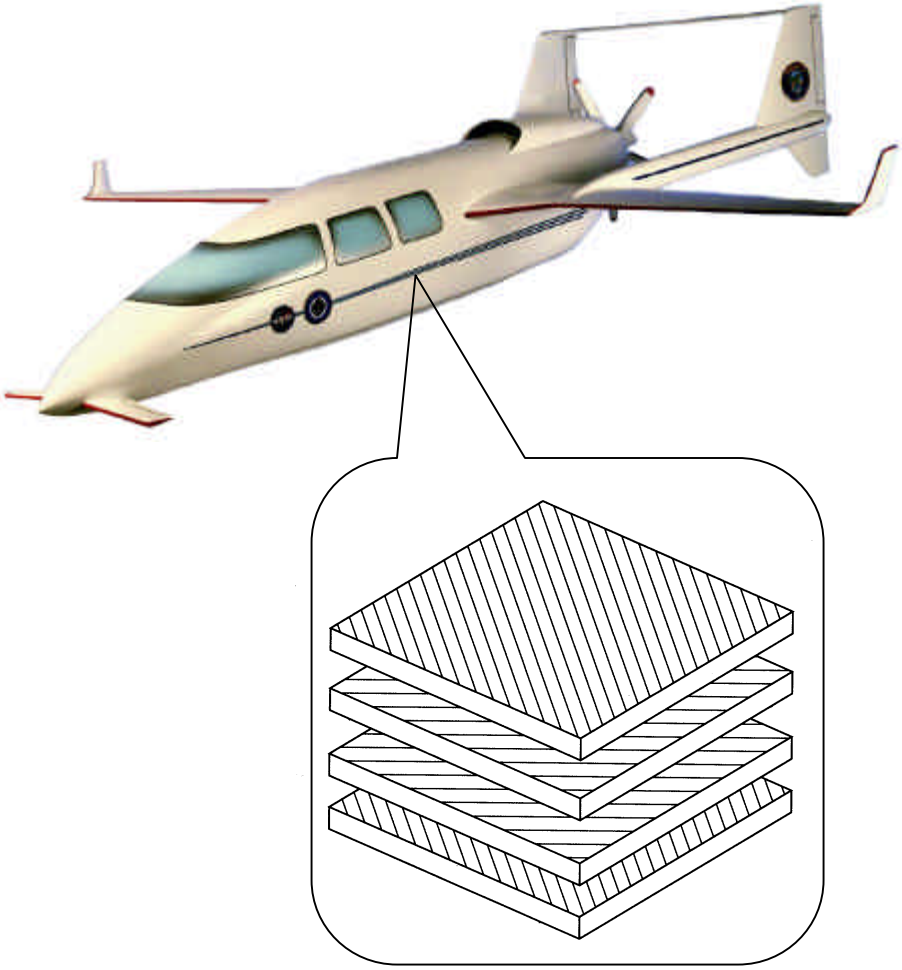

Overview of Advanced Materials Research for the NASA-AGATE Program

Dr. John Tomblin
Task Leader

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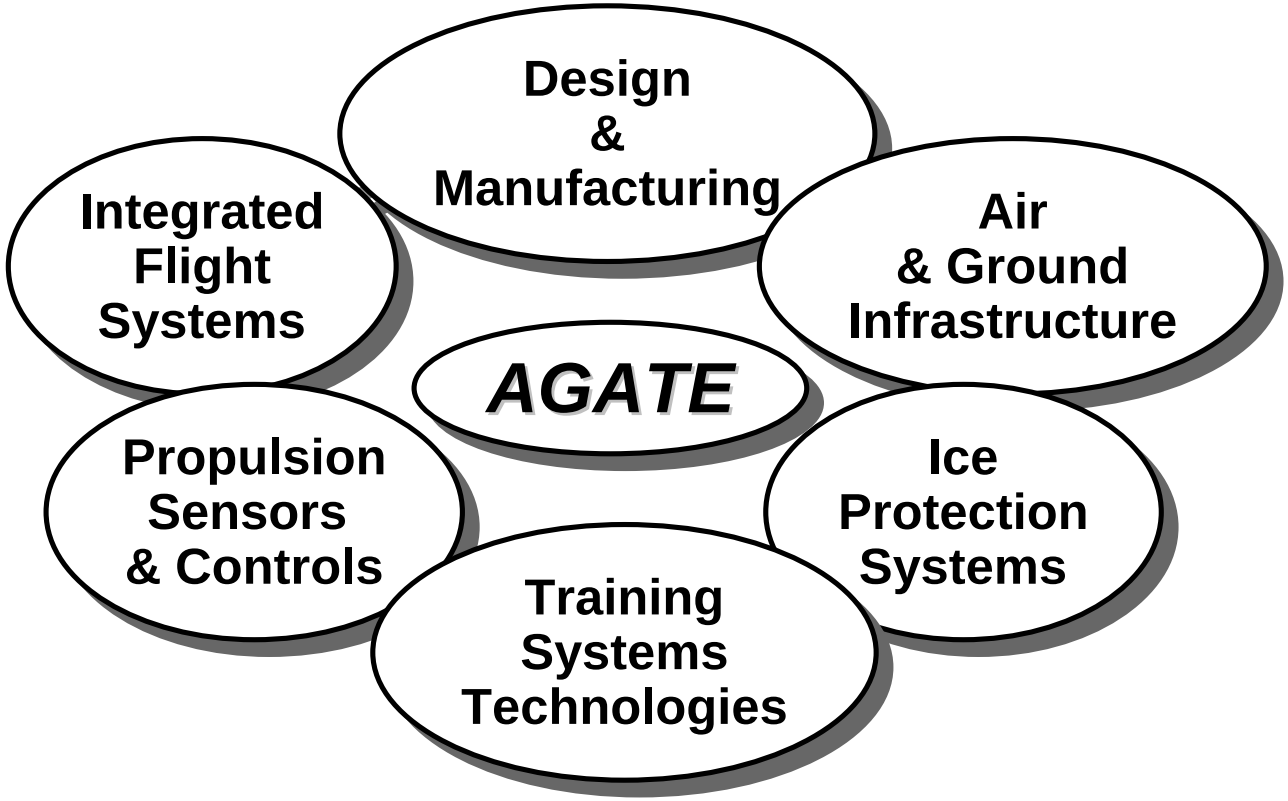
WHAT IS AGATE ?

GOAL:

To revitalize U.S. general aviation through development and deployment of advanced technologies in support of retrofit markets and a general aviation transportation system

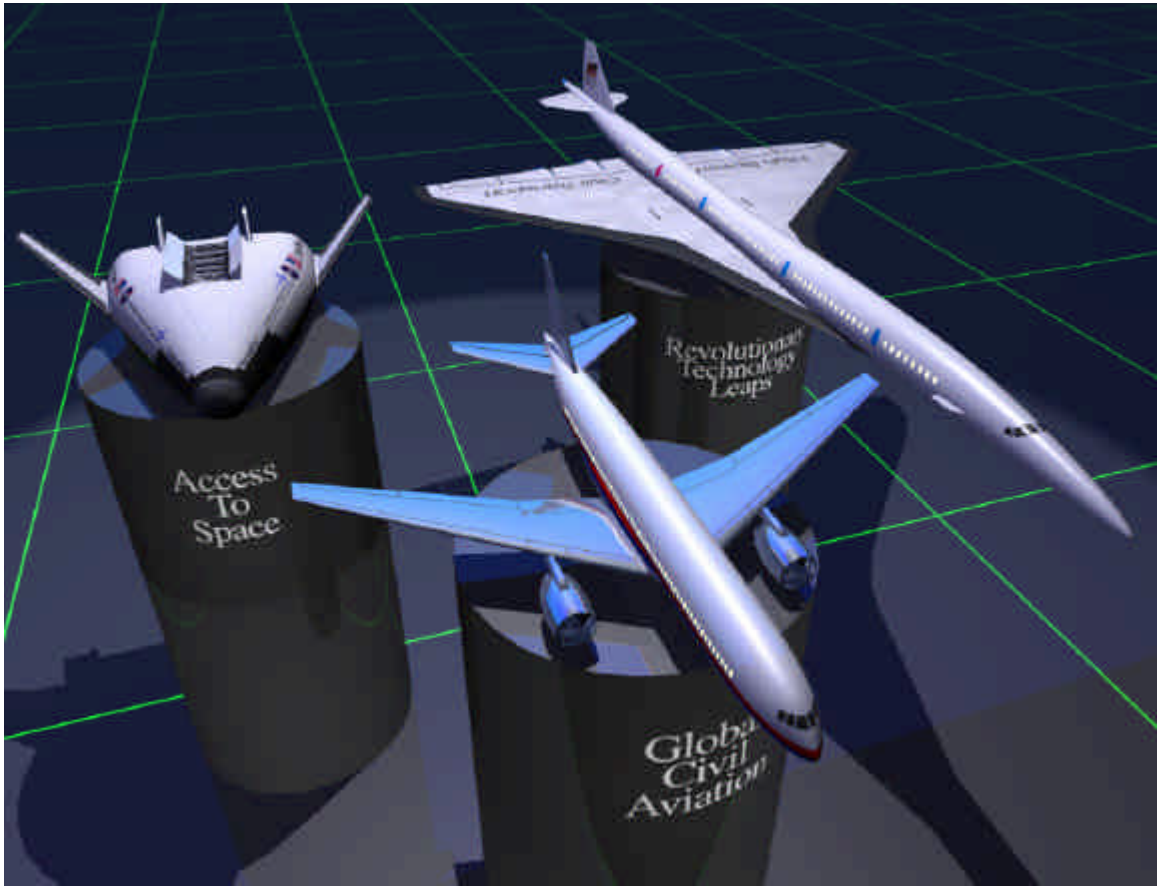


Three Pillars for Success

AGATE

Integrated Design and Manufacturing

NASA's Response to Achieve the National Priorities in Aeronautics and Space Transportation

