTION PRODUCT		
(x)RL Rating	0		1		2		3		4	5	6 - 7
					2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9			
EXAMPLE PROPERTIES/ CHARACTERISTICS/ ACTIVITIES			• Viscosity and chemical tests plus volatiles on resin components and mixed liquid resin, Reaction kinetics (time/temperature profile), • Cured neat resin Tg-modulus-CTE-density tests, Initial lab prepregging performed and evaluated for translation of resin properties into composite	• Continued viscosity and chemical tests plus volatiles on resin components and mixed liquid resin, Reaction kinetics (time/temperature profile), • Cured neat resin Tg-modulus-CTE-density tests, moisture absorption, toxicity, fluid resistance, thermal decomposition in air, K1C, Flex at RT and ET • Preliminary ingredient inbalence studies	• moisture absorption, toxicity, fluid resistance, thermal decomposition in air, K1C, Flex at RT and ET Ingredient variations and storage evaluations using viscosity and chemical tests plus volatiles on resin components and mixed liquid resin, •Test on lab scale with relavant fiber or fabric for interfacial affects	Ingredient variations and storage evaluations using reaction kinetics (time/temperature profile), • Ingredient variations and storage evaluations using cured neat resin Tg-modulus-CTE-density tests, specific specialized tests as identified and conducted, K1C, Flex at RT and ET	Multiple lots and batches but not systematic evaluations, Continued testing with mechanicals Majority of testing from this point on is done in next higher level of material	Refine impregnation conditions flow vs temp profile of uncured resin as well as final cure recommendations	Multiple lot and batch test plan, Continued testing with mechanicals	Multiple lots and batches in a systematic approach, Continued testing with mechanicals	
MATERIAL INFORMATION			Preliminary testing, liquid components and mixed resin, cured neat resin cured composite with model reinforcement	Additional testing, liquid components and mixed resin, cured neat resin and cured composite with model reinforcement system	Additional cured resin testing begin testing on specific relavant fiber or fabric for further translation testing	Mass sensitivities investigated, Ingredient storage studies, Alternative suppliers investigated,	Used in multiple lots of prepreg (next higher level of product) Majority of testing done on prepreg from this point on	Multiple lots and batches but not systematic evaluations, Continued testing with mechanicals	Multiple lot and batch test plan, Continued testing with mechanicals	Multiple lots and batches in a systematic approach, Continued testing with mechanicals	
PROCESSES	Material Concept Identified	Concept Attempted with Lab/Experimental Number	Key steps ID'd and evaluated (I.e. weighing, mixing, heating, etc.), Processes conducted in a laboratory environment	Mixing times, temperatures, pressures and sequencing established, Packaging and storage requirements ID'd, Processes conducted in a laboratory environment	first scale up beyond lab reactors Time, temperature, pressure impacts evaluated, Indirect materials ID'd-checked for compatibility, Preliminary PCD established	Processes conducted in production relevent environment	Time, temperature, pressure impacts checked, Indirect materials ID'd-checked, PDC documented	Processes conducted in operational environment, Final PCD approved for production, processes validated			
EQUIPMENT			Laboratory reactors/mixing, Special requirements ID'd,	Laboratory reactor/mixing of product with possible initial pilot reactor use Lab prepregging to test for translation of properties	Reactor/mixing requirements ID'd, Indirect materials ID'd-checked for compatibility,	Intermediate sized reactor/mixing for product, Scale-up issues ID'd, Elements evaluated, Qualification requirements established,	Full scale reactor/mixing for product	Maintenance requirements and schedules established, Approved for production			
TOOLING			Special tooling ID'd					Approved for production			
VARIABILITY			Variability items ID'd, Measurement methods ID'd	Preliminary ingredient imbalance studies,	Ingredient and product storage studies started,	Expanded imbalance studies, Qualification requirements established,	Control variables established, PDC documented	Control variables validated, Final PCD approved, Measurement processes in place,			
QUALITY - IN-PROCESS			Requirements ID'd, Control methods ID'd,	PCD control items ID'd, Preliminary metrics established,	Control limits investigated	Preliminary control limits validated	Control limits established, PDC documented,	Control limits validated, Final PCD approved,			
QUALITY - FINAL PRODUCT			Quality items ID'd,	Defect items ID'd, Preliminary quality metrics established,	Effects of defects investigated	Preliminary effects of defects defined,	Draft material specification buy-off	Final material specification	Material specification approved,	Material specification validated	
APPLICATION MATURITY			Neat resin evaluations, Key cure characteristics/ requirements ID'd	Product used to make next higher level product form in a laboratory environment, Flat and ramped panels, Some lamina panels/properties	Product used to make next higher level product form in a relevant environment, Flat-multiple thickness and ramped panels,	Generic featured parts fab'd, Flat multiple thickness panels, Some laminate properties, Preliminary wet information	Product used to make next higher level product form in an operational environment, Flat and ramped panels	Design to properties, Generic scale up parts fab'd	Product used to make next higher level product form in an operational environment,	Multi batch qualification complete, Production representative parts fab'd,	
COST/BENEFIT ANALYSIS			Cost elements ID'd	Costs projected	Costs tracked vs Projected	Costs tracked to projected				Costs tracked to projected	
REGULATORY			Ingredient family known for MSDS	Specific MSDS Issued for material, Environmental check for solvents,	Shipping and handling ID'd	Monitored Health and Safety, Solvents controlled,	Shipping and handling ID'd	Monitored Health and Safety, Solvents controlled,		Health and Safety and environmental documented,	
Intellectual Property			PIA drafted	PIA signed							

Figure A-38 Example Materials-Resin XRL Sheet

Materials – Fiber

FIBER READINESS LEVEL (xRL) **Date: 10/6/2003**

	LABORATORY PRODUCT				PILOT PLANT PRODUCT		PRE-PRODUCTION PRODUCT		PRODUCTION PRODUCT		
(x)RL Rating	0			1	2		3		4	5	6 - 7
					2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9			
MATERIAL INFORMATION					tensile strength and modulus, yeild, of first pilot lots of fiber	tensile strength and modulus as well as yield on first exoperimental production lots	repeat of production lots data generated in next higher form of material ie in prepreg material	repaetability of properties including composite properties demonstrated by multiple production lots	initial qualifiaction testing underway. Expanded test matrix to demonstrate all relevant properties	Fiber qualification complete for coupon testing	
PROCESSES			determine material and processes such as precursor material sizing and shear treatments as well as temperatures and pressures for spinning and Carbonization	Time, temperature, pressure impacts evaluated, Indirect materials ID'd-checked for compatibility,	Processes conducted in a relavent environment,	Initial attempts on production equipment	repeat of production on production equipment Initial PCD in place	PCD refined			
EQUIPMENT			lab and pilot equipment	lab and pilot equipment	pilot and initial small production use	pilot and initial small production use	Maintenance requirements and schedules established, Approved for production	Production equipment utilized exclusively			
TOOLING											
VARIABILITY			Variability items ID'd, Measurement methods ID'd	Preliminary ingredient imbalance studies,	Ingredient and product storage studies started,	Expanded imbalance studies, Qualification requirements established,	Control variables established, PDC documented	Control variables validated, Final PCD approved, Measurement processes in place,			
QUALITY - IN-PROCESS			Requirements ID'd, Control methods ID'd,	PCD control items ID'd, Preliminary metrics established,	Control limits investigated	Preliminary control limits validated	Control limits established, PDC documented,	Control limits validated, Final PCD approved,			
QUALITY - FINAL PRODUCT			Quality items ID'd,	Defect items ID'd, Preliminary quality metrics established,	Effects of defects investigated	Preliminary effects of defects defined,	Draft material specification buy-off	Final material specification	Material specification approved,	Material specification validated	
APPLICATION MATURITY				Product used to make next higher level product form in a laboratory environment, Flat and ramped panels, Some lamina panels/properties	Product used to make next higher level product form in a relavent environment, Flat-multiple thickness and ramped panels,	Generic featured parts fab'd, Flat multiple thickness panels, Some laminate properties, Preliminary wet information	Product used to make next higher level product form in an operational environment, Flat and ramped panels	Design to properties, Generic scale up parts fab'd	Product used to make next higher level product form in an operational environment,	Multi batch qualification complete, Production representative parts fab'd,	
COST/BENEFIT ANALYSIS			Cost elements ID'd	Costs tracked to projected		Costs tracked to projected				Costs tracked to projected	
REGULATORY			Ingredient family known for MSDS	Specific MSDS Issued for material, Environmental check for solvents,	Shipping and handling ID'd	Monitored H&S, Solvents controlled,	Shipping and handling ID'd	Monitored H&S, Solvents controlled,		H&S and environmental documented,	
Intellectual Property			PIA drafted	PIA signed							

