Composite Aircraft Certification

TASI'S MODULUS - DD CASE STUDY

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DD Case Study

- DD and its Advantages
- Aircraft certification
- Next steps and Conclusions

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Double-Double

BI-ANGLE LAMINATIONS

Double Double Bi-angled plies

[±Φ, ±Ψ]n; [+Φ, +Ψ, -Φ, -Ψ]n; [+Φ, +Ψ, -Ψ, -Φ]n

- With n=2 minimal coupling
- With n>=4 unperceived coupling

- Balanced
- Symmetric
- Homogenized
- Ply-drops
- Optimization tools

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Tsai's Modulus

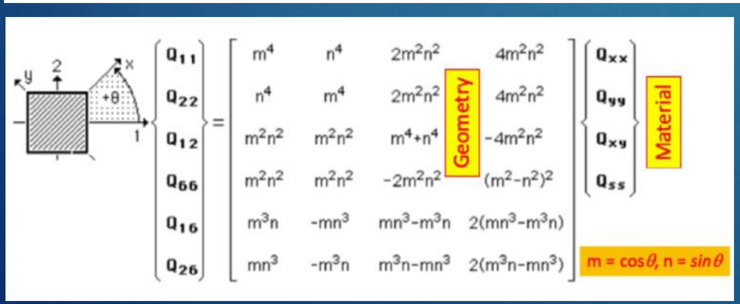
$$\begin{Bmatrix} N \\ M \end{Bmatrix} = \begin{bmatrix} [A] & [B] \\ [B] & [D] \end{bmatrix} \begin{Bmatrix} \epsilon^0 \\ K \end{Bmatrix}$$

$$\begin{Bmatrix} \epsilon^0 \\ K \end{Bmatrix} = \begin{bmatrix} [\alpha] & [\beta] \\ [\tilde{\beta}] & [\delta] \end{bmatrix} \begin{Bmatrix} N \\ M \end{Bmatrix}$$

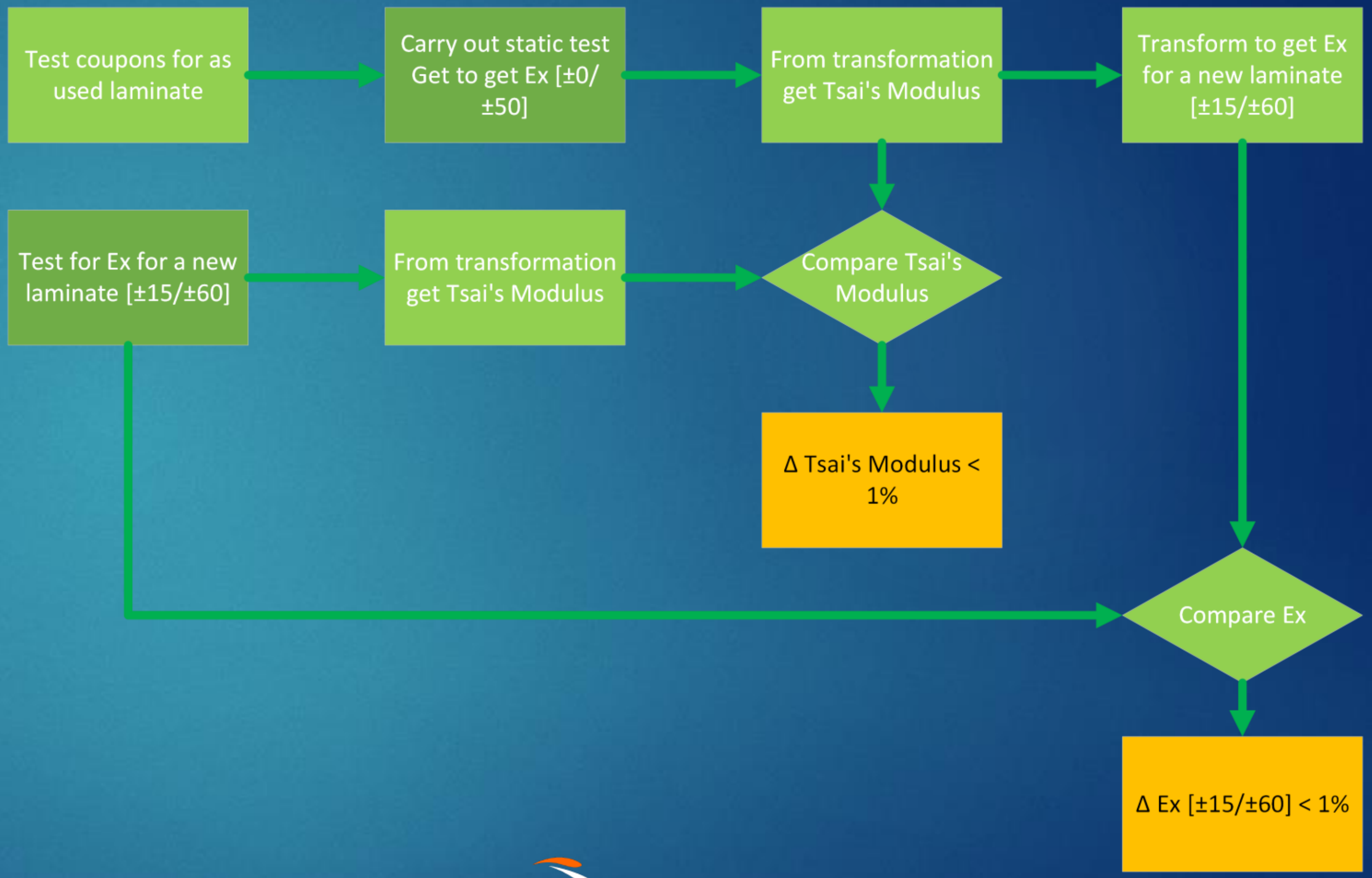
- A=D, B=[0]
- Tsai's modulus = $Trace[Q] = Q_{11} + Q_{22} + 2Q_{66}$
- Tsai's Modulus = total material stiffness.

