CIMNE, ECCOMAS - Composites 2023 – 3rd Day of the Technical Programme - Impact

11th – 14th SEPTEMBER 2023

INVESTIGATION OF SEVERAL IMPACT ANGLES FOR PREDICTING BIRD-STRIKE DAMAGE IN A RIVETED EVTOL COMPOSITE WING

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Introduction and Motivation

Comparison of failure initiation of five cases, including the standard and oblique α, $-\alpha$, 2α and -2α for a riveted wing leading edge model of an eVTOL are investigated ply by ply concerning Tsai-Wu failure with this study. *Net section*, *shear out*, *bolt pulling through the laminate*, *cleavage tension*, *bearing* and *bolt failure* are the possible failure modes for the joints of mechanically fastened unidirectional composites.

Investigation of the best absorbent core material to be implemented to develop the lightest composite eVTOL leading edge which can stand against bird impact.

Figure – 1 Airbus nextGen (eVTOL)

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Introduction and Motivation

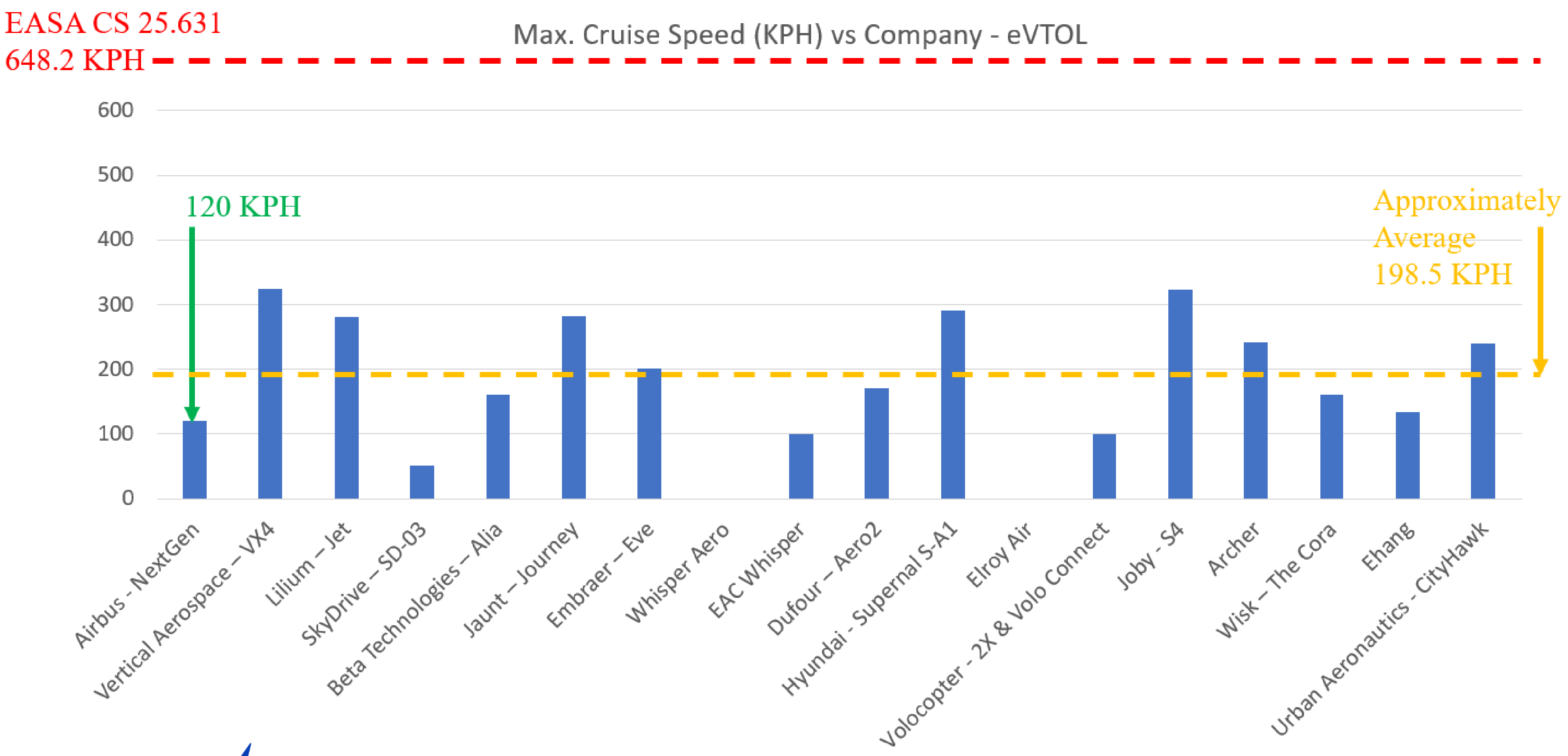

Figure – 2 Comparison of eVTOL Cruise Speeds

Introduction and Motivation

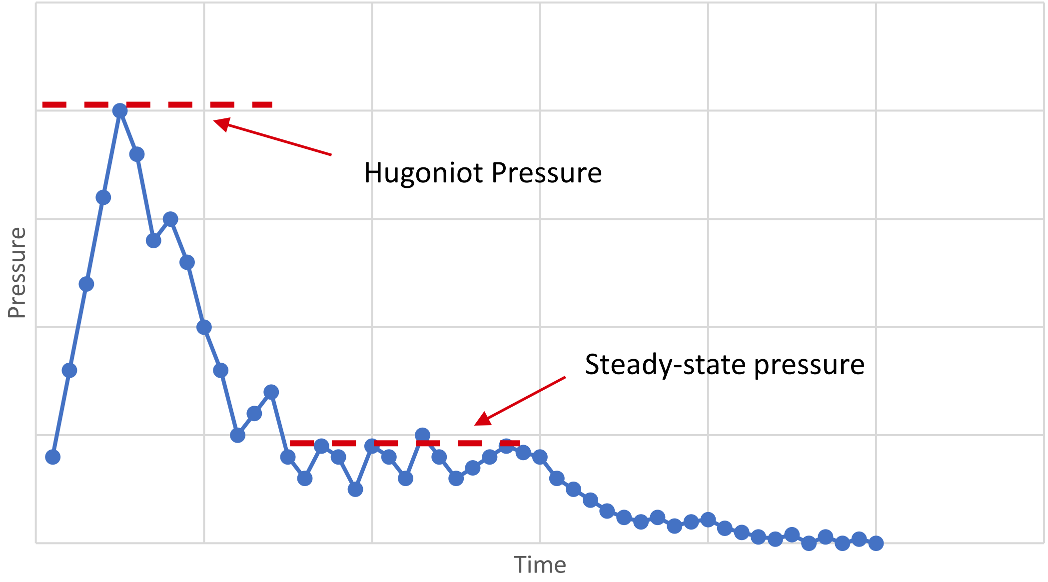

Figure – 3 Hugoniot Pressure

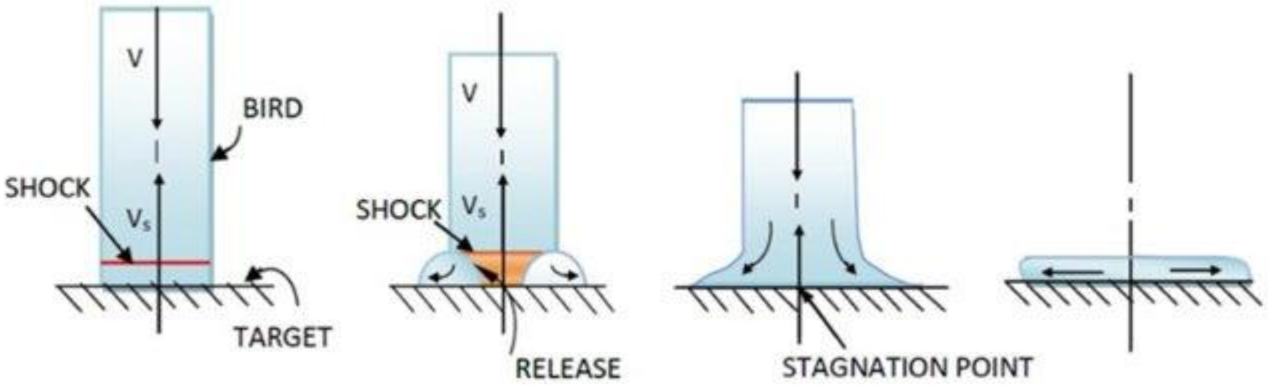

Figure – 4 Shock Phases

[1] M. Guida, F. Marulo, F. Z. Belkhelfa, and P. Russo, A review of the bird impact process and validation of the SPH impact model for aircraft structures, Progress in Aerospace Sciences, 129, 2022.