Material Concept Identified

Concept Attempted with Lab/Experimental Number

Figure A-38 Example Materials-Fiber XRL Sheet

Materials – Prepreg

PREPREG READINESS LEVEL (xRl Date: 10/6/2003

	LABORATORY PRODUCT				PILOT PLANT PRODUCT		PRE-PRODUCTION PRODUCT		PRODUCTION PRODUCT		
(x)RL Rating	0			1	2		3		4	5	6 - 7
					2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9			
EXAMPLE PROPERTIES/ CARACTERISTICS/ ACTIVITIES				• Viscosity and chemical tests and kinetic test plus volatiles on neat resin and prepreg resin, • Prepreg resin content and fiber areal weight, tack and drapability and resin flow evaluations. • Cured prepreg panel per ply thickness, Tg (dry, wet), density, 0° Tension (RT), 0° Compression (RT), ILS (RT, ET, ET wet), micrographs	• Viscosity and chemical tests and kinetic test plus volatiles on neat resin and prepreg resin, • Prepreg resin content and fiber areal weight, tack and drapability and resin flow evaluations. • Cured prepreg panel per ply thickness, Tg (dry, wet), density, 0° Tension (RT), 0° Compression (RT), ILS (RT, ET, ET wet), OHC-laminate (RT), Solvent resistance, Moisture absorption, G1C, Micrographs	• Test data reduction/accumulation for statistical for variability and statistical evaluations • Resin content variailton effect on mechanical properties • Effect of defect cured prepreg panel per ply thickness, Tg (dry, wet), density, 0° Tension (RT), 0° Compression (RT), ILS (RT, ET, ET wet), OHC-laminate (RT), micrographs • ILS (RT, ET, ET wet) for out time and freezer time evaluations • Decomposition in air, Thermal cycle, Thermal spike, Heat damage, Microcracking, Micrographs	• Viscosity and chemical tests and kinetic test plus volatiles on neat resin and prepreg resin, • Prepreg resin content and fiber areal weight, tack and drapability and resin flow evaluations. • Cured prepreg panel per ply thickness, Tg (dry, wet), density, 0° Tension (RT), 0° Compression (RT), ILS (RT, ET, ET wet), OHC-laminate (RT), micrographs	• Multiple lots and batches but not systematic evaluations, • Viscosity and chemical tests and kinetic test plus volatiles on neat resin and prepreg resin, • Prepreg resin content and fiber areal weight, tack and drapability and resin flow evaluations. • Cured prepreg panel per ply thickness, Tg (dry), density, 0° Tension (RT), 0° Compression (RT), ILS (RT, ET, ET wet), OHC-laminate (RT), micrographs	• Cured prepreg panel per ply thickness, Tg (dry), density, 0° Tension (RT), 0° Compression (RT), ILS (RT, ET, ET wet), OHC-laminate (RT), micrographs Initial pilot parts made and tested in relavent environment in ground tests	• Multiple lots and batches in a systematic approach, • Viscosity and chemical tests and kinetic test plus volatiles on neat resin and prepreg resin, • Prepreg resin content and fiber areal weight, tack and drapability and resin flow evaluations. • Cured prepreg panel per ply thickness, Tg (dry), density, 0° Tension (RT), 0° Compression (RT), ILS (RT, ET, ET wet), OHC-laminate (RT), micrographs	
MATERIAL INFORMATION			Very preliminary bench prepregging opertions of neat resin onto a fiber tow on a bench for initial investigations.	Preliminary testing of mixed resin, prepreg and cured panels from prepreg	More extensive testing on cured panels work from optimum formulation	Mass sensitivities investigated, Ingredient storage studies, Alternative suppliers investigated, Define prepreg PCD	Prepreg PCD in place allowables testing begun	Complete allowables testing on panels and coupons.	Initial pilot parts. Parts processing optimized Parts tested in flight type environment	Multiple lots and batches in a systematic approach, Continued testing with mechanicals	
PROCESSES			Key steps ID'd and evaluated (I.e. filming/solvent impregnation, prepregging, etc.), Processes conducted in a laboratory environment	Times, temperatures, pressures and sequencing established, Packaging and storage requirements ID'd, Processes conducted in a laboratory environment	Processes conducted in a relavent environment, Time, temperature, pressure impacts evaluated, Indirect materials ID'd-checked for compatibility,	Processes conducted in a relavent environment,	Time, temperature, pressure impacts checked, Indirect materials ID'd-checked, PDC documented	Processes conducted in operational environment, Final PCD approved for production, processes validated			
EQUIPMENT			Laboratory/bench impregnation, Special requirements ID'd,	initial use of pilot prepregging equipment for product	Filming/prepregging requirements ID'd, Indirect materials ID'd-checked for compatibility, Spool requirments	Intermiediate sized filming/prepregging equipment for product, Scale-up issues ID'd, Elements evaluated, Qualification requirements established,	Full scale filming/prepregging for product, All equipment ID for production qualification, Spool requirements ID'd	Maintenance requirements and schedules established, Approved for production			
TOOLING			Special tooling ID'd					Approved for production			
VARIABILITY			Variability items ID'd, Measurement methods ID'd	Preliminary imbalance studies,	Product storage studies started,	Expanded variability studies, Qualification requirements established,	Control variables established, PDC documented	Control variables validated, Final PCD approved, Measurement processes in place,			
QUALITY - IN-PROCESS			Requirements ID'd, Control methods ID'd,	PCD control items ID'd, Preliminary metrics established,	Control limits investigated	Preliminary control limits validated	Control limits established, PDC documented,	Control limits validated, Final PCD approved,			
QUALITY - FINAL PRODUCT			Quality items ID'd,	Defect items ID'd, Preliminary quality metrics established,	Effects of defects investigated	• Preliminary effects of defects defined, • Out time and freezer time evaluations	Draft material specification buy-off	Final material specification	Material specification approved,	Material specification validated	
APPLICATION MATURITY			Neat resin evaluations, Key cure characteristics/ requirements ID'd	Flat and ramped panels, Some lamina panels/properties initial coupon testing	Flat-multiple thickness and ramped panels, further coupon testing	Continued coupon testing and initial generic featured parts fab'd, Flat multiple thickness panels, Some laminate properties, Preliminary wet information	Flat and ramped panels	Design allowables complete, Generic scale up parts fab'd	Product used to make components in an operational environment, Flat and ramped panels	Multi batch qualification complete, Production representative parts fab'd,	
COST/BENEFIT ANALYSIS			Cost elements ID'd	Costs tracked to projected		Costs tracked to projected				Costs tracked to projected	
REGULATORY			Ingredient family known for MSDS	Specific MSDS Issued for material, Environmental check for solvents,	Shipping and handling ID'd	Monitored H&S, Solvents controlled,	Shipping and handling ID'd	Monitored H&S, Solvents controlled,		H&S and environmental documented,	
Intellectual Property			PIA drafted	PIA signed							

Material Concept Identified

Concept Attempted with Lab/Expermental Number

Figure A-40 Example Materials-Prepreg XRL Sheet

Fabrication/Producibility – Cutting

HAND CUTTING (x)RL Criteria Conformance Summar Date: 10/6/2003

(x)RL Rating	0	1	2		3		4	5
			2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9		
PART MATERIAL	Environmental conditions defined from neat resin evaluations. Fiber cutting requirements identified.	Prepreg spool size and weight information, Indirect material identification (backing paper information and separator information if used),	Prepreg spool and weight information, preliminary material out time evaluations		Prepreg spool and weight information, formalized out time limits evaluations		Prepreg spool and weight information	
CUTTING PROCESSES		Backing/separator paper slivers with cutting, Tack evaluations for separator application	Preliminary out time evaluations for cutting and separator use,	Indirect material compatibility with resin,	Formalized out time limits evaluations for cutting started, Formalized freezer time evaluations for cutting started, Preliminary process specification,	Indirect material compatibility over time completed, Production spool requirements ID'd	Process specification,	Process specification validated
CUTTING FACILITIES	Cutting area environmental requirements ID'd	Cutting done in laboratory environment	Cutting done in relevant environment,	Cutting done in relevant environment,	Cutting done in operational environment,	Cutting done in operational environment,	Cutting done in operational environment,	Cutting done in operational environment,
CUTTING EQUIPMENT		Spool handling equipment ID'd, if required	Spool handling equipment ID'd		Spool handling equipment ID'd	Spool handling equipment ID'd	Spool handling equipment ID'd	
TOOLING for CUTTING		Templates/straight edges, hand tools (knives)	Templates/straight edges	Templates/straight edges	Templates/straight edges	Templates/straight edges	Templates/straight edges	Templates/straight edges
CUTTING VARIABILITY		x and y dimensions, angle, environment conditions, tack, tooling, indirect matrrials	Cutting validated with any material change, x and y dimensions, angle, environment conditions	x and y dimensions, angle, environment conditions	Cutting validated with any material change, Control variables established,			
CUTTING QUALITY - IN-PROCESS		Measured length-width of cut plies to template length and width, Angle measured to fiber direction, Slivers with cutting, logged times and temperatures,	Measured length-width of cut plies to template length and width, Angle measured to fiber direction, Slivers with cutting, logged times and temperatures,	Measured length-width-angle greater than 30 times,	Control limits established, Ply identification-marking-storage methods ID'd, Preliminary process specification,	Control limits validated	Quality plan, Process specification	Process specification validated
QUALITY - FINAL PRODUCT		Cutting size and angle tolerance, Slivers with cutting; x, y, and angle accuracy	Indirect material size NDE detectability, Sliver detectability if applicable; x, y, and angle accuracy	Indirect material size NDE detectability, Sliver detectability if applicable; x, y, and angle accuracy	Preliminary process specification,		Quality plan, Process specification	Process specification validated
APPLICATION MATURITY	Neat resin,	Flat and ramped panels fab'd	Multiple thickness flat panels, ramped panels,	Generic featured parts fab'd	Multiple thickness flat panels, ramped panels,	Generic scale up parts fab'd	Multiple thickness flat panels, ramped panels,	Production representative parts
COST/BENEFIT ANALYSIS								
REGULATORY		Spool sizes, weights and handling, MSDS handling requirements,	Spool sizes and handling,		Spool sizes and handling,		Spool sizes and handling,	
Intellectual Property								

Figure A-41 Example Fabrication/Producibility Cutting XRL Sheet

Fabrication/Producibility – Hand Layup

HAND LAYUP (x)RL Criteria Conformance Summary Date: 10/6/2003

(x)RL Rating	0	1	2		3		4	5
			2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9		
PART MATERIAL	Environmental conditions defined from neat resin evaluations	Indirect material identification (Backing paper information, separator information if used),	Preliminary material out time evaluations		Formalized out time limits evaluations	Prepreg	Prepreg	Prepreg
LAYUP PROCESSES		Backing paper removal evaluations, Separator removal evaluations, Tack evaluations, Ply removal evaluations, Indirect material identification,	Backing paper removal evaluations, Separator removal evaluations, Tack evaluations, Ply removal evaluations, Preliminary out time evaluations, Investigations of indirect material compatability with resin/plies,	Indirect material compatibility with resin, Layup done in relevant environment,	Formalized out time limits evaluations for layup tack started, Formalized freezer time evaluations for layup tack started, Preliminary process specification, Layup done in operational environment,	Indirect material compatibility over time completed, Layup done in operational environment,	Process specification, Layup done in operational environment,	Layup done in operational environment, Process specification validated
LAYUP FACILITIES	Layup area environmental requirements ID'd	Layup done in laboratory environment	Layup done in relevant environment,	Layup done in relevant environment,	Layup done in operational environment,	Layup done in operational environment,	Layup done in operational environment,	Layup done in operational environment,
LAYUP EQUIPMENT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
LAYUP TOOLING		Templates/straight edges, hand tools (sqeegees/scrapers, etc) idnetified	Tooling compatability investigations with resin/prepreg	Templates/straight edges	Templates/straight edges, Acceptance plan established,	Templates/straight edges	Templates/straight edges	Templates/straight edges
LAYUP VARIABILITY		x and y position, angle, tack, environmental conditions, tooling, indirect materials	Layup validated with any material change, x and y position, angle, tack, environmental conditions, tooling, indirect materials,	x and y position, angle, tack, environmental conditions, tooling, indirect materials	Layup validated with any material change, tack, environmental conditions, Control variable limits established,	x and y position, angle, tack, environmental conditions,	Layup validated with any material change,	
LAUP QUALITY - IN-PROCESS		Measured length-width position of laid up plies to reference position, Angle measured to reference direction, logged times and temperatures	Measured length-width position of laid up plies to reference position, Angle measured to reference direction, logged times and temperatures, limits investigated for position and angles,	Measured length-width-angle positions greater than 30 times, limits validated	Positional control limits established, Preliminary process specification,	Control limits validated	Quality plan, Process specification	Process specification validated
QUALITY - FINAL PRODUCT		Layup positional and angle accuracy	Layup positional and angle accuracy, Indirect material NDE detectability and compatability,	Layup positional and angle accuracy, Indirect material NDE detectability and compatability,	Preliminary process specification,		Quality plan, Process specification	Process specification validated
APPLICATION MATURITY	Neat resin,	Flat and ramped panels fab'd	Multiple thickness flat panels, ramped panels,	Generic featured parts fab'd	Multiple thickness flat panels, ramped panels,	Generic scale up parts fab'd	Multiple thickness flat panels, ramped panels,	Production representative parts
COST/BENEFIT ANALYSIS								
REGULATORY								
Intellectual Property								