Tsai's Modulus & Transformations

Laminate	[0]	[0/90]	[π/4]	Soft1	Hard1	Soft2	Hard2	Tr (GPa)
% [0]	100	50	25	10	50	9	55	
% [±45]	0	0	50	80	40	73	36	
% [90]	0	50	25	10	10	18	9	
IM6/epoxy	0.874	0.463	0.337	0.226	0.518	0.226	0.55	232
IM7/977-3	0.877	0.464	0.337	0.225	0.519	0.225	0.551	218
T300/5208	0.877	0.465	0.337	0.224	0.518	0.225	0.551	206
IM7/MTM45	0.897	0.471	0.337	0.213	0.523	0.217	0.557	195
T800/Cytec	0.888	0.472	0.335	0.211	0.518	0.216	0.552	183
IM7/8552	0.884	0.469	0.336	0.217	0.519	0.22	0.552	180
T800S/3900	0.898	0.476	0.335	0.206	0.521	0.212	0.555	168
T300/F934	0.883	0.472	0.335	0.211	0.517	0.216	0.55	168
T700 C-Ply 64	0.866	0.464	0.337	0.225	0.514	0.226	0.546	163
AS4/H3501	0.852	0.456	0.338	0.237	0.512	0.234	0.543	162
T650/epoxy	0.866	0.465	0.337	0.222	0.514	0.224	0.546	160
T4708/MR60H	0.897	0.475	0.335	0.206	0.521	0.212	0.555	158
T700/2510	0.877	0.47	0.336	0.215	0.515	0.219	0.548	144
AS4/MTM45	0.889	0.474	0.335	0.206	0.518	0.214	0.552	143
T700 C-Ply 55	0.869	0.466	0.337	0.222	0.515	0.224	0.547	139
Mean	**0.880**	**0.468**	**0.336**	**0.218**	**0.517**	**0.221**	**0.550**	
Coeff. Var. %	1.50	1.17	0.31	4.17	0.58	2.84	0.70	