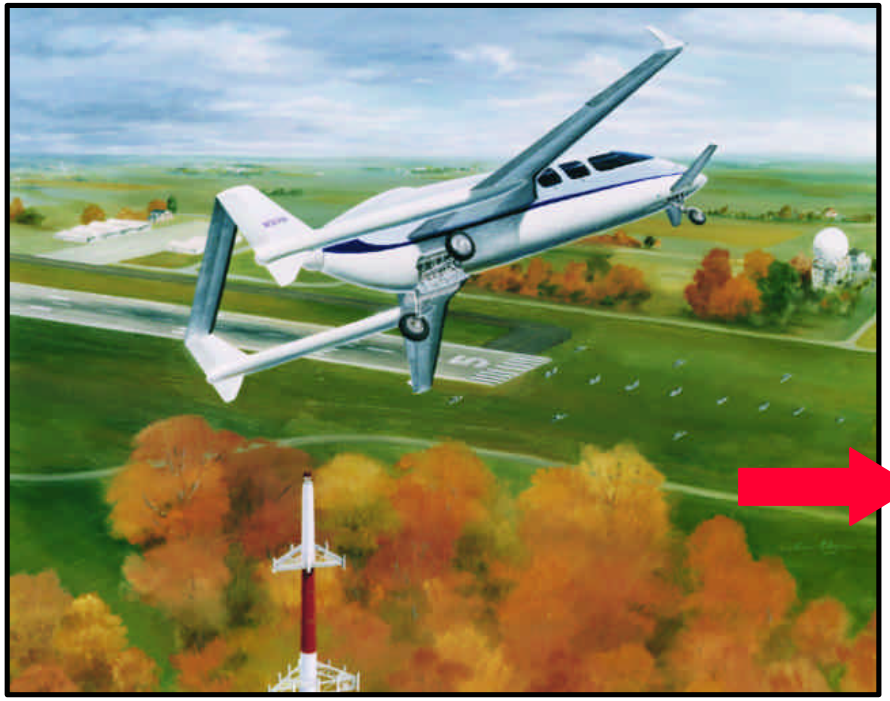


Office of Aeronautics & Space Transportation Technology
National Aeronautics and Space Administration

Pillar Two: Revolutionary Technology Leaps

AGATE

Integrated Design and Manufacturing



- **Reduce the Travel Time to the Far East and Europe** by 50% within 20 years, and do so at today's subsonic ticket prices.
- **Invigorate the General Aviation Industry**, delivering 10,000 aircraft annually within 10 years, and 20,000 aircraft annually within 20 years.
- Provide next-generation design tools and experimental aircraft to increase design confidence and **Cut the Development Cycle Time for Aircraft in Half**.

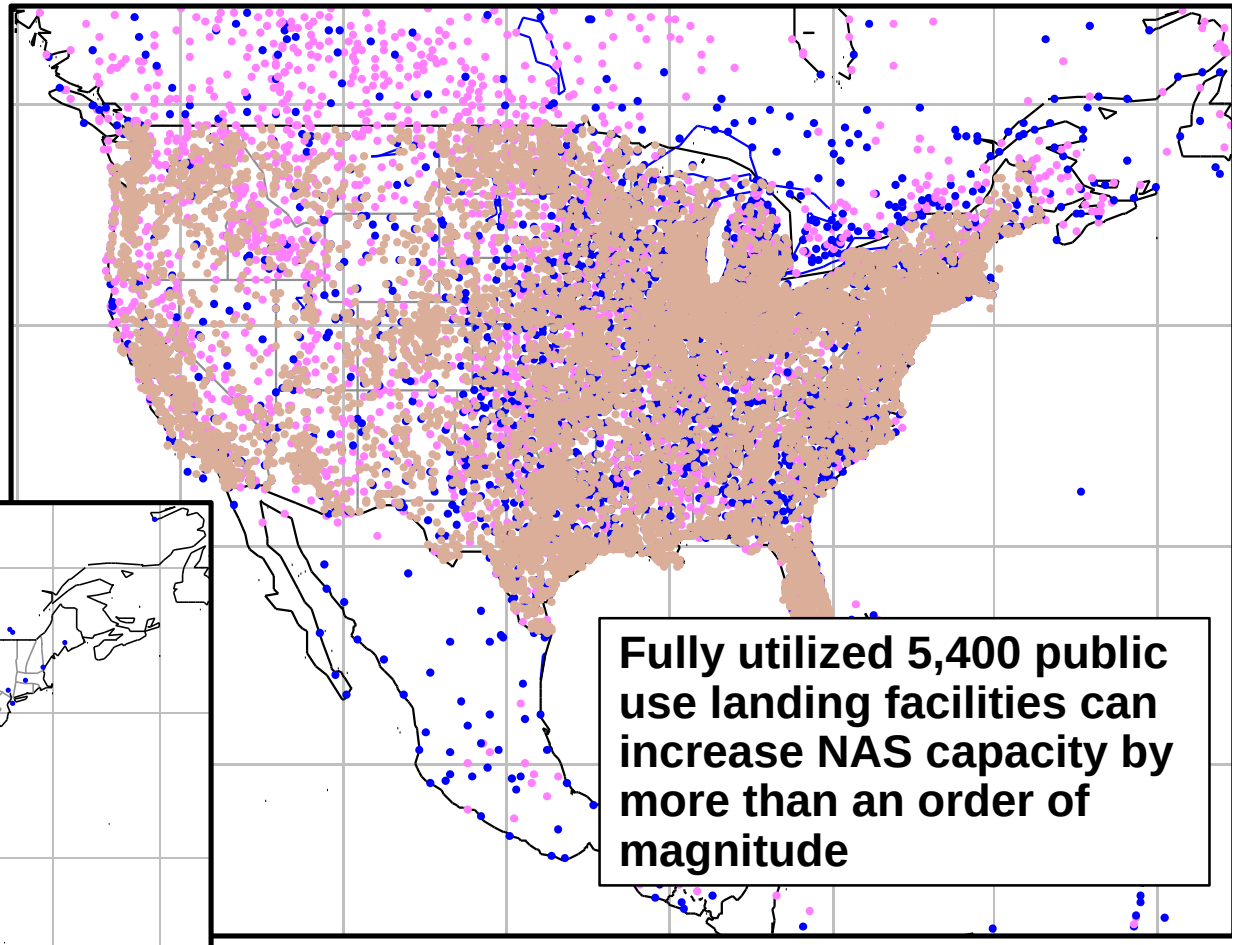
GENERAL AVIATION IMPACT ON CAPACITY

AGATE

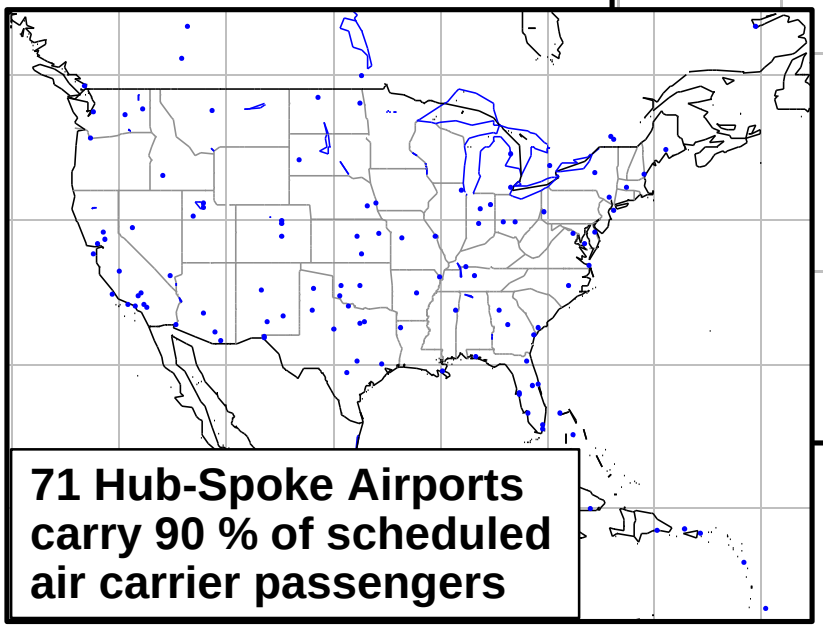
Integrated Design and Manufacturing

Increased capacity results from

- ***more approaches***
- ***during more weather***
- ***at more airports***



Fully utilized 5,400 public use landing facilities can increase NAS capacity by more than an order of magnitude



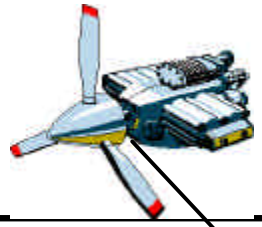
71 Hub-Spoke Airports carry 90 % of scheduled air carrier passengers

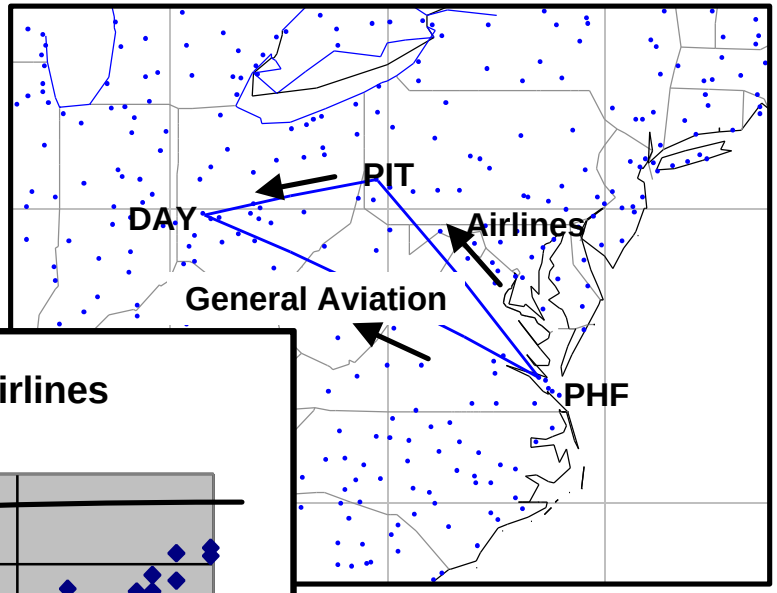
Aesop was right...