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Numerical Models & Cases
Rivet-connected eVTOL Wing Under Bird-Strike

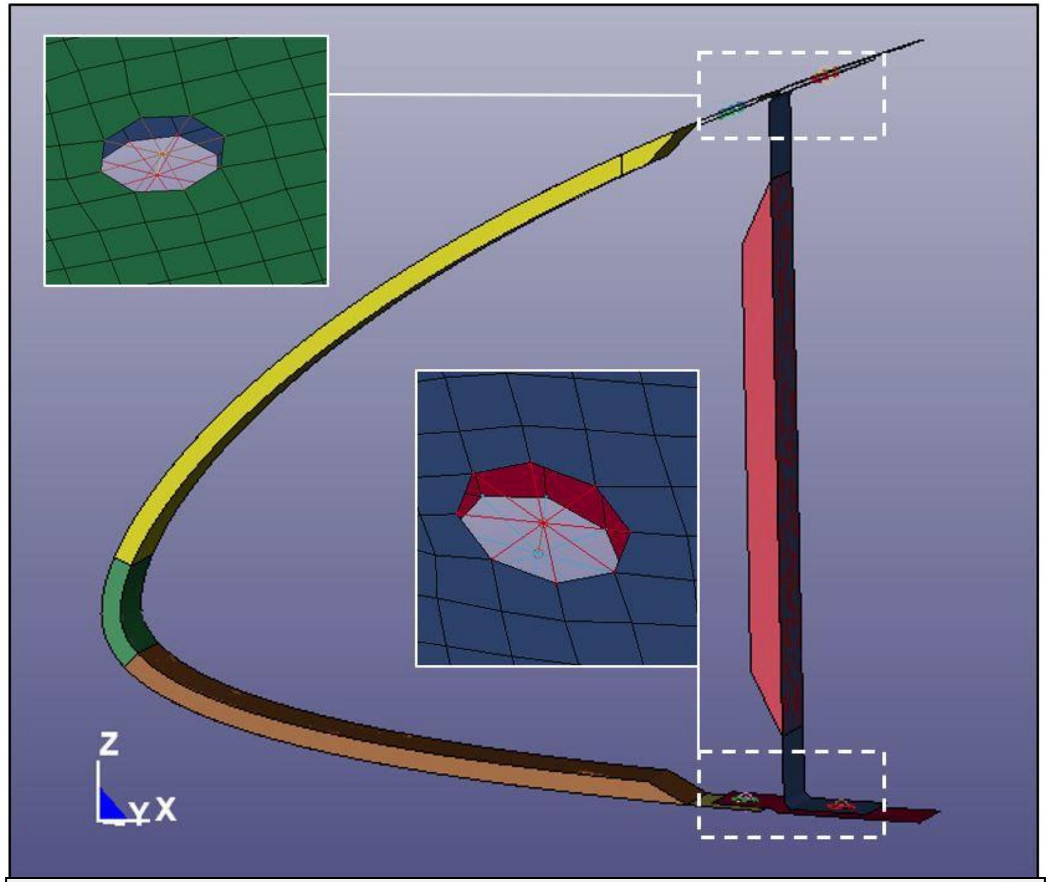
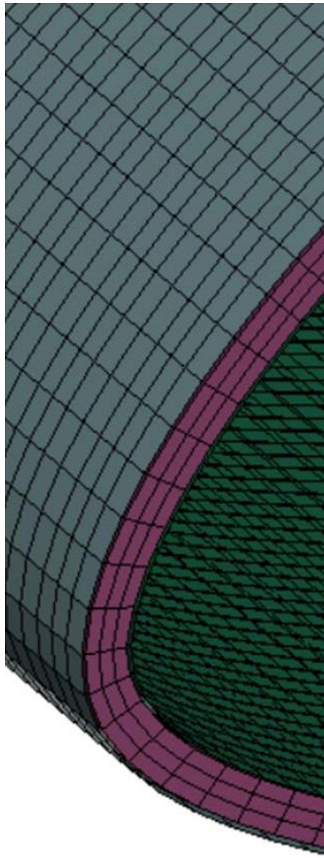


Figure – 5 Skin, honeycomb and auxiliary spar attachment configurations at the leading edge of the wing, The rivet-connected configuration