Figure A-42 Example Fabrication/Producibility Layup XRL Sheet

Fabrication/Producibility – Debulking

DEBULKING (x)RL Criteria Conformance Summary (Date: 10/6/2003

(x)RL Rating	0	1	2		3		4	5
			2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9		
PART MATERIAL	Neat resin, Key time and temperature requirements for cure ID'd for all reactive materials to be used together.	Prepreg kinetic and viscosity results for understanding time and temperature relationships for all reactive materials.	Prepreg	Prepreg	Prepreg	Prepreg	Prepreg	Prepreg
DEBULK PROCESSES	Key time and temperature requirements for debulking ID'd	Debulking methods investigated (times, temperatures, pressures), Indirect materials identified, facilities, equipment and tooling requirements identified	Limits identified for debulking methods - times - temperatures -- pressures relative to flow/voids and porosity and thickness,	Limits validated, Out time & cure evaluations complete,	Preliminary process specifications established,	Preliminary process specifications validated,	Process specification finalized,	Final process specification validated,
DEBULK FACILITIES		Lab environment, facility requirements identified	Relevant environment	Relevant environment	Operational environment	Operational environment	Operational environment	Operational environment
DEBULK EQUIPMENT		Debulk equipment ID'd, Capabilities investigated,	Debulk equipment ID'd, Capabilities known, Characterized,	Debulk equipment capability validated,	Debulk equipment ID'd with know capabilities and characterized, Certification requirements ID'd	Certification requirements validated,	Debulk equipment ID'd with known capabilities and characterized, Certification requirements finalized	Certification complete,
DEBULK TOOLING		Quick look at multiple tool material/concept simulations	Limits identified for multiple tooling materials and concepts,	Some tooling material/concepts validated, Initiate residual stress compensation factors investigations,	Expanded tooling material/concept simulations,	Expanded tooling material/concept validations,	Finalized tooling IPT and BTP information	Validated information
DEBULK VARIABILITY	Key material time/temperature characteristics ID'd, Key variability items ID'd,	Key variability items investigated (time, temperature, pressure, number of plies), ***Iterate debulk cycle variables to achieve acceptable final product quality*** .	Debulk validated with material changes, Additional variability items ID'd (i.e. thickness and out-of-plane fiber distortion), ***Iterate dbbulk cycle variables to achieve acceptable final product quality or institute special debulk*** ,	Control variables validated,	Debulk validated with any material change, Preliminary process specifications established	Preliminary process specifications validated	Process specification finalized,	Final process specification validated
DEBULK QUALITY - IN-PROCESS	Control Items ID'd and logged,	Control methods established (time, temperature, pressure, number of plies), Preliminary tolerances established for control items impacting thickness and out of-plane fiber distortion and voids/porosity,	Additional controls and tolerances established if necessary, Control limits established (time temperature, pressure, number of plies) that impact thickness and out-of-plane fiber distortion and voids/porosity,	Debulk profiles and tolerances validated, Control limits validated relative to thicknesses, out-of-plane fiber waviness, and voids/porosity	Preliminary process specifications established	Preliminary process specifications validated	Process specification finalized,	Final process specification validated
QUALITY - FINAL PRODUCT	Multiple end of cure metrics evaluated, Void porosity assessment,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated, Defects ID'd,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated, Defects evaluated	Preliminary process specifications established, Effect of defect formalized studies,	Preliminary process specifications validated, Effects of defects known,	Process specification finalized,	Final process specification validated
APPLICATION MATURITY	Neat resin,	Flat and ramped panels fab'd	Multiple thickness flat panels, ramped panels,	Generic featured parts fab'd	Multiple thickness flat panels, ramped panels,	Generic scale up parts fab'd	Multiple thickness flat panels, ramped panels,	Production representative parts
COST/BENEFIT ANALYSIS								
REGULATORY								
Intellectual Property								

Figure A-43 Example Fabrication/Producibility Debulking XRL Sheet

Fabrication/Producibility – Bagging

BAGGING (x)RL Criteria Conformance Summary Ch Date: 10/6/2003

(x)RL Rating	0	1	2		3		4	5
			2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9		
PART MATERIAL	Neat resin, Key time and temperature requirements for cure ID'd, Offgassing byproducts identified,	Prepreg, offgassing investigations	Prepreg	Prepreg	Prepreg	Prepreg	Prepreg	Prepreg
BAGGING PROCESSES	Key time and temperature requirements for debulking ID'd	Bagging methods investigated (for times, temperatures, pressures). Indirect materials for bleeder/breather and bagging identified along with properties, facilities, equipment and tooling requirements identified, inner and outer bagging requirements identified	Limits identified for bagging methods - times - temperatures - pressures relative to flow/voids and porosity and thickness and cure,	Limits validated, Out time & cure evaluations complete,	Preliminary process specifications established,	Preliminary process specifications validated,	Process specification finalized,	Final process specification validated,
BAGGING FACILITIES		Lab environment, facility requirements identified	Relevant environment	Relevant environment	Operational environment	Operational environment	Operational environment	Operational environment
BAGGING EQUIPMENT								
BAGGING TOOLING		Compatability of bagging and tooling/mold releases investigated	Limits identified for multiple tooling materials and concepts,	Some tooling material/concepts validated, Initiate residual stress compensation factors investigations,	Expanded tooling material/concept simulations,	Expanded tooling material/concept validations,	Finalized tooling IPT and BTP information	Validated information
BAGGING VARIABILITY	Key material time/temperature characteristics ID'd, Key variability items ID'd,	Key variability items investigated (time, temperature, pressure, number of plies), ***Iterate bagging variables (inner/outer bag, breathing, bleeder, pleats, sealant) to achieve acceptable final product quality*** .	Bagging validated with material changes, Additional variability items ID'd, ***Iterate bagging variables to achieve acceptable final product quality or institute special bagging procedures*** .	Control variables validated,	Bagging validated with any material change, Preliminary process specifications established	Preliminary process specifications validated	Process specification finalized,	Final process specification validated
BAGGING QUALITY - IN-PROCESS	Control Items ID'd and logged,	Control methods established (time, temperature, pressure, number of plies), Preliminary tolerances established for control items,	Additional controls and tolerances established if necessary, Control limits established (time temperature, pressure, number of plies),	Debulk profiles and tolerances validated,	Preliminary process specifications established	Preliminary process specifications validated	Process specification finalized,	Final process specification validated
QUALITY - FINAL PRODUCT	Multiple end of cure metrics evaluated, Void porosity assessment,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated, Defects ID'd,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated, Defects evaluated	Preliminary process specifications established, Effect of defect formalized studies,	Preliminary process specifications validated, Effects of defects known,	Process specification finalized,	Final process specification validated
APPLICATION MATURITY	Neat resin,	Flat and ramped panels fab'd	Multiple thickness flat panels, ramped panels,	Generic featured parts fab'd	Multiple thickness flat panels, ramped panels,	Generic scale up parts fab'd	Multiple thickness flat panels, ramped panels,	Production representative parts
COST/BENEFIT ANALYSIS								
REGULATORY								
Intellectual Property								

Figure A-44 Example Fabrication/Producibility Bagging XRL Sheet

Fabrication/Producibility – Cure

CURE (x)RL Criteria Conformance Summary Chart Date: 10/6/2003

(x)RL Rating	0	1	2		3		4	5
			2.0 - 2.4	2.5 - 2.9	3.0 - 3.4	3.5 - 3.9		
PART MATERIAL	Neat resin, Key time and temperature requirements for cure identified for all reactive materials to be used together. Off gassing byproducts identified,	Kinetic and viscosity test results for behavior understanding of time and temperature relationships for all reactive materials. By products investigated,	Kinetic and viscosity test results for behavior modeling of all reactive materials	Prepreg	Prepreg	Prepreg	Prepreg	Prepreg
CURE PROCESSES	One or two cure cycle variations tried,	Initial investigations to establish a very preliminary time temperature pressure cure profile relative to degree of cure, viscosity, and voids. One or two cure cycle variations tried. Requirements for facilities and equipment identified including vacuum and static port/line requirments,	Limits identified for heat up and cure times - temperatures -- pressures relative to flow/voids and porosity/end of cure relative to part thickness, equipment capability and tooling options; Exotherm potential evaluated, Cure impact on properties and residual stresses. Limits established for vacuum and static port/line items.	Limits validated; Out time & cure evaluations complete,	Preliminary process specifications established,	Preliminary process specifications validated,	Process specification finalized,	Final process specification validated,
CURE FACILITIES	Laboratory environment	Laboratory environment	Relevant environment	Relevant environment	Operational environment	Operational environment	Operational environment	Operational environment
CURE EQUIPMENT	Oven	Autoclave ID'd, Capabilities investigated and variabilities identified,	Autoclave ID'd, Capabilities known, variabilities characterized (heating/cooling and pressurization rates and convective coefficients),	Autoclave capability validated,	Autoclave ID'd with know capabilities and characterized, Certification requirements ID'd	Certification requirements validated,	Autoclave ID'd with know capabilities and characterized, Certification requirements finalized	Certification complete,
CURE TOOLING	Simple plates/pans,	Quick look at multiple tool materials/concepts	Limits investigated for multiple tooling materials and concepts,	Some tooling material/concepts validated; Initiate residual stress compensation factors investigations,	Expanded tooling material/concept simulations,	Expanded tooling material/concept validations,	Finalized tooling IPT and BTP information	Validated inbrmation
CURE VARIABILITY	key material cure characteristics ID'd, Key cure variability items ID'd relative to the material,	Key variability items investigated for materials (time, temperature, pressure for individule and combined materials), tooling and equipment, ***Iterate cure cycle variables to achieve acceptable final product quality***,	Cure validated with any material changes, Additional variability items ID'd, ***Iterate cure cycle variables to achieve acceptable final product quality or institute special cure*** ,	Control variables validated,	Cure validated with any material changes, Preliminary process specifications established	Preliminary process specifications validated	Process specification finalized,	Process specification validated
CURE QUALITY - IN-PROCESS	Control Items ID'd and logged (time, temperature, pressure),	Control methods established, Preliminary tolerances established for control items,	Additional controls and tolerances established if necessary. Control abort limits established,	Cure profiles and tolerances validated,	Preliminary process specifications established	Preliminary process specifications validated	Process specification finalized,	Final process specification validated
QUALITY - FINAL PRODUCT	Multiple end of cure metrics evaluated, Void porosity assessment,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated, Defects ID'd,	Multiple end of cure measurements, Voids and porosity results evaluated, Part thicknesses evaluated, Part resin content evaluated, Defects evaluated	Preliminary process specifications established, Effect of defect formalized studies,	Preliminary process specifications validated, Effects of defects known,	Process specification finalized,	Final process specification validated
APPLICATION MATURITY	Neat resin,	Flat and ramped panels fab'd	Multiple thickness flat panels, ramped panels,	Generic featured parts fab'd	Multiple thickness flat panels, ramped panels,	Generic scale up parts fab'd	Multiple thickness flat panels, ramped panels,	Production representative parts
COST/BENEFIT ANALYSIS								
REGULATORY								
Intellectual Property								

Figure A-45 Example Fabrication/Producibility Cure XRL Sheet

Appendix B – References with Brief Abstracts

The purpose of this appendix is to provide a brief abstract for each of the references which appear in this methodology document. References from each section of the document are listed below by section. Abstracts of each reference follow this list in the order of their first appearance.

1. Methodology Overview

1. Banisaukas, J., Office of Naval Research, Contract No. N00014-97-C-0417, "New Materials, New Processes and Alternate Second Source Materials Data Base Generation and Qualification Protocol Development," Enclosure 4 to the Final Report dated 31 August 2000.
2. Lincoln, J. W., "USAF Experience in the Qualification of Composite Structures," Composite Structures: Theory and Practice, ASTM STP 1383, P. Grant, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000, pp. 1-11.
3. The Composites Materials Handbook-MIL17, MIL-HDBK-17E, Technomic Publishing Company, Inc., Lancaster, Pennsylvania, 1997.
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5. Funke, R.W., Rubin, A., Bogucki, G., and Ashton, H., Christenson, S., Contract No. N00421-01-3-0098, "Composite Materials and Structures Certification Process – Experience and Recommendations," Report No. BOE-STL 2001X0010, 15 March 2002.
6. Wallace, D.R., Abrahamson, S., Nicola, S., and Sferro, P., "Integrated Design in a Service Marketplace, Computer-aided Design," Volume 32, No. 2, pp. 97-107, 2000.
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9. Interim Defense Acquisition Guidebook, AP6. Appendix 6 – Technology Readiness Levels and Their Definitions, October 30, 2002

2. Risk Management

1. Banisaukas, J., Office of Naval Research, Contract No. N00014-97-C-0417, "New Materials, New Processes and Alternate Second Source Materials Data Base Generation and Qualification Protocol Development," Enclosure 4 to the Final Report dated 31 August 2000.
2. Lincoln, J. W., "USAF Experience in the Qualification of Composite Structures," Composite Structures: Theory and Practice, ASTM STP 1383, P. Grant, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000, pp. 1-11
3. Department of the Air Force, *Acquisition Risk Management Guide*, AFMC Pamphlet 63-101, 15 September 1993.
4. The Composites Materials Handbook-MIL17, MIL-HDBK-17E, Technomic Publishing Company, Inc., Lancaster, Pennsylvania, 1997.