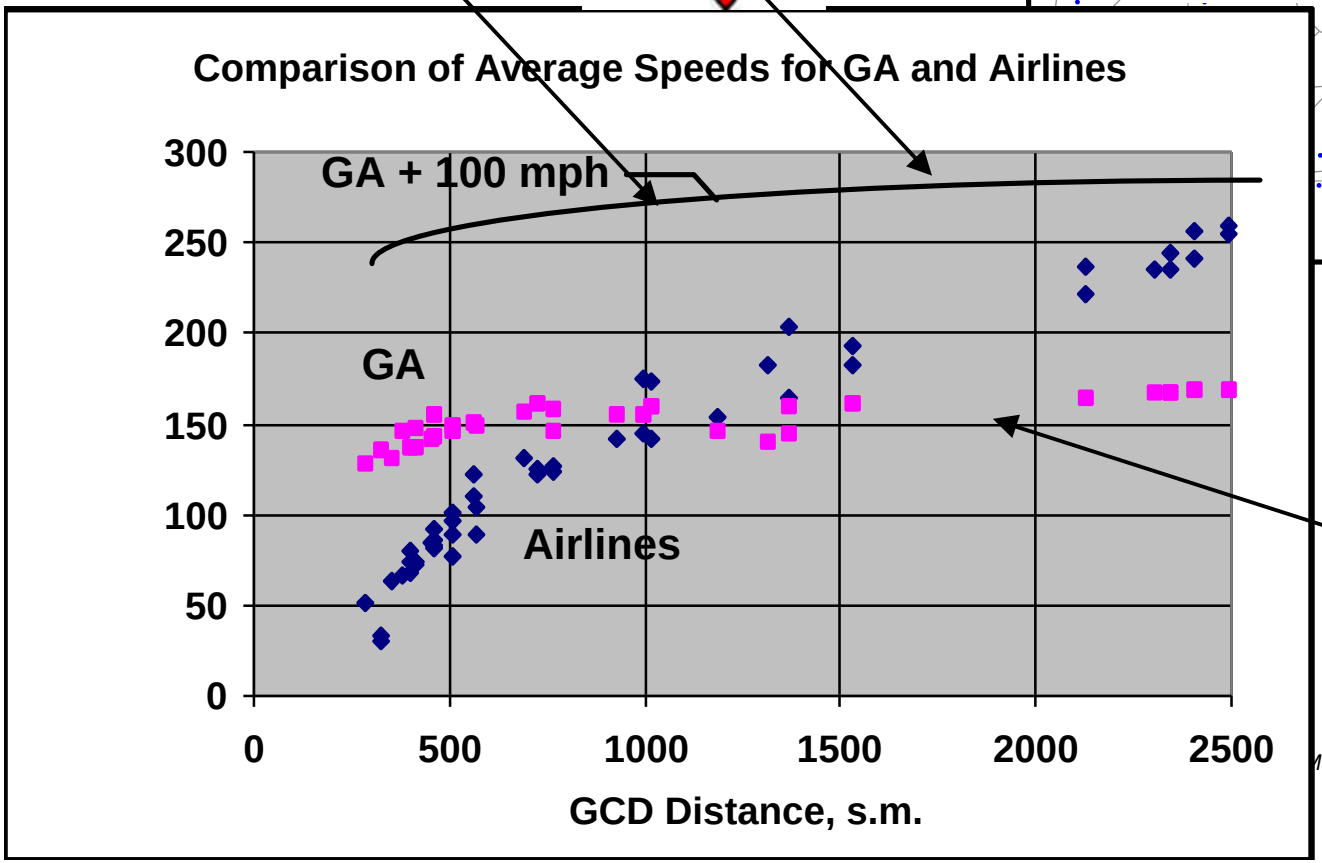
AGATE

Integrated Design and Manufacturing

Small aircraft portal-to-portal speed advantage







- **GA+100 mph, plus destination benefit**

Materials Group Organization and Membership

AGATE

Integrated Design and Manufacturing

Small Airplane Directorate

Local Aircraft Certification Offices

National Resource Specialist

Technical Center

AERONAUTICS

Materials Group Objectives

1993 General Aviation Task Force Report

Recommendation for Materials - "*NASA should develop a design manual for the use of composite materials in GA aircraft*"

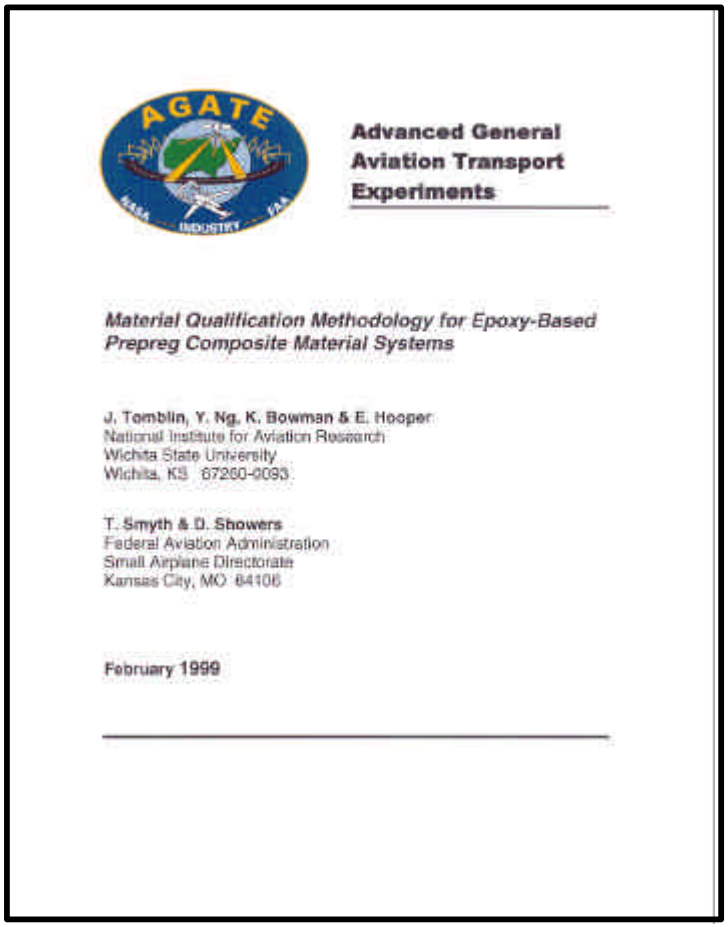
- **standardize test methodology**
- **develop database for applicable GA materials**
- **develop methodology for manufacturing process control**
- **develop methodology for suppliers to incorporate new materials and processes**
- **develop priority of materials to be characterized**
- **shorten development and certification cycle**
  - ***5 years to 3 years***

Material Qualification

AGATE

Material Qualification Document Completed for Epoxy Based Prepreg Systems

- Used for all future AGATE testing
- Detailed descriptions of panels required for testing as well as manufacturing and testing procedures
- Allows "apple-to-apple" comparison of data across the working group
- Reviewed by all AGATE ID&M materials group members and the FAA (NRS, Small Airplane Directorate, Tech Center and several ACO's)
- Generation of B and A basis design allowables included



AGATE

Advanced General Aviation Transport Experiments

Material Qualification Methodology for Epoxy-Based Prepreg Composite Material Systems

J. Tomblin, Y. Ng, K. Bowman & E. Hooper
National Institute for Aviation Research
Wichita State University
Wichita, KS 67260-0093

T. Smyth & D. Showers
Federal Aviation Administration
Small Airplane Directorate
Kansas City, MO 64106

February 1999

Material Qualification

- **Currently concentrated on epoxy-based prepreg systems**
  - **250° F cure systems with both low-pressure autoclave and vacuum cure cycles**
  - **Glass fabric (7781)**
  - **Carbon fabric (plain weave and 8 harness satin)**
  - **Unidirectional (S2 glass and carbon)**
  - **MIL-HDBK-17 format *with reduced process specification attached***
  - **possible submittal to MIL-HDBK-17 in the future (AGATE data restrictions)**

B-Basis Testing Requirements

AGATE

Integrated Design and Manufacturing

NO.	TEST	METHOD	NO. OF REPLICATES PER TEST CONDITION			
			CTD[1]	RTD[2]	ETW[3]	ETD[4]
1	0° (warp) Tension Strength	ASTM D3039-95	1x4	3x4	3x4	3x4
2*	0° (warp) Tension Modulus, Strength and Poisson's Ratio	ASTM D3039-95	1x2	3x2	3x2	3x2
3	90° (fill) Tension Strength	ASTM D3039-95	1x4	3x4	3x4	3x4
4*	90° (fill) Tension Modulus and Strength	ASTM D3039-95	1x2	3x2	3x2	3x2
5	0° (warp) Compression Strength	SACMA SRM 1-94	1x6	3x6	3x6	3x6
6*	0° (warp) Compression Modulus	SACMA SRM 1-94	1x2	3x2	3x2	3x2
7	90° (fill) Compression Strength	SACMA SRM 1-94	1x6	3x6	3x6	3x6
8*	90° (fill) Compression Modulus	SACMA SRM 1-94	1x2	3x2	3x2	3x2
9	In-Plane Shear Strength	ASTM D5379-93	1x4	3x4	3x4	3x4
10*	In-Plane Shear Modulus and Strength	ASTM D5379-93	1x2	3x2	3x2	3x2
11	Short Beam Shear	ASTM D2344-89	--	3x6	--	--