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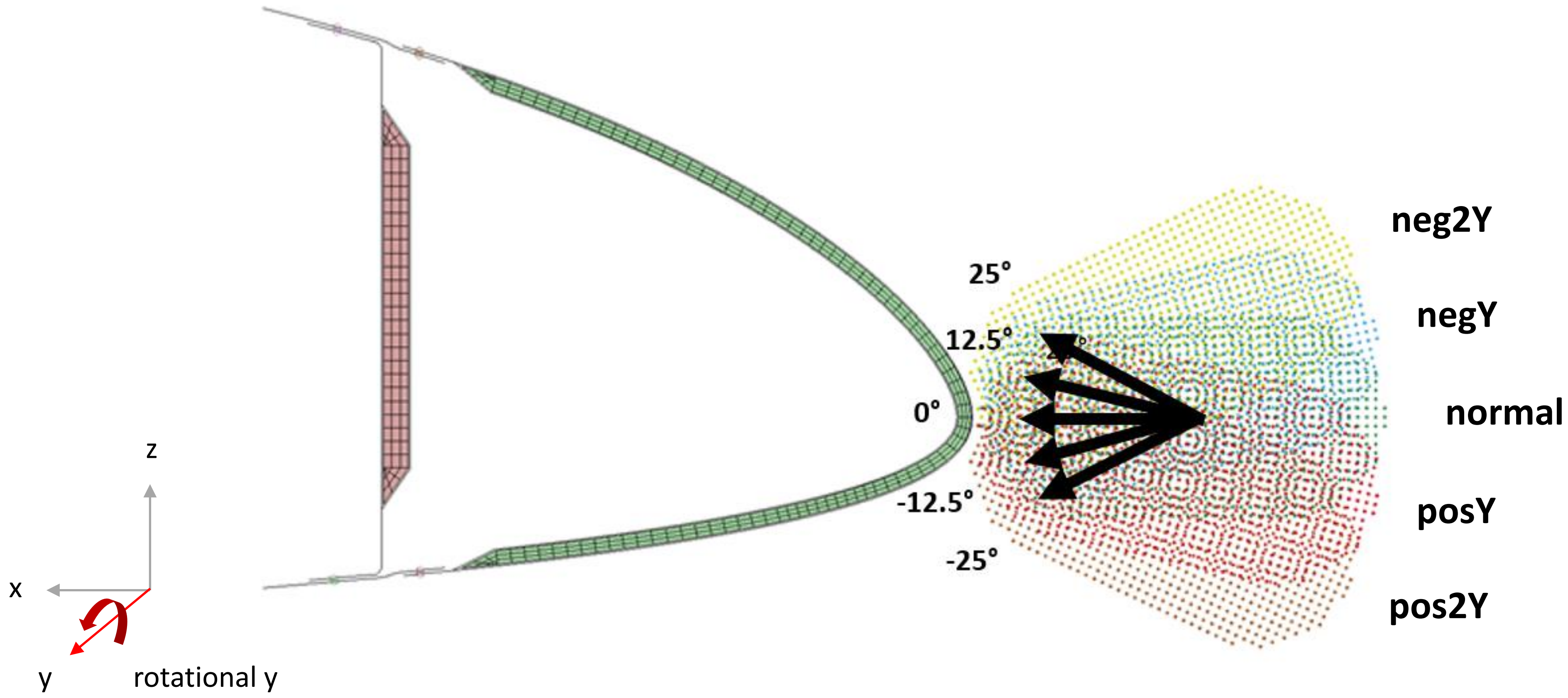
Numerical Models & Cases
Rivet-connected eVTOL Wing Under Bird-Strike



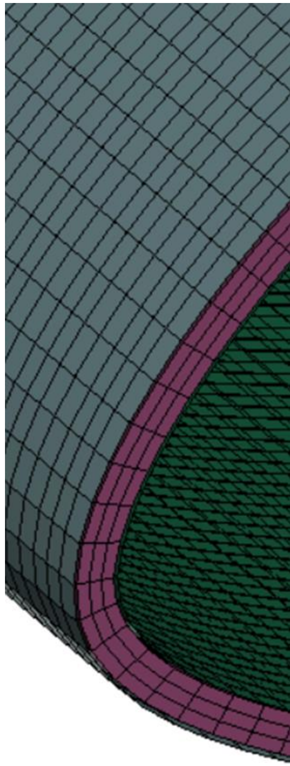


Figure – 6 Oblique impact cases

Material Properties & Test Campaign (UD Skin & Aramid Core)