3. Business Case

1. McCarty, Robert, and Saff, C.R., "Next Generation Transparency," *Affordability Transition Conference,* Williamsburg, Virginia, 2000.

2. Younossi, O., Kennedy, M., and Graser, J., Military Airframe Costs – The Effects of Advanced Materials and Manufacturing Processes, The RAND Corporation, 2001.

3. Mabson, G.E., Fredrikson, H.G., Graesser, , D.L., Metschan, S.L. , Proctor, M.R., Stogin, D.C. , Tervo, D.K. , Tuttle, M.E., Zabinsky, Z.B. , Gutowski, T.G. , "Cost Optimization Software For Transport Aircraft Design Evaluation," 6th NASA Advanced Composite Technology Conference, 1995.

4. Technical Acceptability

1. Banisaukas, J., Office of Naval Research, Contract No. N00014-97-C-0417, "New Materials, New Processes and Alternate Second Source Materials Data Base Generation and Qualification Protocol Development," Enclosure 4 to the Final Report dated 31 August 2000.

2. Griffith, J. and Thomas, H., Precision Assembly for Composite Structures, AFRL-ML-WP-TR-1999-4080, April 1999

3. Nelson, Karl M. Processing for Dimensional Control: Testing and Modeling Protocol Manual, F33615-97-C-5006, September 2001.

5. Allowables Development/Equivalency Validation

1. Military Handbook - Polymer Matrix Composites - Volume I - Guidelines, MIL-HDBK-17A.

2. F/A-18E/F Material Substantiating Data and Analysis Report, Report MDC 93B0068, Revision J, dated 15 September 1998.

3. Paul, P.C., and Mahler, M.A., "Out-of-Plane Analysis for Composite Structures – Volume I. Final Report," Report NAWCADWAR-94138-60 (Vol. I), 15 September 1994.

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2. Funke, R.W., Rubin, A., Bogucki, G., and Ashton, H., Christensen, S., Contract No. N00421-01-3-0098, "Composite Materials and Structures Certification Process – Experience and Recommendations," Report No. BOE-STL 2001X0010, 15 March 2002.

7. Validation and Verification

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8. Systems Engineering

1. Blanchard, Benjamin S. and Fabrycky, Wolter J. *Systems Engineering and Analysis*, Prentice Hall International, 1998.

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3. Kasser, Joe. *Applying Total Quality Management to Systems Engineering,* Artech House, Boston, MA, 1995.

4. Westerman, H. Robert. *Systems Engineering Principles and Practice*, Artech House, Boston, MA, 2001.

Selected Abstracts

Banisaukas, J., Office of Naval Research, Contract No. N00014-97-C-0417, "New Materials, New Processes and Alternate Second Source Materials Data Base Generation and Qualification Protocol Development," Enclosure 4 to the Final Report dated 31 August 2000.

The effective qualification of new or alternative composite materials and processes has been a significant problem for numerous military aircraft programs in recent years. Often, an older generation material or process has continued in use, not because of low risk or cost, but because qualifying a next generation material or an innovative process was cost prohibitive to a small program. At other times, a material or process has been qualified numerous times, each time duplicating the efforts of other qualifications while adding details particular to an application, an environment, or a user. Data sharing among programs has been deficient, even among programs supporting the same branch of service. In still other instances, established programs must contend with "qualification" of material or process changes due to obsolescence, plant relocations, substitutions due to environmental regulations, changes due to new safety requirements, or suppliers or processors going out of business.

This protocol was written to deal with the above issues. This document provides a framework for enhancing affordability, cycle time, and technical excellence in the development of material and process qualifications. It provides a methodology or framework for developing qualification success criteria, divergence and risk analyses,

and guidelines as to the technical attributes of the material or process which might not require testing confirmation. It is not a catalog of test matrices to be followed without fore thought and business justification. This protocol document does not compete with Mil-Hdbk-17, SACMA, ASTM, or the other fine documents in the industry that provide test guidance or variability analysis. However, it does provide a methodology or framework for questioning the most appropriate qualification approach based on a written and agreed-to problem statement, and, therefore, it complements these other documents.

The intent of this qualification protocol is to provide a methodology when (a) attempting a blank sheet qualification of a material or process; (b) evaluating material or process changes to an already qualified material or process; and (c) evaluating the equivalency of second sources or alternate processes. This document should be used as a guide for any or all elements of the qualification process.

Lincoln, J. W., "USAF Experience in the Qualification of Composite Structures," Composite Structures: Theory and Practice, ASTM STP 1383, P. Grant, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000, pp. 1-11.

The prospect of significant reduction in aircraft structural mass has motivated the United States Air Force (UASF) and the aerospace industry to incorporate composite structures in their aircraft designs. The USAF found threats to structural integrity such as moisture, temperature, delaminations, and impact damage that made them take a cautious approach for the acquisition of aircraft with composite materials. However, the USAF has successfully incorporated composites on several aircraft including the B-2, C-17, and F-22. The challenge is to find new approaches for the qualification of composite structures that will make them more economically viable for future procurements. It is the purpose of this paper to discuss the background for the current qualification program for composites and suggest some possibilities for improvement of the certification process.

The Composites Materials Handbook, MIL-HDBK-17, Technomic Publishing Company, Inc., Lancaster, Pennsylvania, 1997.

MIL-HDBK-17 is a standardization of engineering data development methodologies related to characterization testing, data reduction, and data reporting of properties for polymer matrix composite materials. MIL-HDBK-17 publishes properties on composite material systems for which data meeting specific requirements is available. In addition, MIL-HDBK-17 provides selected guidance on technical topics related to composites, including material selection, material specification, material processing, design, analysis, quality control and repair of typical polymer matrix composites. MIL-HDBK-17 is published in three volumes: Volume 1 – Guidelines for Characterization of Structural Materials; Volume 2 – Material Properties; and Volume 3 – Materials Usage, Design, and Analysis Guidelines.

Tomblin, J.S., Ng, Y.C., and Raju, K.R., DOT/FAA/AR-00/47, "Material Qualification and Equivalency for Polymer Matrix Composite Material Systems," Final Report Dated April 2001.

This document presents a qualification plan that will provide the detailed background information and engineering practices to help ensure the control of repeatable base material properties and processes, which are applied to both primary and secondary structures for aircraft products using composite materials. This qualification plan includes recommendations for the original qualification as well as procedures to statistically establish equivalence to the original data set. The plan describes in detail the procedures to generate statistically based design allowables for both A- and B-basis applications. This plan only covers the initial material qualification at the lamina level and does not include procedures for laminate or higher-level building block tests. The general methodology, however, is applicable to a broader usage.

Funke, R.W., Rubin, A., Bogucki, G., and Ashton, H., Christenson, S., Contract No. N00421-01-3-0098, "Composite Materials and Structures Certification Process – Experience and Recommendations," Report No. BOE-STL 2001X0010, 15 March 2002.

This report presents the F/A-18 E/F composite materials certification process in some detail. It begins with material and process development and proceeds structural testing. It presents how the problem was approached, what was done, and the outcome. Lessons learned are presented which could be utilized to facilitate future qualifications.

Wallace, D.R., Abrahamson, S., Nicola, S., and Sferro, P., "Integrated Design in a Service Marketplace, Computer-aided Design," Volume 32, No. 2, pp. 97-107, 2000.

This paper presents a service marketplace vision for enterprise-wide integrated design modeling. In this environment, expert participants and product development organizations are empowered to publish their geometric design, CAE, manufacturing, or marketing capabilities as live services that are operable over the Internet. Product developers, small or large, can subscribe to and flexibly inter-relate these services to embody a distributed product development organization, while simultaneously creating system models that allow the prediction and analysis of integrated product performance. It is hypothesized that product development services will become commodities, much like many component-level products are today. It will be possible to rapidly interchange equivalent design service providers so that the development of the product and definition of the product development organization become part of the same process. Computer-aided design tools will evolve to facilitate the publishing of live design services. A research prototype system called DOME is used to illustrate the concept and a pilot study with Ford Motor Company is used in a preliminary assessment of the vision.

Department of the Air Force, *Acquisition Risk Management Guide*, AFMC Pamphlet 63-101, 15 September 1993; Revised 09 July 1997.

This pamphlet does not apply to the Air National Guard or US Air Force Reserve units and members. This pamphlet is intended to provide program managers and their program management team a basic understanding of the terms, definitions and processes associated with effective risk management.

Current acquisition reform initiatives embrace closer government/industry relationships and greater reliance on commercial technologies -- both designed to provide reliable, lower cost weapon systems. Hand-in-hand with these initiatives is an accompanying focus on risk management.

The risk management concepts and ideas presented in this pamphlet are focused on encouraging the use of risk-based management practices and suggesting ways to address the program risk without prescribing the use of specific methods or tools. Rather, this pamphlet was prepared as a guide, with the expectation that program risk management processes will be developed to meet the intent of this document.

McCarty, Robert, and Saff, C.R., "Next Generation Transparency," *Affordability Transition Conference,* Williamsburg, Virginia, 2000.

The design features developed for both the single piece canopy and the one piece, Next Generation Transparency (NGT) windscreen/canopy for the F-15 were used to estimate the costs for each of these candidate applications and to support a cost estimate for drop in replacement transparencies for the F-15. These analyses were done to evaluate the costs associated with replacements ranging from drop-in to complete reconfiguration. These costs are compared to the current costs for replacement of the F-15 windscreen and canopy. Windscreen replacements were not considered for either the drop-in replacements and the one piece canopy replacement.

When we get to the bottom line, it is apparent that NGT is far more cost effective in new designs than in retrofit designs. In retrofit designs the technology is hampered by the constraints of the existing design developed for the older transparency systems. It negates the savings and actually makes the NGT technology more costly than the original transparency system. But in new configurations, where the frameless transparency can be fully utilized in both production costs and life cycle costs, cradle to grave costs are reduced by more than half using the NGT technology.

Younossi, O., Kennedy, M., and Graser, J., <u>Military Airframe Costs – The Effects of Advanced Materials and Manufacturing Processes</u>, The RAND Corporation, 2001.

This is one of a series of reports from the RAND Project AIR FORCE project entitled "The Cost of Future Military Aircraft: Historical Cost Estimating Relationships

and Cost Reduction Initiatives." The purpose of the project is to improve cost-estimating tools available for projecting the cost of future weapon systems. It focuses on how recent technical, management, and government policy changes affect cost. This report discusses the effects of airframe material mix and manufacturing techniques on airframe costs, emphasizing the effect of new manufacturing techniques. It also presents statistical analyses of a new airframe historical cost data set, MACDAR, which is owned by the Air Force Cost Analysis Agency (AFCAA). The study took place in Project AIR FORCE's Resource Management Program.