* strain gages used during testing

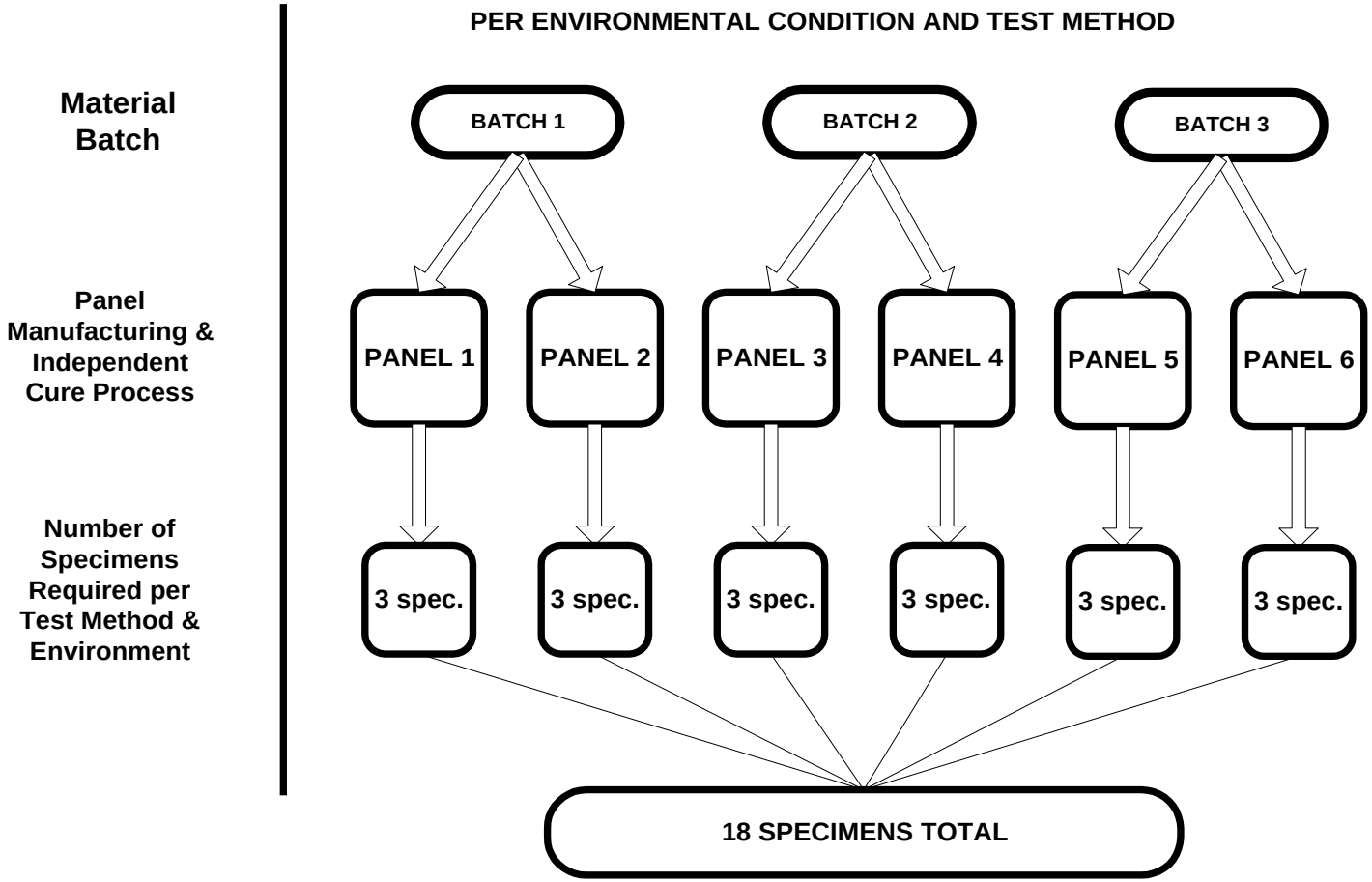
Notes :

1. Only one batch of material is required (test temperature = -65 ± 5° F, moisture content = as fabricated[5])
2. Three batches of material are required (test temperature = 70 ± 10° F, moisture content = as fabricated[5])
3. Three batches of material are required (test temperature = 180 ± 5° F, moisture content = per section 3.2)
4. Three batches of material are required (test temperature = 180 ± 5° F, moisture content = as fabricated[5])
5. Dry specimens are "as fabricated" specimens that have been maintained at ambient conditions in an environmentally controlled laboratory.

Material Qualification

SPECIMEN SELECTION METHODOLOGY AND BATCH TRACEABILITY

PER ENVIRONMENTAL CONDITION AND TEST METHOD



Statistical Design Allowable Generation

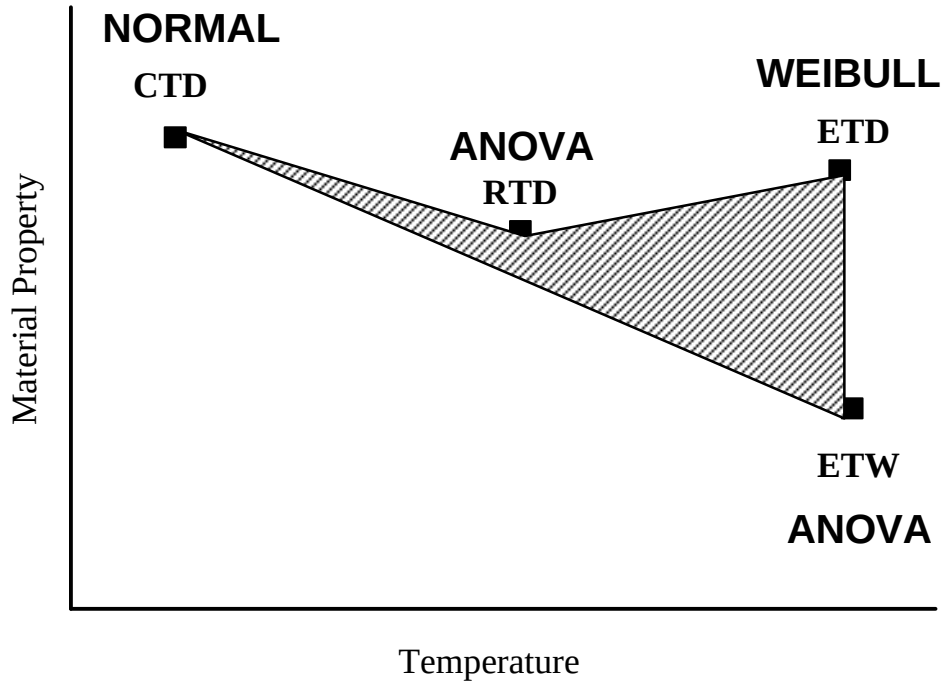
- **Due to the relatively small number of specimens (3 batches of 6 replicates = 18 specimens per condition), the design allowable was generated by the method presented by Shyprykevich[1]**
- **Data is pooled across all test environments to generate population variability factors**
- **Assumptions**
  - **failure modes for each environment should not significantly change**
  - **variability across environments should be comparable**
  - **batch-to-batch variability neglected**

---

1 Reference : Shyprykevich, P., "The Role of Statistical Data Reduction in the Development of Design Allowables for Composites," ***Test Methods for design Allowables for Fibrous Composites : 2nd Volume, ASTM STP 1003, C.C. Chamis, Ed., ASTM, Philadelphia, PA, 1989, pp. 111-135.***

Statistical Design Allowable Generation

- **Overcomes the problem of "distributional changes" which commonly occurs across environments**
- **Extremely difficult to obtain "realistic" load enhancement factors**
- **For this AGATE procedure, only a "normal" distribution was utilized**