- ASTM C365 - Applied Force vs Displacement

0.5 min/mm 6.35 x 50 x 50 mm

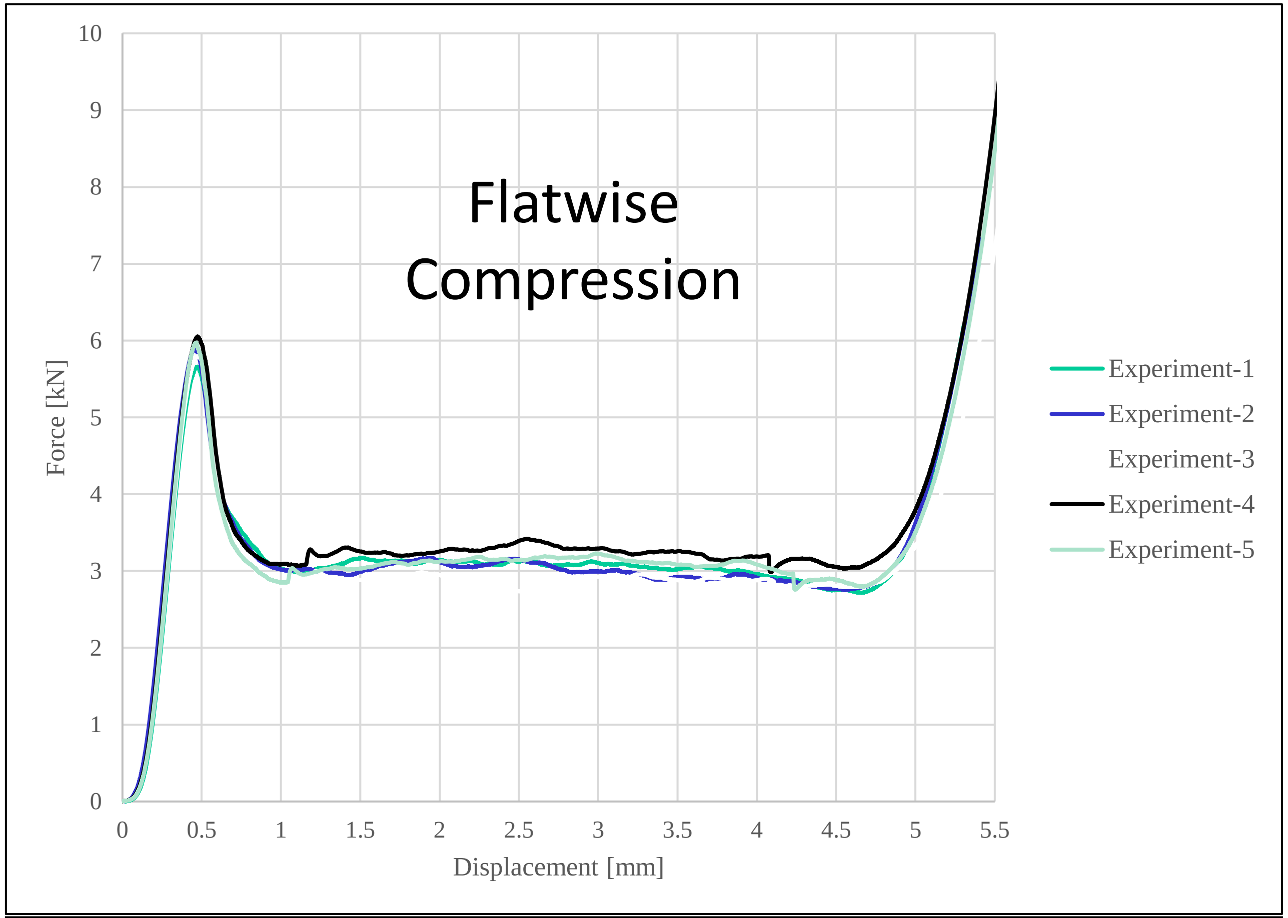


Figure – 7 ASTM C365 (5 Experiments)

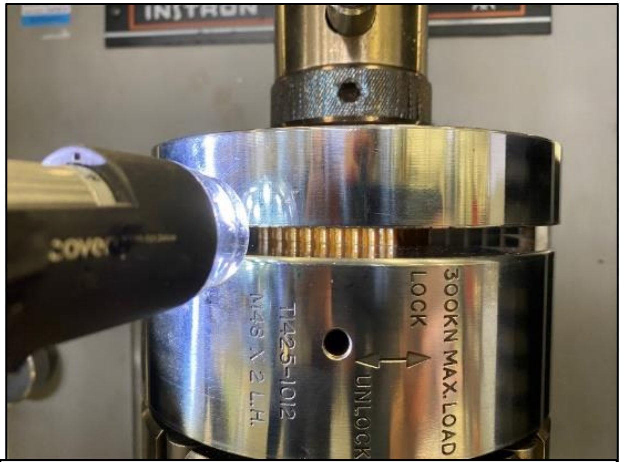


Figure – 8 Core Specimen for C365

Figure – 9
Core Specimen for C365

- UD; Stacking: [0/90/-45/45]s UD M91/IM7 Each ply: 0.184mm (8 plies Facing & 8 plies Backing)

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Material Properties & Test Campaign (UD Skin & Aramid Core)