Mabson, G.E., Fredrikson, H.G., Graesser, , D.L., Metschan, S.L. , Proctor, M.R., Stogin, D.C. , Tervo, D.K. , Tuttle, M.E., Zabinsky, Z.B. , Gutowski, T.G. , "Cost Optimization Software For Transport Aircraft Design Evaluation," 6th NASA Advanced Composite Technology Conference, 1995.

Cost Optimization Software for Transport Aircraft Evaluation (COSTADE) is being developed as a tool to support design build teams in their efforts to develop cost effective and feasible commercial aircraft composite fuselage structures. COSTADE is a multidisciplinary evaluation and optimization tool that includes cost, weight, design, stress, and manufacturing modules. Fabrication costs are included early in the structural cevelopment process allowing the identification of cost-weight sensitivities. The use of this tool also reduces engineering development costs by shortening design cycles times and by providing improved starting points for more detailed evaluations.

This paper presents details of the major modules included in COSTADE, and applications illustrating its use on the Advanced Technology Composite Aircraft Structures (ATCAS) program. Emphasis is given to the development of cost model equations. Applications of the cost model to the ATCAS full barrel are included.

F/A-18E/F Material Substantiating Data and Analysis Report, Report MDC 93B0068.

This report presents the F/A-18 E/F Material Substantiating Data and Analysis requirements in compliance with Addendum 697 to SD-8706C, Paragraph 3.10.5, dated 09 January 1992. This report was submitted in partial fulfillment of the data requirements for Contract N00019-92-C-0059, Exhibit A, Data Item Number A012.

This report includes data and analyses to substantiate the use of material property values and design allowables from sources other than MIL-HDBK-5 and MIL-HDBK-17, specifically, composites and adhesives. This report … covers testing and design allowable development completed to date on the F/A-18 E/F carbon/epoxy material systems IM7/977-3 tape, and AS4/977-3 cloth. All IM7/977-3 tape, AS4/977-3 tape, AS4/977-3 cloth, and AS4/977-3 hybrid testing and allowable development performed to date is covered in this report. This report presents the composites design allowables development testing and how the test results are utilized in the F/A-18 E/F structural

designs. Subjects covered include the design allowable philosophy, test methods used for design allowable tests, environmental effects on composite properties, test results and how they were used to develop the carbon/epoxy structure design allowables.

Paul, P.C., and Mahler, M.A., "Out-of-Plane Analysis for Composite Structures – Volume I. Final Report," Report NAWCADWAR-94138-60 (Vol. I), 15 September 1994.

Composite airframe structures have recently experienced several unexpected failures due to the effects of out-of-plane loads. These loads are inherent to laminated, cocured, and adhesively bonded composite structures. There is great difficulty accounting for these loads and predicting their failures since the strength in the out-of-plane direction is commonly weak and inadequate design tools have been available.

The objective of this program was to develop simple two dimensional analysis methods that can be used to predict the primary out-of-plane failure modes and strengths of composite airframe structures. The primary sources of out-of-plane failures addressed by these developed analytical techniques are:

- induced stresses in laminate corner radii
- induced stresses due to ply drop off
- induced stresses due to panel buckling
- direct stresses due to fuel pressure loads
- induced stresses due to stiffener runouts or other load path changes

Military Handbook – MIL HDBK-5F

This handbook is primarily intended to provide a source of design, mechanical, and physical properties, and joint allowables. Material property and joint data obtained from tests by material and fastener producers, government agencies, and members of the airframe industry are submitted to MIL-HDBK-5 for review and analysis. Results of these analyses are submitted to the membership during semi-annual coordination meetings for approval and, when approved, are published in this Handbook.

Appendix C. Definitions

Algorithm	A standard set of procedures to solve a mathematical problem.
Analysis Method	A procedure for implementing a theoretical result. In the context of AIM-C, a set of engineering calculations generally performed by a computer code.
Bayesian Statistics	Baye's rule states that probability that both of the two events will occur is the probability of the first multiplied by the probability that if the first has occurred the second will also occur. There are two kinds of probability. The classical type based on empirical information and subjective probability. Bayesian statistics is based on subjective probabilities.
Causative Event	The beginning in time of an activity that results in particular outcomes of the activity.
Coefficient of Correlation	A statistical measure that is used to describe how well one variable is explained by another. When dealing with samples, it is the sample coefficient of variation.
Confidence Interval	A range of values that has some designated probability of including the true population parameter value.
Confidence Level	A range of values that has some designated probability of including the true population parameter value.
Confidence Limits	The upper and lower boundaries of a confidence interval.
Correlation	A statistical tool that is used to describe the degree to which one variable is *linearly* related to another.
Counterintuitive	Occurrence of things that we knew about but wrote-off as most unlikely to occur.
DDSHM	Discrete Damage Space Homogenization Method
DDSHM_disbond_ Aijkl Code	Code that analyzes the Discrete Damage Space Homogenization Method (DDSHM) for the A-matrix ($\mathbf{A}_{ijkl}$ in lamination plate theory).
DDSHM_disbond_ SERR model	Model that analyzes the Discrete Damage Space Homogenization Method (DDSHM) for strain energy release rate (SEER)
Deformation Free Temperature	The temperature at which an composite angle takes on the same shape as the tool from which it was manufactured.
Demo-Version Module	The version of the modules that will be used in the demonstration.
Dummy Module	A module created by the integration team, having the I/O structure of the proposed module, but none of the algorithms or models.
Empirical	Originating in or based on experience.

Estimate	A specific observed value of an estimator.
Estimator	A sample statistic used to estimate a population parameter.
Extrapolation	An inference made about the systems behavior in a new range of variables from experience in an old familiar range.
Fiber Module	Provides properties of fiber, given temperature and fiber type. Uses historical data to provide values and variability. Outputs physical and mechanical properties.
Frequentist Probability	The probability of an event occurring in a particular trial as the *frequency* with which it occurs in a long sequence of similar trails. More precisely, the probability is the value to which the long-run frequency converges as the number of trials increases.
Heuristic	Describing an operational maxim derived from experience and intuition.
Independence	A property shared by two or more entities when the performance of any one or any group has no effect on the performance of any other one or group.
Input	Information, data, parameter values, etc, that is read by a module or model during the course of its execution, other then those values which the module or model itself writes and reads for internal operation.
Interval Estimate	A range of values used to estimate an unknown population parameter.
Lamina Module	An assemblage of analysis methods that predicts the governing damage/deformation mechanisms and the resulting effective engineering properties, such as moduli and strength, of a fiber-reinforced material given the properties of a fiber, resin, inter-phase, and constituent volume fractions, fiber architectures, and processing conditions.
Laminate Module	An assemblage of analysis methods that provide the macroscopic constitutive relation for a laminated composite material constructed by stacking lamina. In the context of AIM-C, the laminate module provides the engineering properties and stress or strain results at a discrete point within the material. An example of a calculation to be performed in the laminate module would be resolving results of an un-notched coupon test to lamina stresses.

Mechanistic or Physically Based Failure Criteria A failure criterion in which the mode, or failure mechanism (in addition to failure level) is included in the analysis method. A physically based failure criterion has the key attributes of (1) allowing for calibration independent of the data set that it is being used to predict, i.e., it possesses a predictive capability beyond simple interpolation within a known data set and (2) being capable of independent verification via more than one observation (i.e., not just a failure load, but the extent of damage, or the deformation state, are correctly predicted). Examples of physically based failure criteria include: maximum strain, maximum stress, Hashin interaction, and the unified physics-based approach developed by Boeing including Von-Mises and Tresca yield criteria for metals (based on the mechanisms of dislocations moving under the influence of the resolved shear stresses) and fracture mechanics for homogeneous materials (based on the mechanism of crack propagation). These methods have the capability of predicting structural-level response from coupon-level test data. An example of a phenomenological based method (i.e., that is not physically based) is the well-known Tsai-Wu polynomial criteria. At this point it is a matter of debate as to which composite failure criteria have a mechanistic basis and which do not.

Methodology

1. An open system of procedures.
2. An overlying assemblage of processes, and procedures that defines a method, allowing one to achieve a particular goal or objective. Relative to the AIM-C program, it is the disciplined process, developed in close coordination with certifying personnel representing Department of Defense and commercial agencies.

Model

1. An abstraction of reality that is always an approximation to reality.
2. An assemblage of one or more mathematical expressions describing relationships between the input and output values.

Model Error Approximations in the model and/or in the algorithms.

Module A logical grouping of models compiled into a single code. Provides a service when linked with tools and/or other modules. Examples: Resin Module, Fiber Module, etc.

Most Likely Value A structured set of concepts, definitions, classifications, axioms, and assumptions used in providing a conceptual framework for studying a given problem.

Multiple Regression A process by which several variables are used to predict another.

Objective Function A specified mathematical relationship between a dependent variable and a set of independent variables.

Optimization The process of finding a set of system parameters that maximizes the attainment of system goals and objectives

Ordinal Scale An ordering (ranking) of items by the degree to which they satisfy some criterion.

Outcome The final result of an activity initiated by a causative event.

Output	Information, data, parameter values, etc, that is written by a module or model during the course of its execution, excluding those values which the module or model itself writes and reads only for temporary internal operation.
Paradigm	A structured set of concepts, definitions, classifications, axioms, and assumptions used in providing a conceptual framework for studying a given problem.
Parametric Variation	A technique for sensitivity analysis of any given model in which the values of parameters that are input to the model's calculation are systematically varied to permit observation how such variation's affect the model output.
Pareto Optimality	An ideal state in the sense that o further distribution of economic activity will improve one's individual welfare without decreasing the welfare of an another individual.
Pareto Optimization	Optimization using a criterion that each person's needs be met as much as possible with out diminishing the degree of achievement of any other person.
Point Estimate	A single number that is used to estimate an unknown population parameter.
Population	A collection of *all elements* we are studying about which we are trying to draw conclusions.
Precision	The exactness with which a quantity is stated. The number of significant digits is a measure of precision.
Predictive Modeling	Use of a mathematical model that estimates or predicts the value of dependent variable in terms of component factors specified as independent variables
Prepreg Module	Combines resin and fiber into prepreg. Does not currently model temperature effects of impregnation process. Uses historical data to provide values and variability. Outputs physical properties of prepreg and relevant information on impregnation process.
Process Module	Converts uncured, collated debulked structure into cured structure through science-based models including effects of boundary conditions, geometry and material properties. Outputs physical and mechanical properties of cured structure and relevant information on curing process.
Producibility Module	Acts as a controller to compare requirements to capabilities for producibility and inspection. Also acts as a conduit to external producibility/cost tools. Uses a heuristic rules-based architecture.
Quantification	The assignment of a number to an entity or a method for determining a number to be assigned to an entity.
Regression	A general process of predicting one variable from another.
Regression Analysis	A process of developing an estimating equation (mathematical formula) that relates the known variables to unknown variables. It is important to realize this analysis defines the relationship of association *not necessarily* cause and effect.