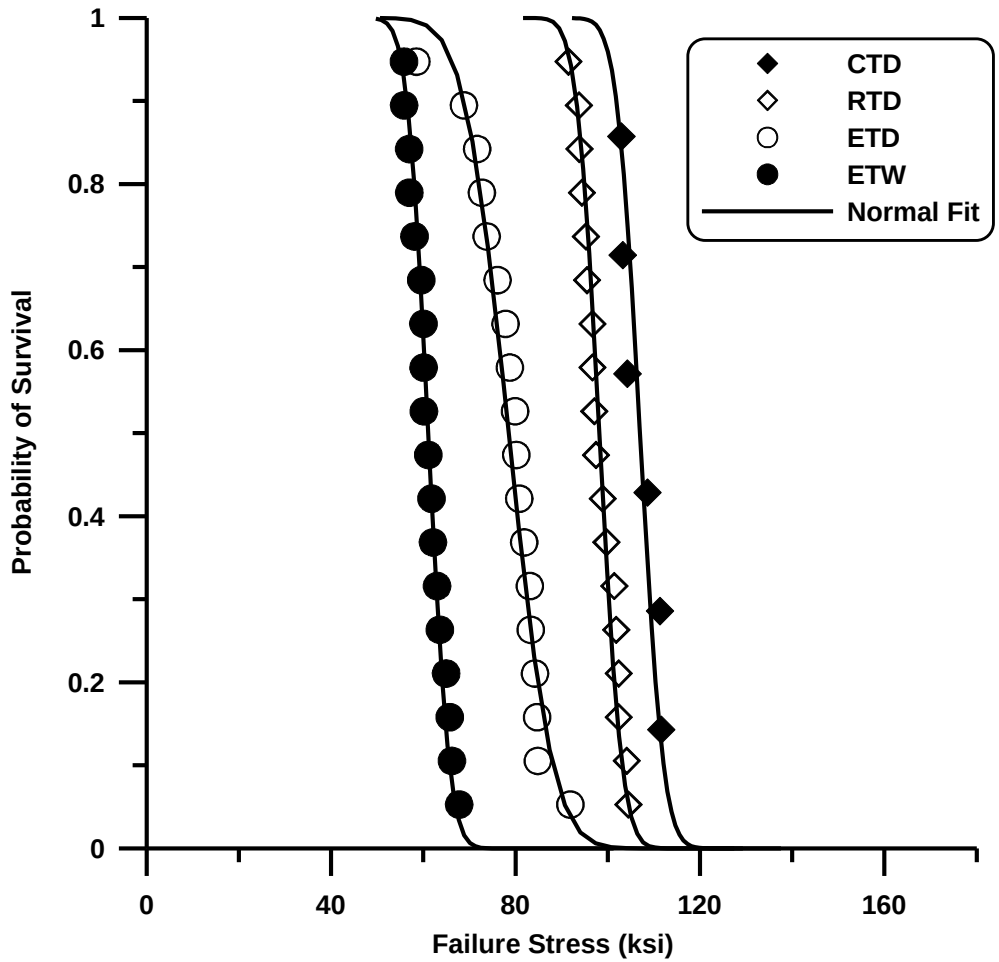
Example Raw Data

AGATE

Integrated Design and Manufacturing

CTD			RTD			ETD			ETW		
Batch	Panel	Data	Batch	Panel	Data	Batch	Panel	Data	Batch	Panel	Data
1	1	103.260	1	1	94.395	1	1	72.712	1	1	55.809
1	1	104.281	1	1	101.854	1	1	81.884	1	1	55.853
1	1	111.588	1	1	102.363	1	1	68.822	1	1	58.091
1	2	111.336	1	2	101.442	1	2	78.771	1	2	63.587
1	2	102.967	1	2	96.687	1	2	84.838	1	2	60.137
1	2	108.615	1	2	104.115	1	2	79.906	1	2	56.951
			2	3	102.360	2	3	58.500	2	3	62.986
			2	3	96.684	2	3	83.108	2	3	67.795
			2	3	97.435	2	3	80.162	2	3	64.954
			2	4	95.267	2	4	80.815	2	4	61.094
			2	4	104.483	2	4	84.690	2	4	65.736
			2	4	98.908	2	4	91.886	2	4	61.769
			3	5	93.750	3	5	76.109	3	5	62.099
			3	5	91.478	3	5	77.838	3	5	60.080
			3	5	93.860	3	5	83.304	3	5	59.553
			3	6	95.519	3	6	73.745	3	6	66.199
			3	6	97.085	3	6	84.229	3	6	56.975
			3	6	99.735	3	6	71.684	3	6	60.037
AVG	**:**	**107.01**	**AVG**	**:**	**98.19**	**AVG**	**:**	**78.50**	**AVG**	**:**	**61.09**
STD	**:**	**4.00**	**STD**	**:**	**3.88**	**STD**	**:**	**7.51**	**STD**	**:**	**3.62**
CV%	**:**	**3.74**	**CV%**	**:**	**3.95**	**CV%**	**:**	**9.57**	**CV%**	**:**	**5.92**
n	**:**	**6**	**n**	**:**	**18**	**n**	**:**	**18**	**n**	**:**	**18**

Normality Check (by environmental condition)



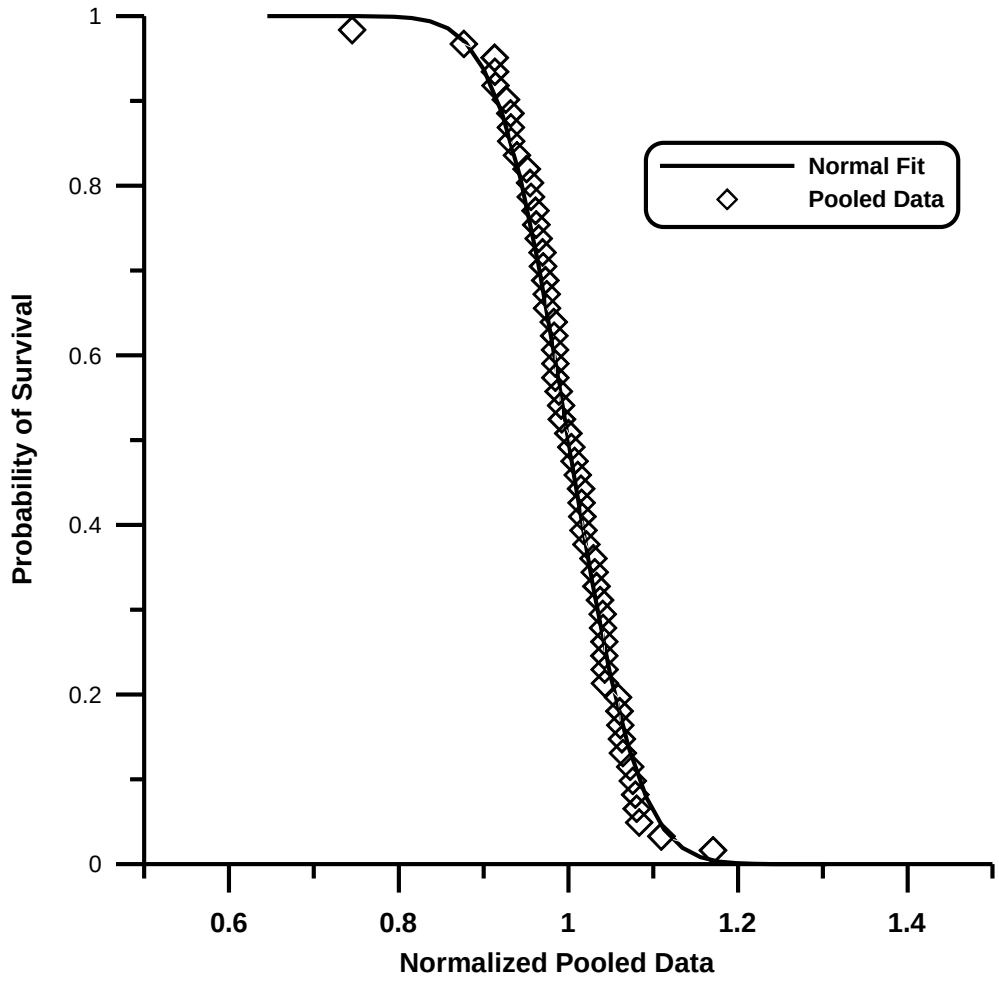
- **Engineering judgement is used to check the data fit**
- **If deviations exist, traditional MIL-17 procedures must be utilized**

Normalization by mean

CTD			RTD			ETD			ETW		
Batch	Panel	Data	Batch	Panel	Data	Batch	Panel	Data	Batch	Panel	Data
1	1	0.965	1	1	0.961	1	1	0.926	1	1	0.913
1	1	0.975	1	1	1.037	1	1	1.043	1	1	0.914
1	1	1.043	1	1	1.042	1	1	0.877	1	1	0.951
1	2	1.040	1	2	1.033	1	2	1.003	1	2	1.041
1	2	0.962	1	2	0.985	1	2	1.081	1	2	0.984
1	2	1.015	1	2	1.060	1	2	1.018	1	2	0.932
			2	3	1.042	2	3	0.745	2	3	1.031
			2	3	0.985	2	3	1.059	2	3	1.110
			2	3	0.992	2	3	1.021	2	3	1.063
			2	4	0.970	2	4	1.029	2	4	1.000
			2	4	1.064	2	4	1.079	2	4	1.076
			2	4	1.007	2	4	1.171	2	4	1.011
			3	5	0.955	3	5	0.970	3	5	1.016
			3	5	0.932	3	5	0.992	3	5	0.983
			3	5	0.956	3	5	1.061	3	5	0.975
			3	6	0.973	3	6	0.939	3	6	1.084
			3	6	0.989	3	6	1.073	3	6	0.933
			3	6	1.016	3	6	0.913	3	6	0.983

Pooled Average :	**1.000**
Pooled Standard Dev. :	**0.0649**
Coeff. of Variation :	**6.494**
Number of Observations :	**60**

Normality Check (pooled across environments)



- **Engineering judgement is used to check the data fit**
- **If deviations exist, traditional MIL-17 procedures must be utilized**