- ASTM C364 5 min/mm 6.35 x 50 x 50 mm

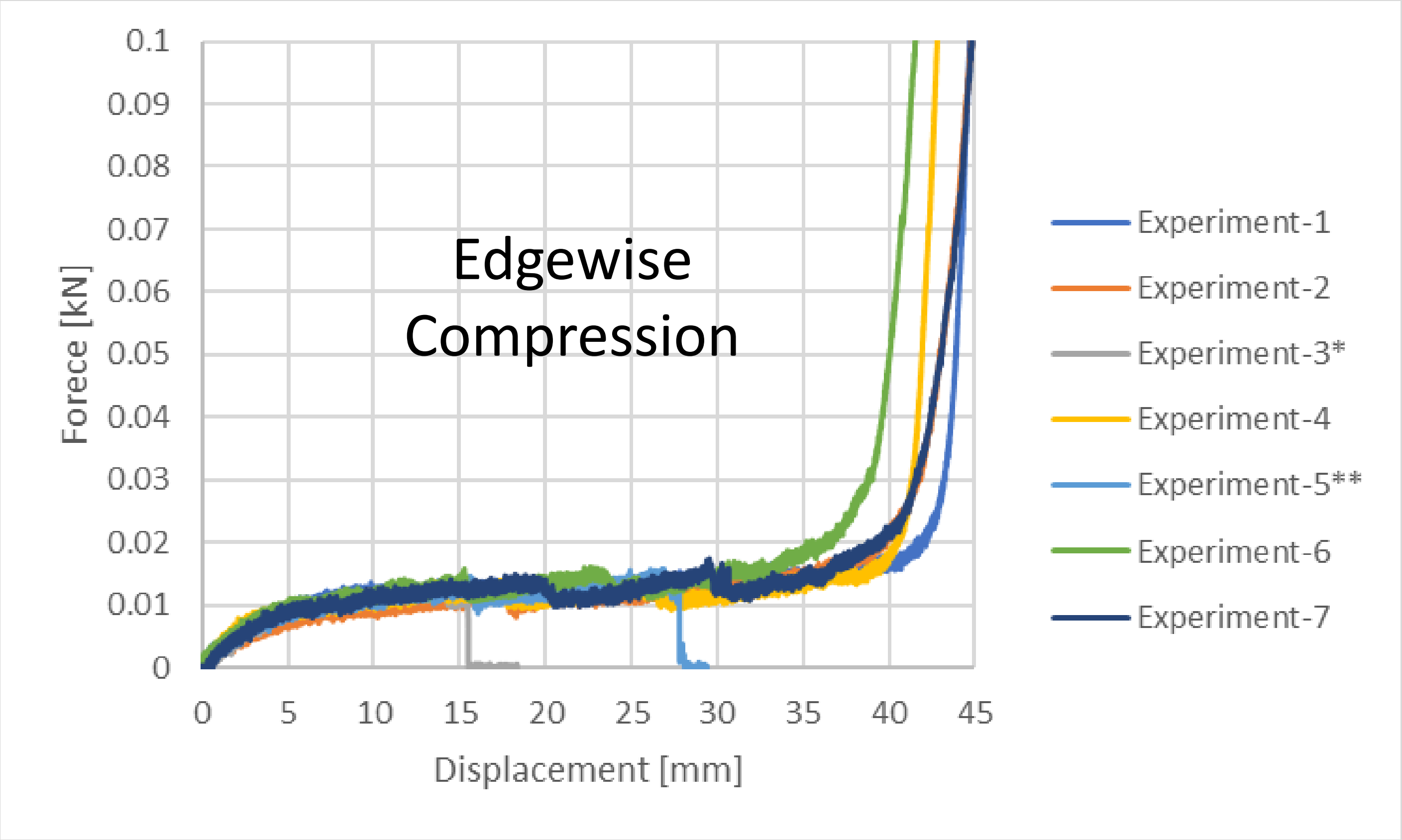

Figure – 10 ASTM C364 (7 Experiments)

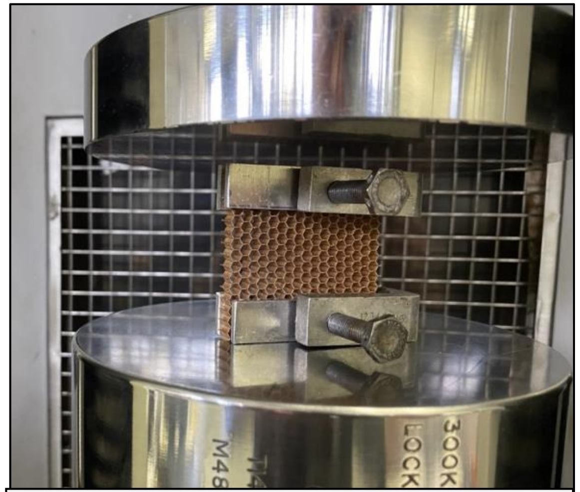

Figure – 11 ASTM C364 (Test System)