Reliability	The probability that the system will perform it's required functions under given conditions for a specified operating time.
Resin Module	Provides properties of resin, given degree of cure, temperature and resin type. Uses science-based models. Outputs physical, mechanical, and chemical properties.
Response	A specific answer or visualization (graph) of data resulting from to the execution of a model or module.
Risk	The potential for realization of unwanted negative consequences of an event.
Risk Agent	A person or a group of persons who evaluates directly the consequence of risk to which he is subjected.
Risk Consequence	The impact to a risk agent of exposure to a risky event.
Sample	A collection of some, *but not all*, of the elements of population.
Sensitivity Analysis	A method used to examine the operation of a system by measuring the deviation of its nominal behavior due to perturbations of its components from their nominal values.
SERR	Strain Energy Release Rate
SFT	Stress Free Temperature
SIFT	Acronym for Strain Invariant Failure Theory
Stochastic System	A system whose behavior cannot be exactly predicted.
Structures Module	An assemblage of analysis methods that provide information on the performance of a material given a information on a structural detail. Examples of structures module analyses would be prediction of notched laminate behavior, free edge effects, and interlaminar stresses developed in curved regions subjected to in-plane loads.
Subjective Probabilities	The assignment of subjective weights to possible outcomes of an uncertain event where weights assigned satisfy axioms of probability
Subjective Probabilities	The assignment of subjective weights to possible outcomes of an uncertain event where weights assigned satisfy axioms of probability.
Surprise	Occurrence of an event previously thought to be of low probability or previously not consciously identified at all.
System	• A complex entity formed of many, often diverse, parts subject to a common plan or serving a common purpose. • A composite of equipment, skills, and techniques capable of performing and/or supporting an operation.

Taxonomy	The identification and definition of properties of elements of universe; a disaggregation.
Template	A set of input and output files and executable code saved as an RDCS project file, which solves a specific problem. The template can be taken, modified and applied to solve the broader, general class of problems.
Test-Version Module	The first series of working version of the modules. These versions will be used for testing the module, trouble-shooting, and fixing errors.
Tool	An integrated software package having a user interface. Example: The comprehensive analysis tool (CAT), RDCS, DOME, ISAAC, COMPRO, CAICAT, CACC.
Unacknowledged Error	Errors due to human mistakes, blunders, etc.
Uncertainty	• A capacious term used to encompass a multiplicity of concepts • Uncertainty may arise from incomplete information • Uncertainty may arise from linguistic imprecision • Uncertainty may refer to variability • Uncertainty may arise because of simplification or approximations introduced to analyze the information cognitively or computationally more tractable • Uncertainty may refer to uncertainty in our decisions • We may even be uncertain about our uncertainty • It is important to distinguish between different types and sources of uncertainty, since they need to be treated differently • Probability is considered as an appropriate way to express some of the above uncertainties • Ultimately uncertainty analysis should be the result of mutually compatible sets of models, beliefs, values and decisions
Uncertainty (Epistemic)	Represents partial ignorance or lack of perfect knowledge on the part of the analyst. This may reduced by further measurement or by improving the knowledge.
Unexpected	The occurrence of events or things that were not anticipated or imagined.
Universe	The totality under consideration often separated into system and environment.
Utility Function	A scale of preference (ordinal) or value (cardinal) to one or many decision makers.
Variability (Aleatory)	Represents diversity or heterogeneity in a population. Aleatory variability cannot be reduced by additional measurements.
Wrapper	A specialized piece of code used to provide the interface between tools and/or modules.

APPENDIX D - Conformance Planning Check Sheets

Introduction

Conformance planning activities cover a large number of areas and items. Different questions are asked when starting the conformance planning activities. These questions establish what is known and what is unknown for conformance to the problem statement objectives and requirements. It is the first step in establishing what has to be conducted by multiple disciplines for qualification and certification of a new material and/or process. The answers form the nucleus of what existing information/data/ knowledge can be used and what has to be generated.

The process for conformance planning (Figure 3.2) includes asking questions about the detailed xRL exit criteria on how conformance will be met for materials, structures and producibility. A key item is that an Integrated Product Team (IPT) conducts this process with concurrence of results by the whole IPT and by customers. The outputs from these planning activities are a series of check sheets for materials, structures and producibility conformance activities listing what, when and how activities will be conducted.

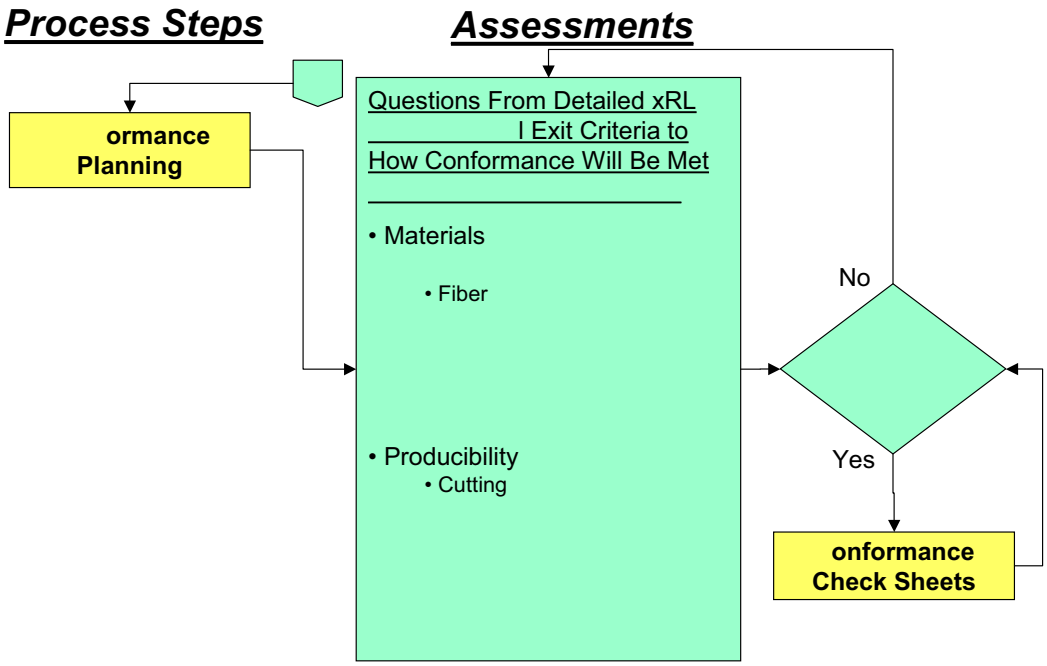

Figure D-33 Conformance Planning Process

There are a series of steps in this question answering process. The following items outline these steps.

- Gather existing knowledge: heuristics, lessons learned, information on similar problems or applications, public literature, analyses, and test results.

- Address every question/requirement. Address functional/disciplinary issues. Address interdisciplinary issues/assumptions/decisions as an IPT with all stakeholders involved.
- Determine divergence risk on existing information.
- Assess the conformance of existing knowledge with requirements.
- Handle Error and Uncertainty (See Methodology Section 18). Determine additional knowledge needed based on knowledge gaps, unacceptable risk, etc.
    - Understand and Classify Potential Uncertainty Sources
    - Determine What Is Important
    - Limit Uncertainty/Variation by Design and /or Process
    - Quantify Variation (Monte Carlo Simulation or Test)
- Address long lead items.
- Perform prudent studies to flesh out the conformance plan – could include trials, test, analyses, and combinations thereof.
- Prepare the conformance plan. Initiate efforts as applicable, while studies are underway to address details of the next maturity level of the plan.
- Address cost, schedule, and technical risk.
- Set up criterion for committal gates – analytical tools, test methods, guidelines, specifications, knowledge committal, maturity assessment, etc.
- Secure commitment to the plan from all stakeholders.
- Address the business case as appropriate.

A simplified tool for identification of areas and items for conformance planning was established. This tool is conformance check sheets for conformance areas and items.

Conformance Check Sheet Areas and Items

Conformance check sheets are generated by individual disciplines addressing the details of what needs to be conducted to achieve conformance to problem statement objectives and requirements. Figure D-34 shows a listing of the different types of conformance check sheets for three disciplines.

- **Structures**
  - Application Failure Modes
  - Material Properties
  - Durability
- **Materials**
  - Fiber
  - Resin
  - Prepreg
- **Producibility**
  - Cutting
  - Layup
  - Debulking
  - Cure
  - In-Process Quality
  - Final Part Quality

Figure D-34 Conformance Check Sheet Areas and Items

Process to Establish Conformance Planning Check Sheets

The purpose of the check sheets are to be simplified, quick look tools of what is planned to be done for conformance to requirements, how they are planned to be done and when they are planned to be done and possible how many to be done. The process to establish conformance check sheets is comprised of four steps. The first step is to identify the area and specific items in the area that are to be evaluated and listing them in a column as shown in Figure D-3.

RESIN - THERMOSET
Uncured Resin
Viscosity
Reaction Rate
Heat of Reaction
Volatile Content/evolution temperature
Volatile Type
Volatile Vapor Pressure
Resin Cost
Density
Resin Cure Shrinkage
CTE

Figure D-35 Establish Check Sheet, Step 1

Step two is to identify the primary variability items that have to be either controlled or have more data for than other areas. This Step 2 is shown in Figure D-4.

RESIN - THERMOSET	
Uncured Resin	
Viscosity	➢
Reaction Rate	➢
Heat of Reaction	➢
Volatile Content/evolution temperature	➢
Volatile Type	➢
Volatile Vapor Pressure	
Resin Cost	
Density	
Resin Cure Shrinkage	
CTE	

Figure D-36 Establish Check Sheet, Step 2

Step three is to add 14 columns to the matrix chart. Columns 1 through 11 are for a listing of the different maturity levels. Column 12 is to identify how the item result is to be obtained and specifics of the method to obtain the item result. The last column is to identify where the specific results would be kept. This Step 3 is shown in Figure D-5.

		TRL/XRL Maturity Level													
RESIN - THERMOSET		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**How Obtained, Test or Anlaysis**	**Test/Analysis Identification**	**Worksheet ID Reference**
Uncured Resin															
Viscosity	➢												Test	ASTM D 4473	
Reaction Rate	➢												Test	DSC via ASTM D 3418 and ISO 11357	
Heat of Reaction	➢												Test	DSC via ASTM D 3418 and ISO 11357	
Volatile Content/evolution temperature	➢												Test	TGA	
Volatile Type	➢												Test/product knowledge	FTIR/Formula access	
Volatile Vapor Pressure													Test		
Resin Cost													Specified Value	Based on vender input	
Density													Analysis	Based on cured/uncured test data	
Resin Cure Shrinkage													Analysis	Based on volumetric test data	
CTE													Analysis	based on TMA or linear dilatometer data	

Figure D-37 Establish Check Sheet, Step 3

Step four is to identify at what maturity level results would be obtained. It could also be used to identify the number of evaluations that would be conducted at each of the maturity levels. This Step 4 is shown in Figure D-6.

		TRL/XRL Maturity Level													
RESIN - THERMOSET		**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**How Obtained, Test or Anlaysis**	**Test/Analysis Identification**	**Worksheet ID Reference**
Uncured Resin															
Viscosity	➢	x	x	x	x	x							Test	ASTM D 4473	
Reaction Rate	➢	x	x	x	x	x							Test	DSC via ASTM D 3418 and ISO 11357	
Heat of Reaction	➢	x	x	x	x	x							Test	DSC via ASTM D 3418 and ISO 11357	
Volatile Content/evolution temperature	➢	x	x	x	x	x							Test	TGA	
Volatile Type	➢	x	x										Test/product knowledge	FTIR/Formula access	
Volatile Vapor Pressure			x										Test		
Resin Cost		x	x	x	x	x							Specified Value	Based on vender input	
Density			x	x	x	x							Analysis	Based on cured/uncured test data	
Resin Cure Shrinkage				x									Analysis	Based on volumetric test data	
CTE													Analysis	based on TMA or linear dilatometer data	

Figure D- 38 Establish Check Sheet, Step 4

Example Conformance Check Sheets

Figure D-7 through D-14 are example check sheets. They are representative of what could be established during a new activity.