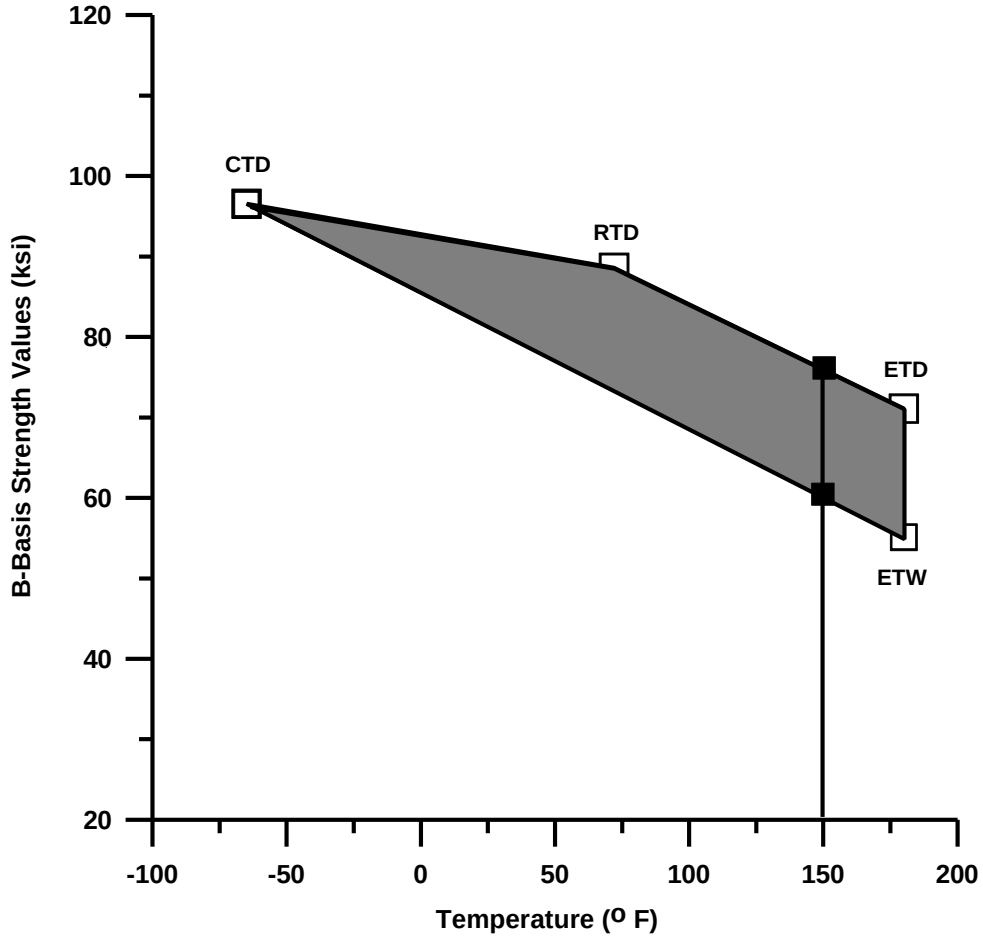
Comparison of Allowables

	AGATE			STAT 17		
	A-Basis	B-Basis	Distrib.	A-Basis	B-Basis	Distrib.
CTD	87.50	95.83	*normal*	N/A	N/A	*N/A*
RTD	80.29	87.93	*normal*	84.79	88.18	*weibull*
ETD	64.19	70.30	*normal*	56.76	62.03	*weibull*
ETW	49.96	54.71	*normal*	33.69	45.89	*ANOVA*

Traditional MIL-HDBK-17 allowable generation methods

Material Qualification

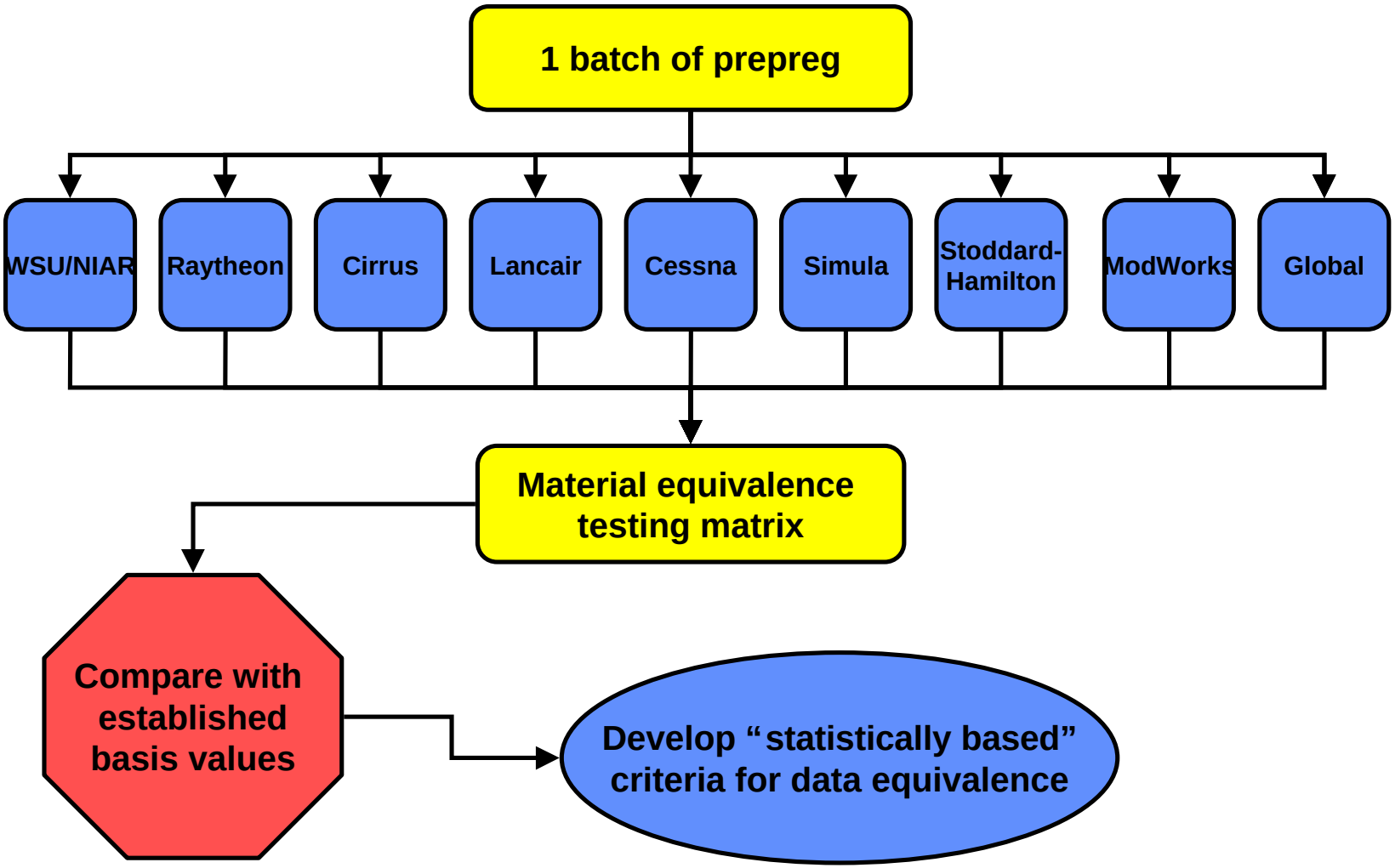
- **All testing to use 180° F as the maximum elevated temperature for GA applications**
- **Use interpolation to obtain values for individual application MOL**



Ongoing Work - Material Equivalence

- **Significance to the AGATE materials program**
  - **Allow minor changes in constituents or constituent manufacturing processes**
  - **Allow identical materials to be processed by different component manufacturers**
  - **Allow identical materials to be processed at different locations by the same manufacturer**
  - **Allow slight changes in processing parameters**
  - **Allow the use of other accepted databases**
  - **some combination of the above**
- **use MIL-HDBK-17 as initial guideline**
- **Jointly developed with FAA oversight**
- **Conduct an AGATE "inverse round-robin" test program to establish criteria and relevant variables**

Material Equivalence



Material Equivalence

NO.	TEST	METHOD	NUMBER OF REPLICATES PER TEST CONDITION[1]	
			RTD[2]	ETW[3]
2*	0° (warp) Tension Modulus, Strength and Poisson's Ratio[5,6]	ASTM D3039-95	8	8
4*	90° (fill) Tension Modulus and Strength[5]	ASTM D3039-95	8	8
5	0° (warp) Compression Strength	SACMA SRM 1-94	8	8
6*	0° (warp) Compression Modulus	SACMA SRM 1-94	2	2
7	90° (fill) Compression Strength	SACMA SRM 1-94	8	8
8*	90° (fill) Compression Modulus	SACMA SRM 1-94	2	2
10*	In-Plane Shear Modulus and Strength[5]	ASTM D5379-93	8	8
11	Short Beam Shear	ASTM D2344-89	8	--

* strain gages used during testing

Notes :

1 Only one batch of material is required
2 Test temperature = 70 ± 10° F, moisture content = as fabricated[4]
3 Test temperature = 180 ± 5° F, moisture content = per section 3.2
4 Dry specimens are "as fabricated" specimens that have been maintained at ambient conditions in an environmentally controlled laboratory
5 Only two specimens require the use of strain gages to obtain modulus
6 Biaxial strain gages must be used to obtain Poisson's ratio

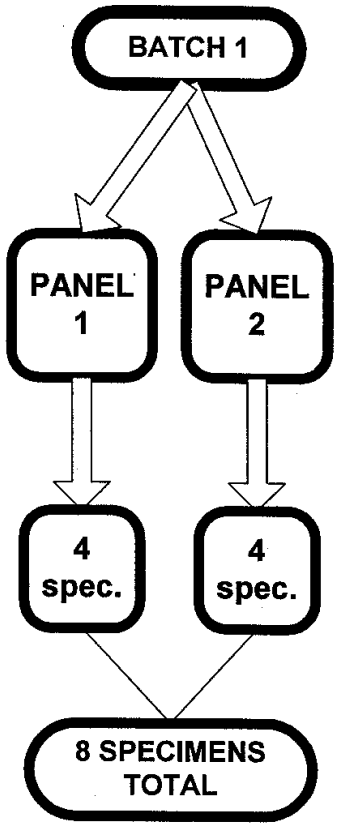
Material Equivalence

- **Draft of material equivalence plan proposed**
- **First, ONLY considering manufacturing location change**
- **Enlist help from MIL-HDBK-17 (Dr. Mark Vangel)**