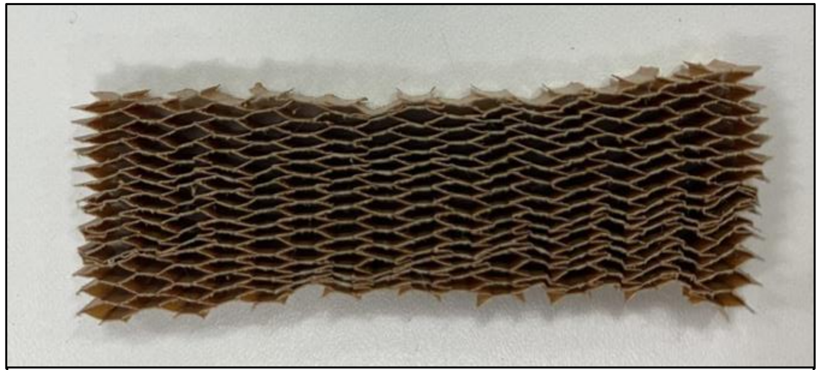

Figure – 12 ASTM C364 (Compacted Specimen)

* Experiment-3 is failed because of stability problems. Therefore, Experiment-4 supersedes, Experiment-3.
** Experiment-5 is failed because of stability problems. Therefore, Experiment-6 supersedes, Experiment-5.

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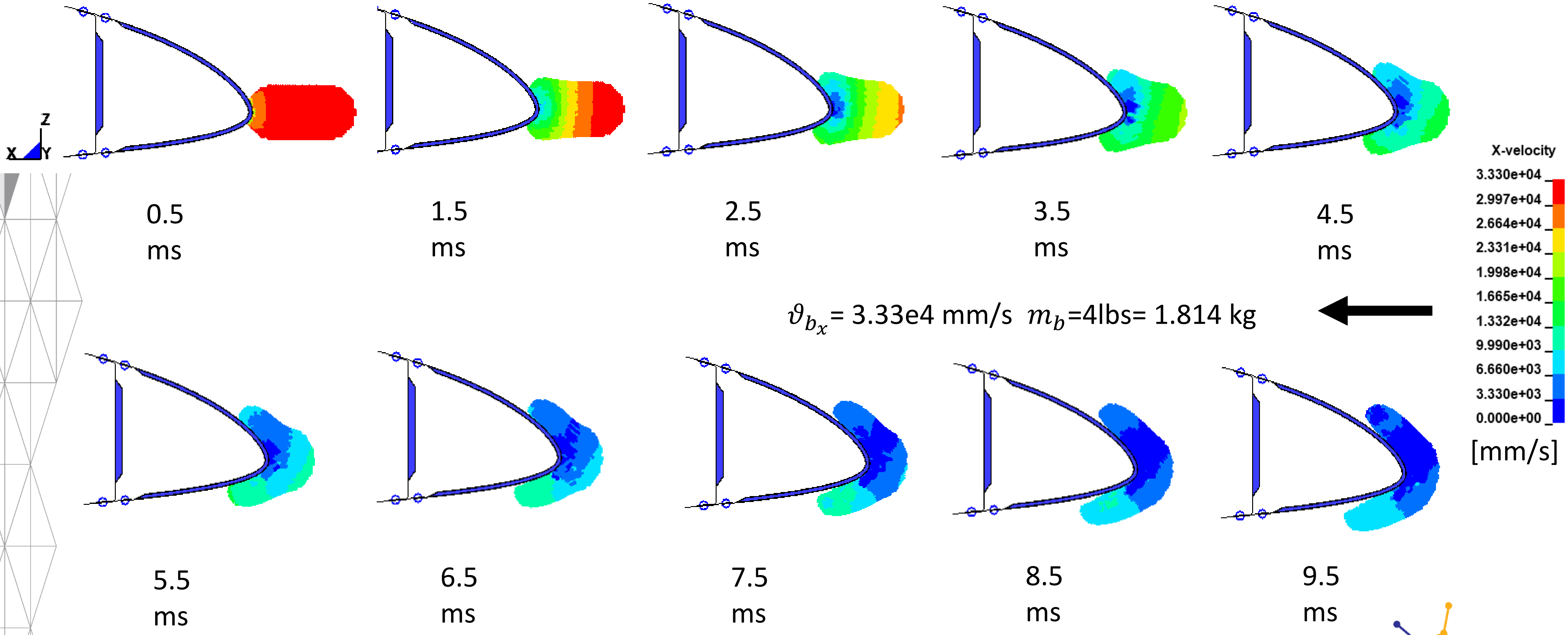
Loading Condition – Normal Impact

- **The Impact Condition vs Time**



[t, mm, N, s, mJ, MPa]

Figure – 13 X Velocity of The Bird and The Wing Model

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FEA Results - 1st Principal Stress