		TRL/XRL Maturity Level													
RESIN - THERMOSET		0	1	2	3	4	5	6	7	8	9	10	How Obtained, Test or Anlaysis	Test/Analysis Identification	Worksheet ID Reference
Uncured Resin															
Viscosity	➢	x	x	x	x	x							Test	ASTM D 4473	
Reaction Rate	➢	x	x	x	x	x							Test	DSC via ASTM D 3418 and ISO 11357	
Heat of Reaction	➢	x	x	x	x	x							Test	DSC via ASTM D 3418 and ISO 11357	
Volatile Content/evolution temperature	➢	x	x	x	x	x							Test	TGA	
Volatile Type	➢	x	x										Test/product knowledg	FTIR/Formula access	
Volatile Vapor Pressure			x										Test		
Resin Cost		x	x	x	x	x							Specified Value	Based on vender input	
Density			x	x	x	x							Analysis	Based on cured/uncured test data	
Resin Cure Shrinkage				x									Analysis	Based on volumetric test data	
CTE													Analysis	based on TMA or linear dilatometer data	
Thermal Conductivity			x										Analysis	Assumed to be that of cured resin	
Specific Heat			x										Analysis	Assumed to be that of cured resin	
Kinetics Model			x	x									Analysis	Based on Reaction Rate	
Viscosity Model			x	x									Analysis	Based on Kinetics Model, Test Data	
Intellectual Property Issues		x	x	x	x	x									
HPLC	➢	x	x	x	x	x							Test		
FTIR	➢	x	x	x	x	x							Test		
Health and Safety Information		x	x										MSDS		
Morphology			x												
Ingredient Suppliers			x	x	x	x									
Cured Resin															
Tensile Stress to Failure		x	x										Test	ASTM D638	
Young's Modulus, Tensile		x	x										Test	ASTM D638	
Tensile Strain to Failure		x	x										Test	ASTM D638	
Glass Transition Temperature		x	x										Test	ASTM D3418	
Volatile Content	➢	x	x	x	x	x							Test	ASTM D3530	
Density	➢	x	x	x	x	x							Test	ASTM D-792	
Modulus as a Function of Temp				x									Test	Function of Temp and Degree of Cure	
CTE				x									Test	ASTM E831 or linear diletometry	
Thermal Conductivity				x									Test	ASTM C177	
Solvent Resistance			x										Test	ASTM D543	
Specific Heat				x									Test	ASTM E-1269 or Modulated DSC	
Bulk Modulus				x									Analysis		
Shear Modulus				x									Test	ASTM E143	
Poisson's Ratio			x										Test	ASTM E143 (Room Temp)	
Coefficient of Moisture expansion				x									Test	No Standard	
Compression Strength				x									Test	ASTM D695	
Compression Modulus				x									Test	ASTM D695	
Mass Transfer Properties				x									Test	eight gain vs time, Ficks Law and modeling	
Viscoelastic Properties					x								Analysis		
Toughness Properties				x									Test		
Tg, Wet		x	x										Test	ASTM D3418	
CME				x									Test		
Solvent (Moisture) Diffusitivity				x									Test		
Solvent Resistance			x										Test		
	➢	= Key Variability Limits Items													

Figure D-39 Example Resin Check Sheet

FIBER		0	1	2	3	4	5	6	7	8	9	10	How Obtained, Test or Anlaysis	Test/Analysis Identification	Worksheet ID Reference
TEST TYPE/PROPERTIES - FIBER															
Tensile Strength	➢	x	x	x	x	x							Analysis	SACMA SRM 16-94	
Tensile Modulus E11 (longitudinal)	➢	x	x	x	x	x							Analysis	SACMA SRM 16-94	
Tensile Strain to Failure	➢	x	x	x	x	x							Analysis	SACMA SRM 16-94	
Yield (MUL)	➢	x	x	x	x	x							Analysis	SACMA SRM 13-94	
Density	➢	x	x	x	x	x							Test	SACMA SRM 15-94	
Heat Capacity (Cp)				x									Test	ASTM E-1269 or Modulated DSC	
Thermal Conductivity Longitudinal				x									Analysis	ASTM E-1225	
Thermal Conductivity Transverse				x									Analysis	ASTM E-1225	
CTE - Axial		x	x										Analysis	Modeling with Lamina and resin CTE information	
CTE - Radial				x									Analysis	Modeling with Lamina and resin CTE information	
Filament Diameter	➢	x	x	x	x	x							Test	Scanning Electron Microscopy	
Filament Count	➢	x	x	x	x	x							Test	Vendor	
Transverse Bulk Modulus				x									Analysis		
Youngs Modulus, E22 Transverse				x									Test	Analysis combined with mechanical test data	
Shear Modulus, G12				x									Analysis	Analysis combined with mechanical test data	
Shear Modulus, G23				x									Analysis	Analysis combined with mechanical test data	
Poissons Ratio, 12				x									Analysis	Analysis combined with mechanical test data	
Poissons Ratio, 23				x									Analysis	Analysis combined with mechanical test data	
Compressive Strength					x								Analysis	Analysis combined with mechanical test data	
Cost		x	x	x	x	x							Specified Value	Vendor Provided	
T(g)			x										Test	DMA	
wet T(g)			x										Test	DMA	
Health and Safety		x	x										MSDS		
Fiber Surface															
Sizing Type	➢	x	x	x	x	x							Specified Value		
Fiber Surface Roughness			x										Test	SEM or similar	
Surface Chemistry		x	x										Specified Value		
Fiber - Other															
Fiber CME beta1 (Longitudinal)				x									Test		
Fiber CME beta2 (transverse)				x									Test		
Fiber Form and Type (Uni and Cloth, ie 5hs or plain or 8hs etc.)		x	x	x											
Defect Identification			x												
Defect Limits				x											
	➢	= Key Variability Limits Items													

Figure D-40 Example Fiber Check Sheet

	TRL/XRL														
PREPREG		0	1	2	3	4	5	6	7	8	9	10	How Obtained, Test or Anlaysis	Test/Analysis Identification	Worksheet ID Reference
TEST TYPE/PROPERTIES - CHEMICAL															
Viscosity	➢	x	x	x	x	x							Test	ASTM D 4473	
Degree of Cure	➢	x	x	x	x	x							Test	DSC via ASTM D 3418 and ISO 11357	
HPLC	➢	x	x	x	x	x									
FTIR	➢	x	x	x	x	x									
TEST TYPE/PROPERTIES - PHYSICAL															
Resin Areal Weight	➢	x	x	x	x	x							Test	? digestion /burn-out ASTM D3171 or ASTM D3529	
Fiber Areal Weight	➢	x	x	x	x	x							Test	? digestion /burn-out ASTM D3171 or ASTM D3529	
Mass Fraction Fiber													Test	digestion /burn-out ASTM D3171 or ASTM D3529	
Prepreg Heat Capacity				x									Analyisis	Rule of mixtures of cured resin / fiber	
Density	➢		x	x	x	x							Analyisis	Rule of mixtures of cured resin / fiber	
Volume Fraction Fiber	➢		x	x	x	x							Analyisis	From mass fraction and densities	
Prepreg Ply Thickness	➢		x	x	x	x							Both	? Measured for unconsolidated, calculated for consolidated	
Prepreg Areal Weight	➢		x	x	x	x							Analyisis	From fiber areal weight	
Fiber Bed Permeability, x				x									Test	Speciallized test	
Fiber Bed Permeability, y				x									Test	Speciallized test	
Fiber Bed Permeability, z				x									Test	Speciallized test	
Drape			x	x									Test	Generally qualitative	
Tack			x	x									Test	Generally qualitative	
Viscoelastic Properties					x								Analyisis		
Prepreg Defect Probability					x	x							Analyisis		
Fiber Bed Elasticity				x									Test		
Cost													Specified Value		
Fiber - Other															
Volume Fraction Fiber Range, One Sigma					x	x							Test		
Backing Material ID			x	x	x	x							Specified Value?		
Separator Material ID			x	x	x	x							Specified Value?		
Available Widths			x	x	x	x							Specified Value?		
Impregnation Level	➢	x	x	x	x	x									
Defect Limits				x											
Defect Identification			x												
Key Variability Limits Items =	➢														

Figure D-41 Example Prepreg Check Sheet

				MECHCANICAL PROPERTIES - LAMINA		0	1	2	3	4	5	6	7	8	9	10	How Obtained, Test or Anlaysis	Test/Analysis Identification	Worksheet ID Reference
PRIMARY LAMINA PROPERTIES And DURABILITY																			
				Density of Composite		3	3	3	3	3							Analysis	Micromechanics	
Room Temperature	Tension		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2		3	x	x	x	x							Analysis	Volume average	
			Tranverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2		3	x	x									Analysis	Volume average	
			Through Thickness	Strength				o									Analysis	Volume average	
				Modulus				o									Analysis	Micromechanics	
	Compression		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2		3	x	x	x	x							Analysis	Volume average	
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x									Analysis	Volume average	
			Through Thickness	Strength				o									Analysis	Volume average	
	Shear		Longitudinal	Strength				o									Analysis	Volume average	
				Modulus 1				o											
				Modulus 2				o									Analysis	Micromechanics	
		±45°		Stength, Modulus, Strain to Failure		3	x	x	x	x									
		0°	ILS	Strength		3	x	x	x	x									
	Other			Bulk Modulus		o	o										Analysis	Micromechanics	
				Transverse Poisson's ratio 3				o									Analysis	Micromechanics	
				Transverse Poisson's ratio 4				o									Analysis	Micromechanics	
				Through Thickness Thermal Conductivity				x									Analysis	Micromechanics	
				Specific Heat				x									Analysis	Micromechanics	
			Longitudinal	Coeff. Of Thermal Expansion		x	x										Analysis	Micromechanics	
			Transverse			x	x										Analysis	Micromechanics	
			Through Thickness					x									Analysis	Micromechanics	
			Longitudinal	Coeff. Of Moisture Expansion					x								Analysis	Micromechanics	
			Transverse						x								Analysis	Micromechanics	
			Through Thickness						x								Analysis	Micromechanics	
			Longitudinal	Thermal Conductivity				x									Analysis	Micromechanics	
			Transverse					x									Analysis	Micromechanics	
	SIFT			Lamina Effective Critical J1		x	x										Test	Boeing method	
				Lamina Effective Critical Equivalent Strain		x	x										Test	Boeing method	
				Lamina Effective Pre -Critical Initiation J1		x	x										Test	Boeing method	
				Lamina Effective Pre-Critical Initiation Equivalent Strain		x	x										Test	Boeing method	
				Fiber Effective Critical J1		x	x										Test	Boeing method	
				Fiber Effective Critical Equivalent Strain		x	x										Test	Boeing method	