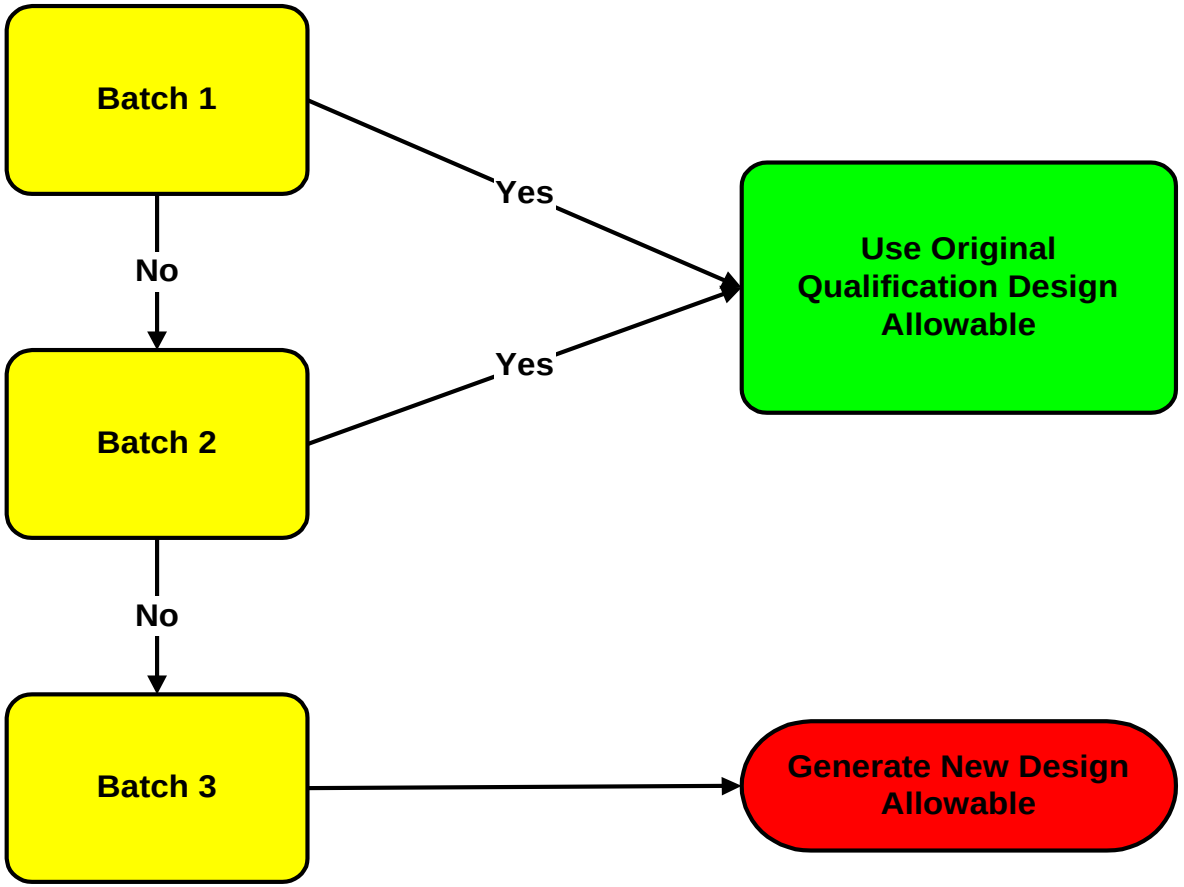
Material Batch

Panel Manufacturing & Independent Cure Process

Number of Specimens Required per Test Method & Environment



Material Equivalence

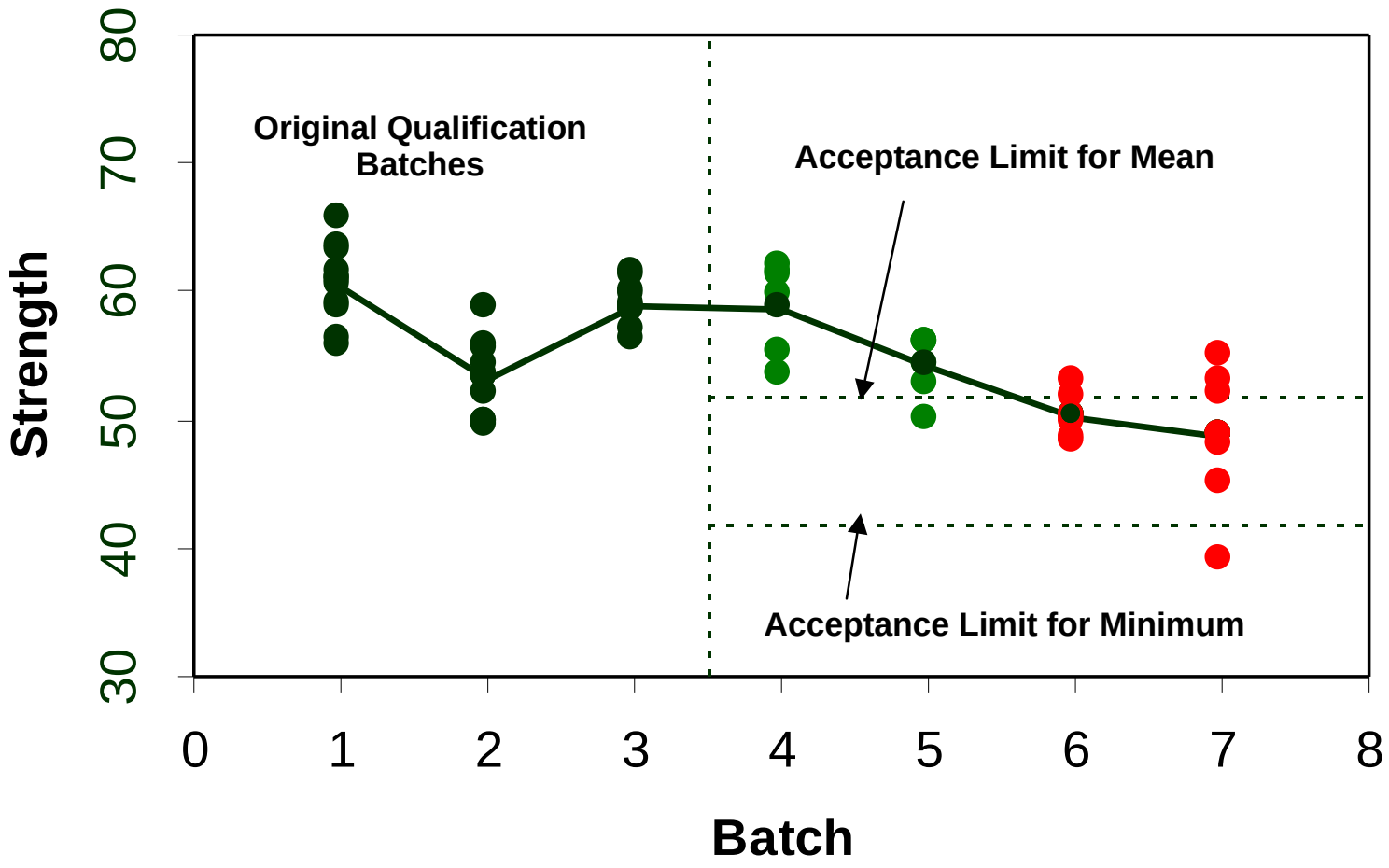


Material Equivalence

EXAMPLE

- Material equivalence must use both average and minimum for acceptance criteria for strength
- For strength, fail if the test if either the average is too low OR else the sample minimum is too low
- For modulus, fail if the test if either the average is either too high or too low
- Generate test statistic using original qualification data and criteria to pass (currently using MIL-HDBK-17 acceptance criteria for prepreg which was proposed in San Diego - yellow pages)

Material Equivalence

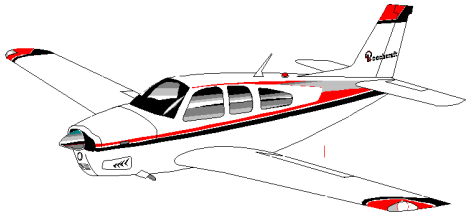


AGATE Advanced Material Research

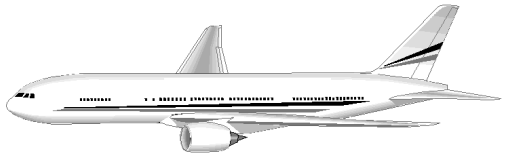
AGATE

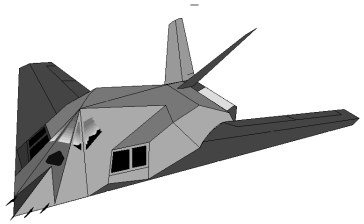
Integrated Design and Manufacturing

- **Multi-Vendor Qualification**
  - **airframe design based upon a combination of material vendors (minimum B-basis criteria)**
  - ***"DESIRED EFFECT"***
    - » **vendor will not have a "monopoly" with respect to a particular aircraft model**
    - » **airframer may switch suppliers based upon price, supply schedule, etc.**
    - » **"price competition" among vendors**



VS





Ongoing Certification Programs

Lancair PAC/USA Columbia 300

- FAR Part 23
- 220 mph cruise speed
- 4 place
- unpressurized
- honeycomb sandwich construction
- hand layup - prepreg
- vacuum bag / oven cure

Ongoing Certification Programs

Cirrus Design Corporation SR20

- FAR Part 23
- 184 mph
- 4 place
- unpressurized
- foam sandwich construction
- hand layup - prepreg
- vacuum bag / oven cure