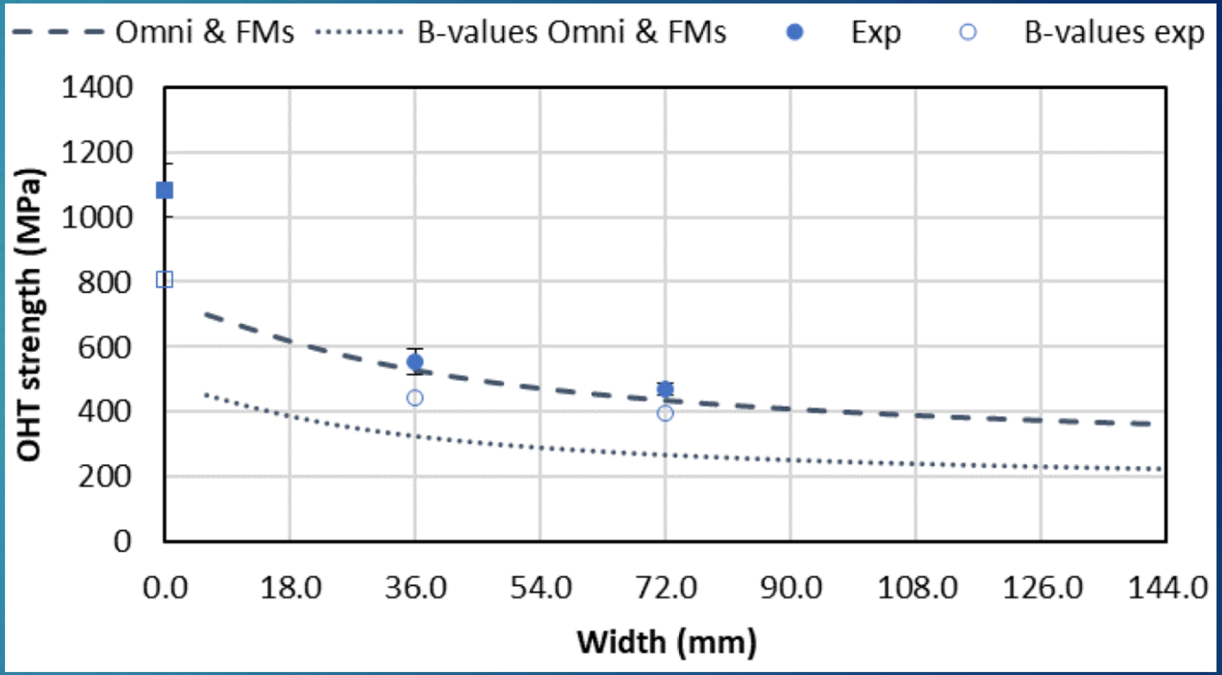


$$\begin{bmatrix} Q_{11} \\ Q_{22} \\ Q_{12} \\ Q_{66} \\ Q_{16} \\ Q_{26} \end{bmatrix} = \begin{bmatrix} m^4 & n^4 & 2m^2n^2 & 4m^2n^2 \\ n^4 & m^4 & 2m^2n^2 & 4m^2n^2 \\ m^2n^2 & m^2n^2 & m^4+n^4 & -4m^2n^2 \\ m^2n^2 & m^2n^2 & -2m^2n^2 & (m^2-n^2)^2 \\ m^3n & -mn^3 & mn^3-m^3n & 2(mn^3-m^3n) \\ mn^3 & -m^3n & m^3n-mn^3 & 2(m^3n-mn^3) \end{bmatrix} \begin{bmatrix} Q_{xx} \\ Q_{yy} \\ Q_{xy} \\ Q_{ss} \end{bmatrix}$$



Data Extrapolation using Finite Fracture Mechanics Models

Extrapolation of notched data to a DD [±0/±50] laminate using data identified from a DD [±15/±60] laminate and comparison with experimentally determined plain and open-hole tension test results (Exp) and corresponding B-Basis values (B-values)



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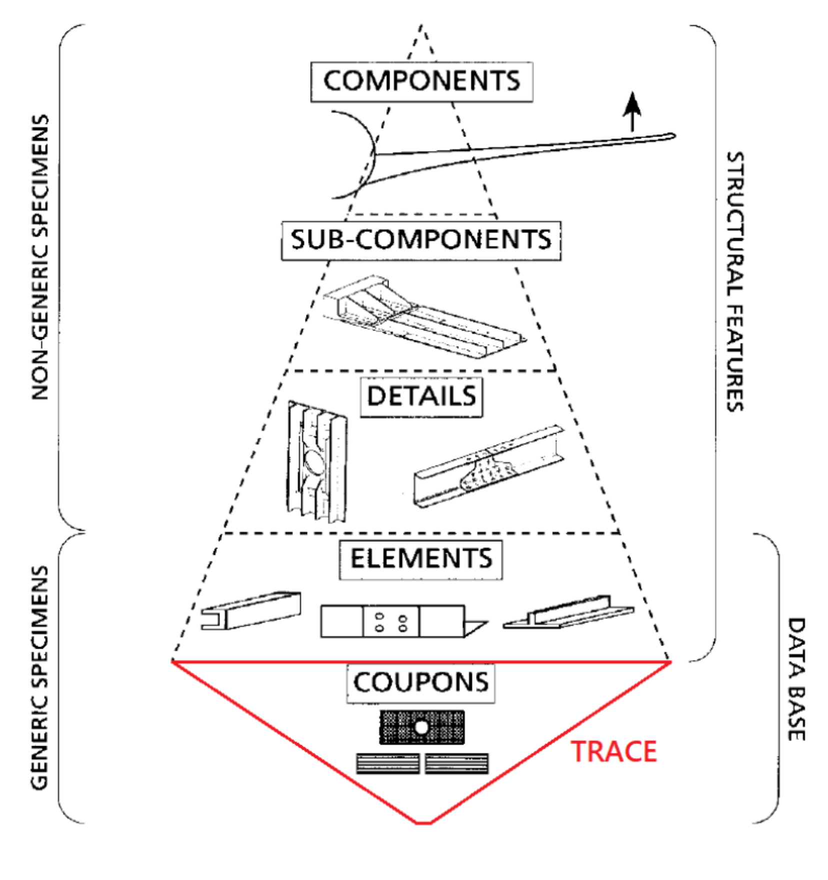
Tsai's Modulus is a Material Property