Figure D-42 Example Lamina Property and Durability Check Sheet, 1 of 3

Low Temperature	Tension		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2		x	x	x									Analysis	Volume average	
			Tranverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2		x	x	x									Analysis	Volume average	
			Through Thickness	Strength		x	x										Analysis	Volume average	
				Modulus		x	x										Analysis	Micromechanics	
	Compression		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x									Analysis	Volume average	
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x									Analysis	Volume average	
			Through Thickness	Strength													Analysis	Volume average	
	Shear		Longitudinal	Strength				x									Analysis	Volume average	
				Modulus 1				x											
				Modulus 2				x									Analysis	Micromechanics	
		±45°		Stength, Modulus, Strain to Failure				x											
		0°	ILS	Strength		x	x	x											
	SIFT			Lamina Effective Critical J1				x									Test	Boeing method	
				Lamina Effective Critical Equivalent Strain				x									Test	Boeing method	
				Lamina Effective Pre -Critical Initiation J1				x									Test	Boeing method	
				Lamina Effective Pre-Critical Initiation Equivalent Strain				x									Test	Boeing method	
				Fiber Effective Critical J1				x									Test	Boeing method	
				Fiber Effective Critical Equivalent Strain				x									Test	Boeing method	
Elevated Temperature 1	Tension		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2													Analysis	Volume average	
			Tranverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2													Analysis	Volume average	
			Through Thickness	Strength				o									Analysis	Volume average	
				Modulus				o									Analysis	Micromechanics	
	Compression		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2		x	x	x									Analysis	Volume average	
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2		x	x	x									Analysis	Volume average	
			Through Thickness	Strength				o									Analysis	Volume average	
	Shear		Longitudinal	Strength													Analysis	Volume average	
				Modulus 1															
				Modulus 2													Analysis	Micromechanics	
		±45°		Stength, Modulus, Strain to Failure		x	x												
		0°	ILS	Strength		x	x	x											
	SIFT			Lamina Effective Critical J1				x									Test	Boeing method	
				Lamina Effective Critical Equivalent Strain				x									Test	Boeing method	
				Lamina Effective Pre -Critical Initiation J1				x									Test	Boeing method	
				Lamina Effective Pre-Critical Initiation Equivalent Strain				x									Test	Boeing method	
				Fiber Effective Critical J1				x									Test	Boeing method	
				Fiber Effective Critical Equivalent Strain				x									Test	Boeing method	

Figure D-10 Example Lamina Property and Durability Check Sheet, 2 of 3

Elevated Temperature 2	Tension		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2													Analysis	Volume average	
			Tranverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x									Analysis	Volume average	
			Through Thickness	Strength													Analysis	Volume average	
				Modulus													Analysis	Micromechanics	
	Compression		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2			x	x									Analysis	Volume average	
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x									Analysis	Volume average	
			Through Thickness	Strength				o									Analysis	Volume average	
	Shear		Longitudinal	Strength				o									Analysis	Volume average	
				Modulus 1				o											
				Modulus 2				o									Analysis	Micromechanics	
		±45°		Stength, Modulus, Strain to Failure			x	x											
		0°	ILS	Strength			x	x											
	SIFT			Lamina Effective Critical J1				x									Test	Boeing method	
				Lamina Effective Critical Equivalent Strain				x									Test	Boeing method	
				Lamina Effective Pre -Critical Initiation J1				x									Test	Boeing method	
				Lamina Effective Pre-Critical Initiation Equivalent Strain				x									Test	Boeing method	
				Fiber Effective Critical J1				x									Test	Boeing method	
				Fiber Effective Critical Equivalent Strain				x									Test	Boeing method	
Elevated Temperature 1 or 2 and Wet	Tension		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2			x	x									Analysis	Volume average	
			Tranverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x									Analysis	Volume average	
			Through Thickness	Strength				o									Analysis	Volume average	
				Modulus													Analysis	Micromechanics	
	Compression		Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2			x	x	x								Analysis	Volume average	
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x									Analysis	Volume average	
			Through Thickness	Strength													Analysis	Volume average	
	Shear		Longitudinal	Strength													Analysis	Volume average	
				Modulus 1															
				Modulus 2													Analysis	Micromechanics	
		±45°		Stength, Modulus				x											
		0°	ILS	Strength			x	x											
	SIFT			Lamina Effective Critical J1				x									Test	Boeing method	
				Lamina Effective Critical Equivalent Strain				x									Test	Boeing method	
				Lamina Effective Pre -Critical Initiation J1				x									Test	Boeing method	
				Lamina Effective Pre-Critical Initiation Equivalent Strain				x									Test	Boeing method	
				Fiber Effective Critical J1				x									Test	Boeing method	
				Fiber Effective Critical Equivalent Strain				x									Test	Boeing method	
				Key Variability Limits Items =	➢														

Figure D-10 Example Lamina Property and Durability Check Sheet, 3 of 3

7. Detailed xRL for Structures, Material Properties and Material Durability					TRL/XRL 0	1	2	3	4	5	6	7	8	9	10	How Obtained, Test or Anlaysis	Test/Analysis Identification	Worksheet ID Reference
PRIMARY LAMINATE MATERIAL PROPERTIES																		
				Density of laminate	x	x	x	x	x							Test		
Room Temperature	Tension	Layup 1 (Quasi)	Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2	x	x	x	x	x							Test/Analysis		
				Open Hole Tensile Strength			x									Test/Analysis		
				Filled Hole			x											
		Layup 2 (Hard)	Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x								Test/Analysis		
				Open Hole Tensile Strength				x								Test/Analysis		
				Filled Hole				x										
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x								Test/Analysis		
				Open Hole Tensile Strength				x								Test/Analysis		
				Filled Hole				x										
		Layup 3 (Soft)	Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x								Test/Analysis		
				Open Hole Tensile Strength				x								Test/Analysis		
				Filled Hole				x										
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x								Test/Analysis		
				Open Hole Tensile Strength				x								Test/Analysis		
				Filled Hole				x										
	Compression	Layup 1 (Quasi)	Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2	x	x	x	x	x							Test/Analysis		
				Open Hole Compressive Strength	x	x	x									Test/Analysis		
				Filled Hole			x											
		Layup 2 (Hard)	Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x								Test/Analysis		
				Open Hole Compressive Strength				x								Test/Analysis		
				Filled Hole				x										
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x								Test/Analysis		
				Open Hole Compressive Strength				x								Test/Analysis		
				Filled Hole				x										
		Layup 3 (Soft)	Longitudinal	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x								Test/Analysis		
				Open Hole Compressive Strength				x								Test/Analysis		
				Filled Hole				x										
			Transverse	Strength, Modulus, Strain to Failure, Poissons 1 & 2				x								Test/Analysis		
				Open Hole Compressive Strength				x								Test/Analysis		
				Filled Hole				x										
	Shear	Layup 1 (Quasi)	Longitudinal	Shear Strength, Modulus, Strain to Failure												Test/Analysis		
				Interlaminar Shear														
			Transverse	Stength 1, Modulus 1, Strain to Failure 1												Analysis/Test	Laminate Module	
				Stength 2, Modulus 2, Strain to Failure 2												Analysis/Test	Laminate Module	
		Layup 2 (Hard)	Longitudinal	Shear Strength, Modulus, Strain to Failure												Test/Analysis		
			Transverse	Stength 1, Modulus 1, Strain to Failure 1												Analysis/Test	Laminate Module	
				Stength 2, Modulus 2, Strain to Failure 2												Analysis/Test	Laminate Module	
		Layup 3 (Soft)	Longitudinal	Shear Strength, Modulus, Strain to Failure												Test/Analysis		
			Transverse	Stength 1, Modulus 1, Strain to Failure 1												Analysis/Test	Laminate Module	
				Stength 2, Modulus 2, Strain to Failure 2												Analysis/Test	Laminate Module	
	Bearing By-Pass, Tension	Layup 1 (Quasi)	Longitudinal	Strength, Strain to Failure												Test/Analysis		
			Transverse	Strength, Strain to Failure												Analysis/Test	Laminate Module	
		Layup 2 (Hard)	Longitudinal	Strength, Strain to Failure												Test/Analysis		
			Transverse	Strength, Strain to Failure												Analysis/Test	Laminate Module	
		Layup 3 (Soft)	Longitudinal	Strength, Strain to Failure												Test/Analysis		
			Transverse	Strength, Strain to Failure												Analysis/Test	Laminate Module	
	Bearing By-Pass, Compression	Layup 1 (Quasi)	Longitudinal	Strength, Strain to Failure												Test/Analysis		
			Transverse	Strength, Strain to Failure												Analysis/Test	Laminate Module	
		Layup 2 (Hard)	Longitudinal	Strength, Strain to Failure												Test/Analysis		
			Transverse	Strength, Strain to Failure												Analysis/Test	Laminate Module	
		Layup 3 (Soft)	Longitudinal	Strength, Strain to Failure												Test/Analysis		
			Transverse	Strength, Strain to Failure												Analysis/Test	Laminate Module	

Figure D-11 Example Laminate Property and Durability Check Sheet, 1 of 7

7. Detailed xRL for Structures, Material Properties and Material Durability					0	1	2	3	4	5	6	7	8	9	10	How Obtained, Test or Anlaysis	Test/Analysis Identification	Worksheet ID Reference
SECONDARY LAMINATE MATERIAL PROPERTIES																		
Room Temperature	Secondary	Layup 1 (Quasi)		Laminate Interlaminar Mode I Fracture Toughness												Test		
				Laminate Interlaminar Mode II Fracture Toughness												Test		
				Stiffness Matrix												Analysis/Test	Laminate Module	
				Bending Matrix												Analysis/Test	Laminate Module	
				Laminate Poisson's ratio 1												Test/Analysis		
				Laminate Longitudinal Coeff. Of Thermal Expansion												Test		
				Laminate Transverse Coeff. Of Thermal Expansion												Analysis	Laminate Module	
				Laminate Intralaminar Mode I Fracture Toughness												Test/Analysis		
				Laminate Intralaminar Mode II Fracture Toughness												Test/Analysis		
				Flexural, torsional, and combined loading strength												Analysis	Laminate Module	
				Fiber inputs: Weibull parameters, strain to failure												Test	Lamina Module	
				Viscoelastic, nonlinear matrix behavior calculation methods												Analysis	Lamina Module	
				First ply failure envelopes												Analysis	Laminate Module	
				Laminate Shear Modulus												Test/Analysis		
				Laminate Longitudinal Coeff. Of Moisture Expansion												Test		
				Laminate Transverse Coeff. Of Moisture Expansion												Test		
7. Detailed xRL for Structures, Material Properties and Material Durability					0	1	2	3	4	5	6	7	8	9	10	How Obtained, Test or Anlaysis	Test/Analysis Identification	Worksheet ID Reference
OTHER LAMINATE MATERIAL PROPERTIES																		
Room Temperature	Other	Layup 1 (Quasi)		Compressive Elastic Moduli												Analysis	Lamina Module	
				Stochastic calculation methods												Analysis	Laminate Module	
				Coupling Matrix												Analysis/Test	Laminate Module	
				Laminate Through Thickness Tensile Modulus												Test/Analysis		
				Laminate Shear Coeff. Of Thermal Expansion												Analysis	Laminate Module	
				Laminate Longitudinal Thermal Conductivity												Test		
				Laminate Transverse Thermal Conductivity												Test		
				Laminate Through-Thickness Tensile Strength												Test/Analysis		
				Laminate Through-Thickness Tensile Strain to Failure												Test/Analysis		
				Fiber/matrix interface properties												Test	Lamina Module	
				Laminate Transverse Poisson's ratio 3												Analysis	Laminate Module	
				Laminate Transverse Poisson's ratio 4												Analysis	Laminate Module	
				Laminate Through-Thickness Compressive Strength												Test/Analysis		
				Laminate Through-Thickness Compressive Strain to Failure												Test/Analysis		
				Isotropic Fiber Properties and/or option for associated calculation method												Analysis	Lamina Module	
				Laminate Through Thickness Coeff. Of Thermal Expansion												Analysis	Laminate Module	
				Laminate Shear Coeff. Of Moisture Expansion												Analysis	Structures Module	
				Laminate Through Thickness Coeff. Of Moisture Expansion												Analysis	Structures Module	
				Laminate Through Thickness Thermal Conductivity												Analysis	Structures Module	

Figure D-11 Example Laminate Property and Durability Check Sheet, 2 of 7