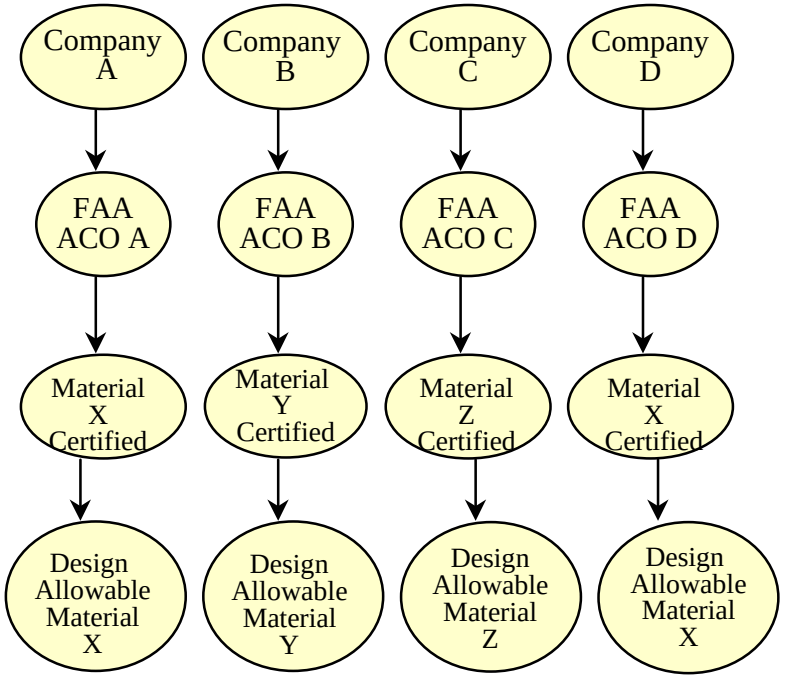
AGATE Advanced Materials

AGATE

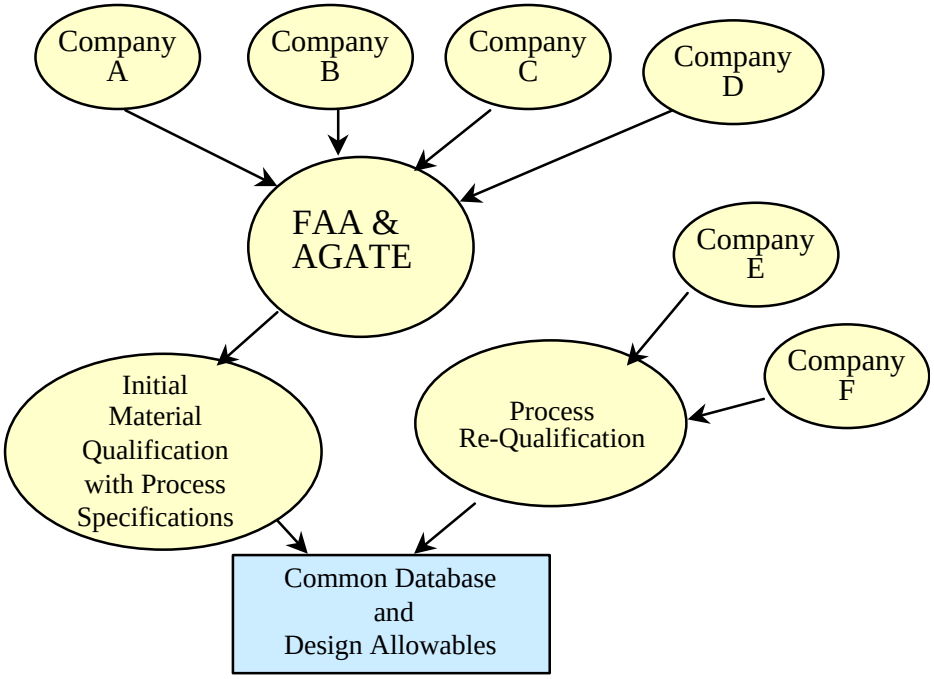
Integrated Design and Manufacturing

- **AGATE Composite Material Certification Methodology Impact**

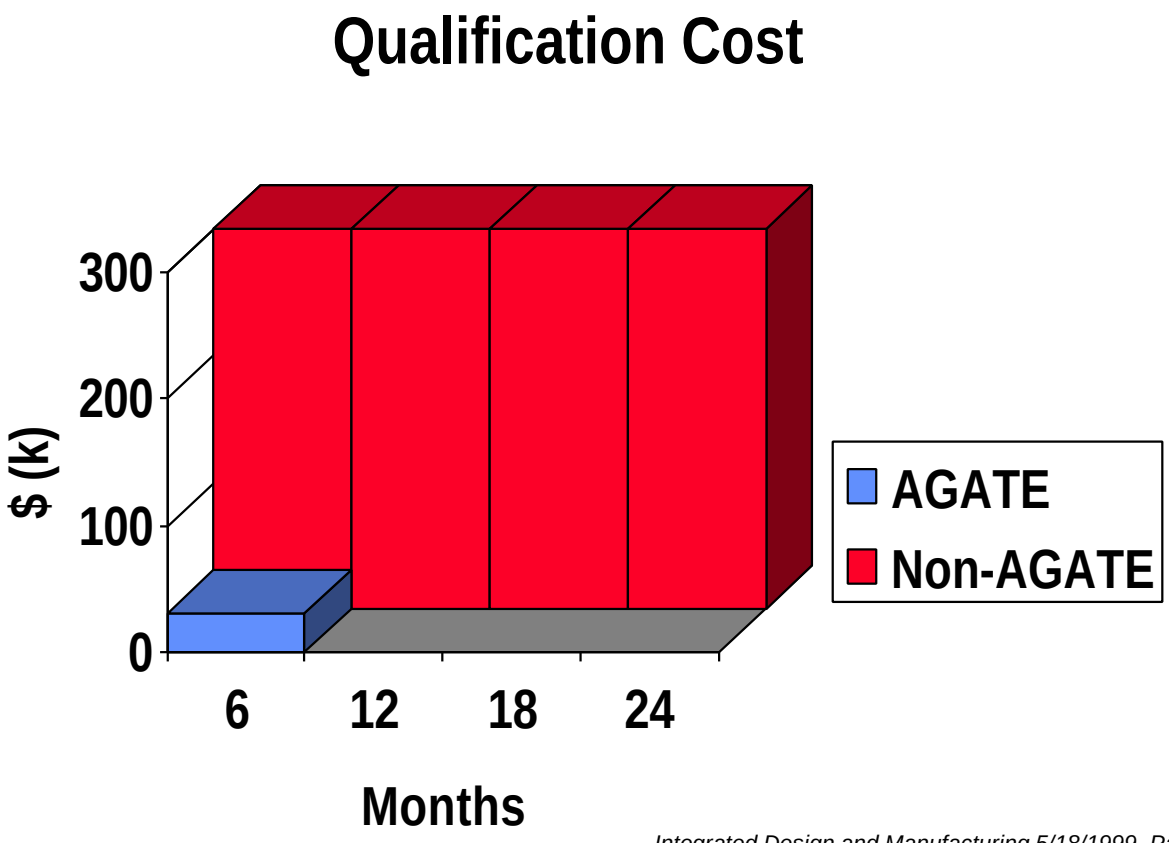
Existing Process



New AGATE Process



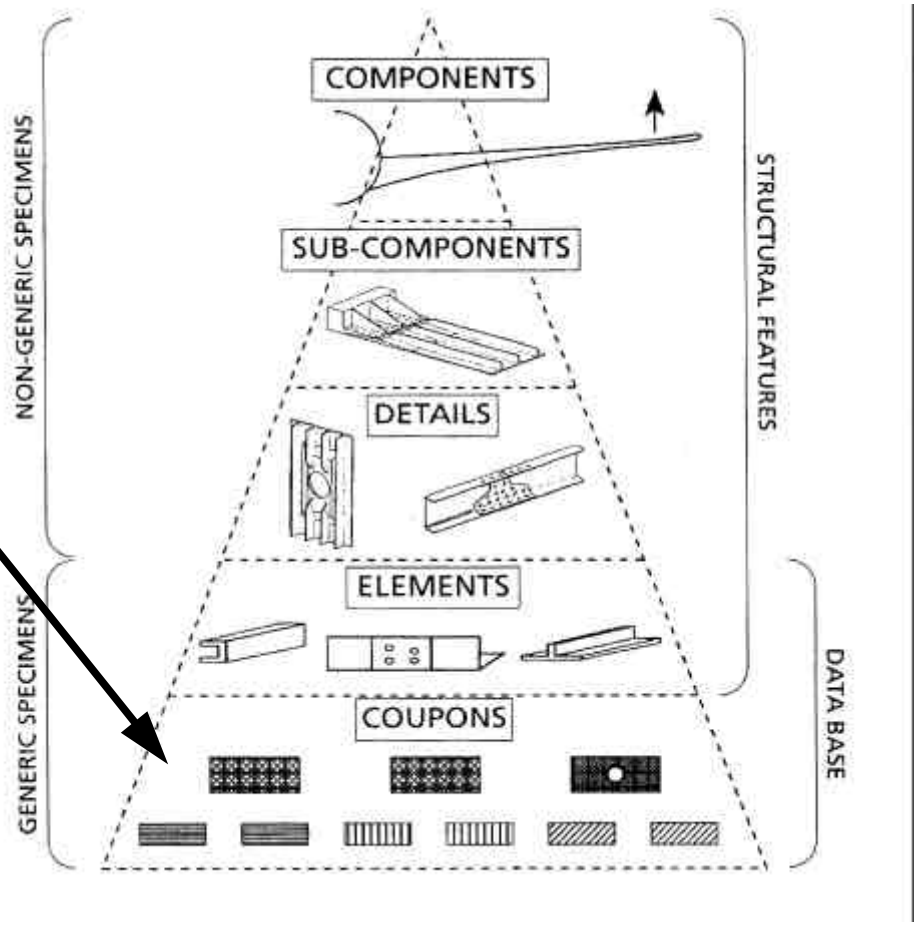
- **AGATE/Industry Material Qualification Cost and Certification Time Comparison**



Focus for Future Advanced Materials Work

AGATE

Integrated Design and Manufacturing

- **Current methodology for certification and use of advanced materials is focused upon "coupon level" testing**

- **Future work will begin to focus on moving to higher levels on the building blocks**