$$\mathrm{Tr} = E_1/0.880$$

Laminate factors	E_x^o/Tr	E_y^o/Tr	G_{xy}^o/Tr	ν_{xy}^o
Universal [0]	0.880	0.052	0.031	0.320
[0/90]	0.468	0.468	0.031	0.036
[π/4]	0.336	0.336	0.129	0.308
$[0_7/\pm45/90]$	0.662	0.175	0.070	0.310
$[0_5/\pm45_2/90]$	0.518	0.208	0.109	0.423
$[0_2/\pm45/90]$	0.445	0.289	0.109	0.308
$[0/\pm45_4/90]$	0.217	0.217	0.187	0.552
[0/±45]	0.370	0.155	0.161	0.734
[0/±45/0]	0.499	0.141	0.129	0.701
[0/±30]	0.510	0.074	0.129	1.220
[0/±30/0]	0.611	0.072	0.104	1.079
[±12.5]	0.764	0.053	0.066	0.913



Aircraft Certification

Classical

- Production/Temp/Environmental/Static/Dynamic
- DOT/FAA/AR-03/19 Material Qualification
- DOT/FAA/AR-10/6
- FAA/AC-21/26A, FAA/AC23-20
- EASA AMC 20-29
- Composite Materials Handbook 17 AC20-107b, AR-96-111, AR-99/49, FAA/CT-86/39

Proposed

- Test matrix according to AR-03/19, production based on AC23-20
- Specimen testing of each material (fiber+epoxy), Basis A or Basis B data generation reduction of subsequent tests based on Tasi's modulus of specimens.
- Extrapolation of all other properties based on Tsai's Modulus and FFM models

Conclusions from testing

- Greener approach
- Fewer test specimens
- One to two orders of magnitude less in cost.
- Quicker and less wastage
- Confidence in data, better than 95%
- One material system's data can be used to fine tune structural performance.

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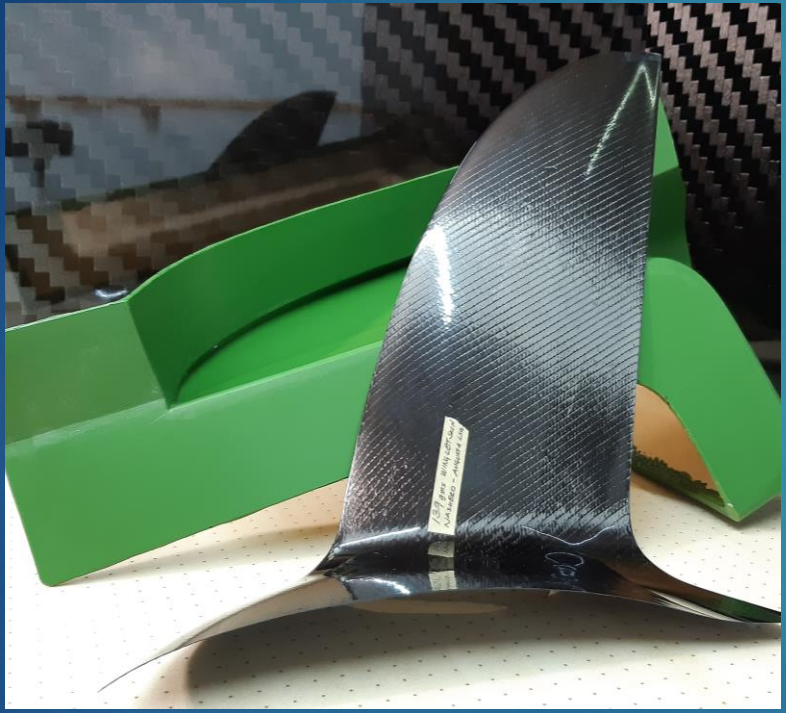
Take home message: Tsai's Modulus and Double-Double

- The only technology that can reduce structural mass by 45% w.r.t. current LQL laminates, start thinking about how you'll use that 45% reduced mass…
- Many practical implications we have not touched on.

Some first aircraft parts in DD using ZeroVoid™ technology of NASHERO



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Questions?

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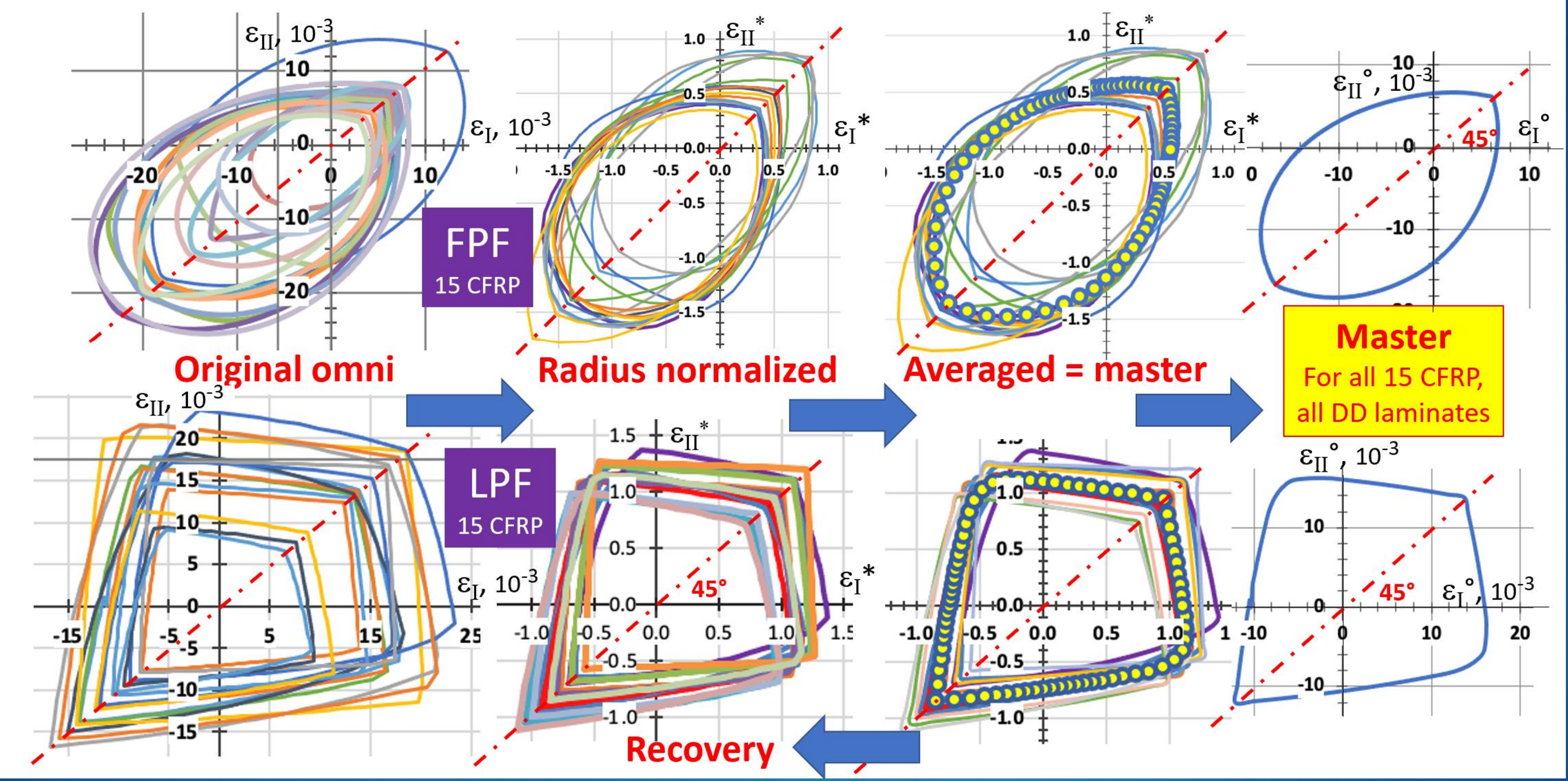
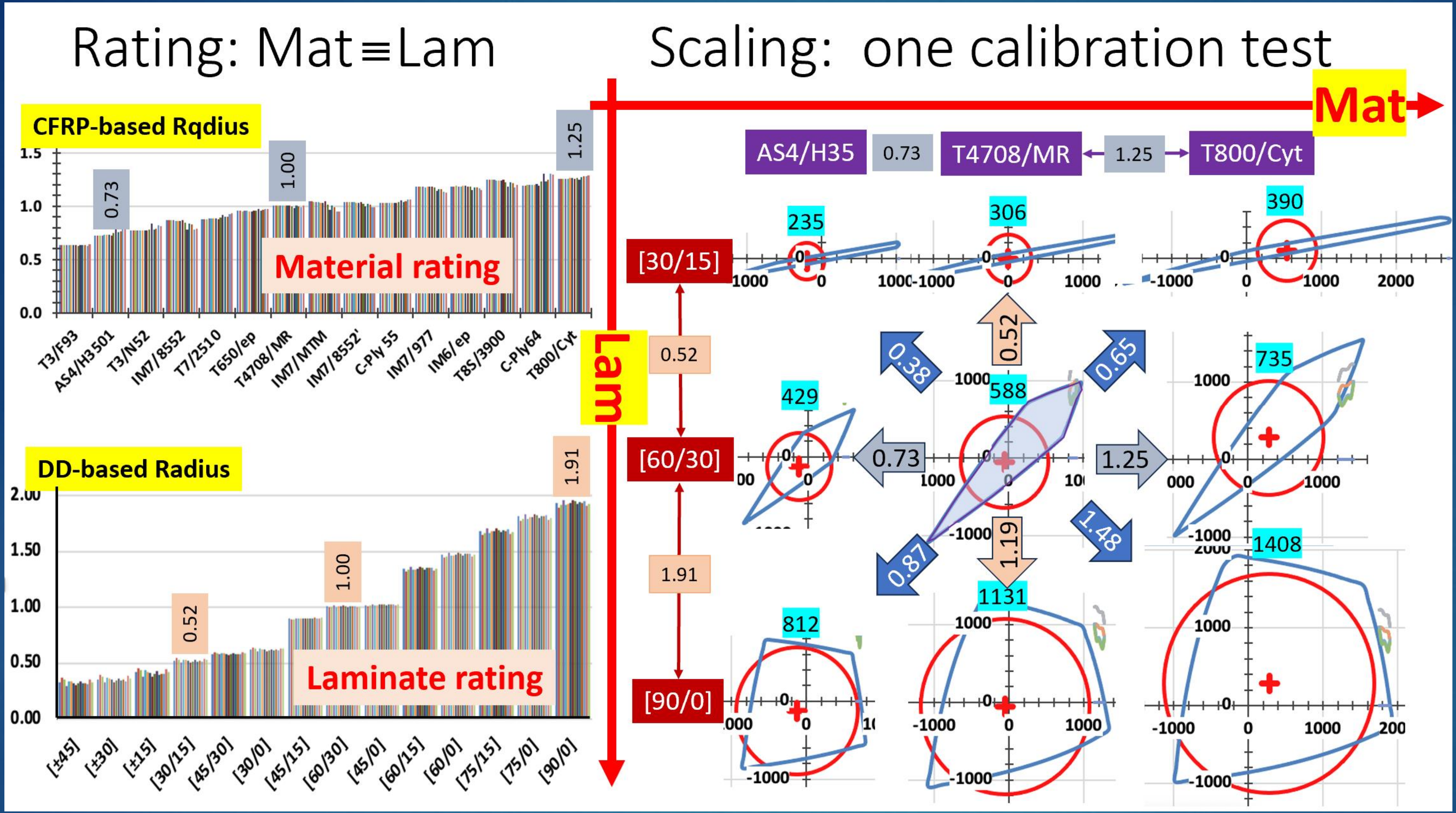
Master envelope: radius normalized



From the ICCM23 Book on DD, by Prof. Stephen W. Tsai



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