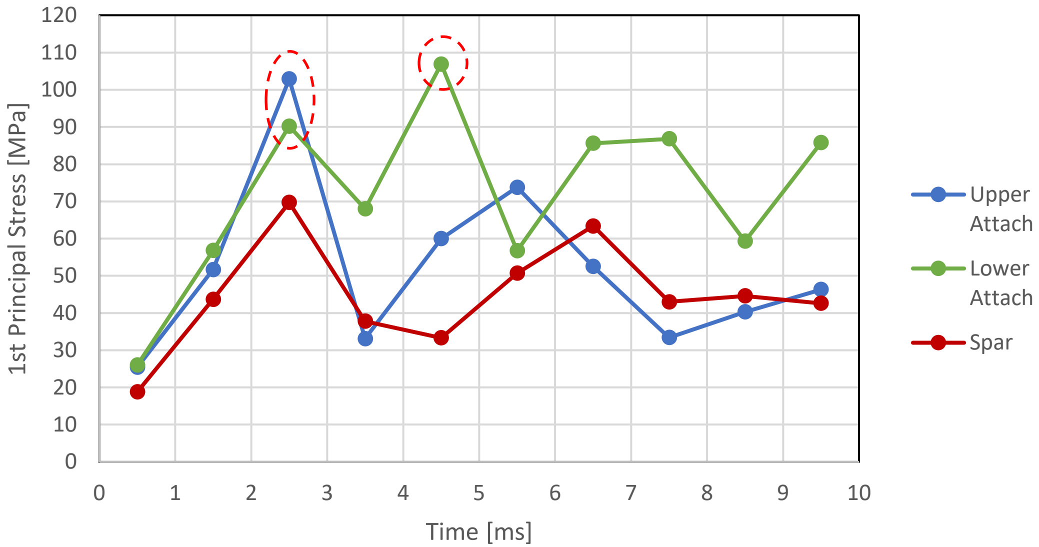

Figure – 14 1st Principal Stress Distribution at The Attachment Parts and Spar of The Rivet Connected Case

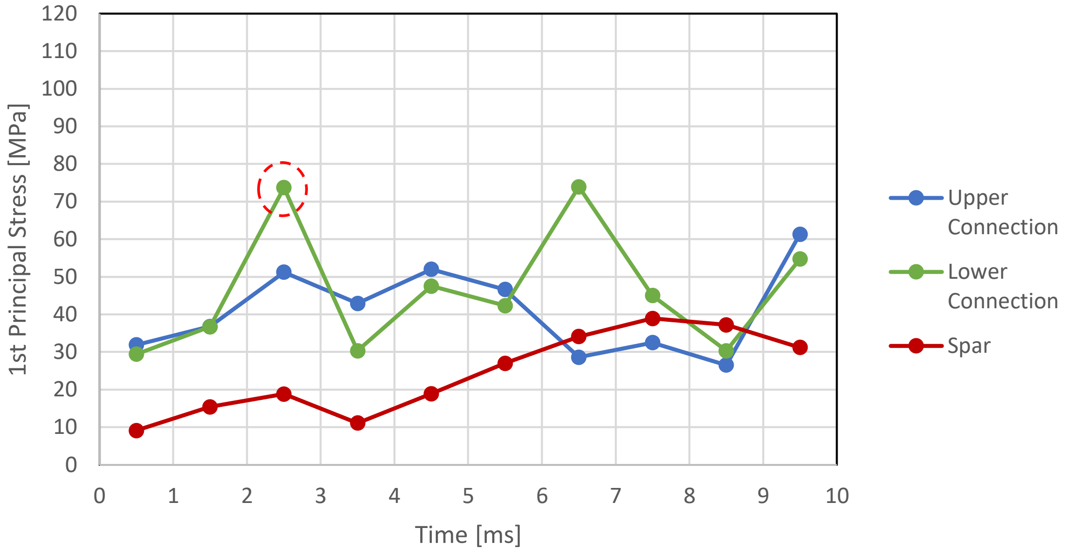

Figure – 15 1st Principal Stress Distribution at The Attachment Parts and Spar of The Adhesively Bonded Case

Tsai-Wu Failure Theory

$$\left(\frac{1}{X_t}-\frac{1}{X_c}\right)\sigma_1+\left(\frac{1}{Y_t}-\frac{1}{Y_c}\right)\sigma_2+\frac{\sigma_1^2}{X_tX_c}+\frac{\sigma_2^2}{Y_tY_c}+\frac{\tau_{12}^2}{S^2}+2F_{12}\sigma_1\sigma_2=\text{Failure Index} \quad \dots (1)$$

X_t, X_c, Y_t and Y_c — Material properties

σ_1, σ_2, S and τ_{12} — FEA results

F_{12} — Numeric parameter

$$\left[\frac{\sigma_1^2}{X_tX_c}+\frac{\sigma_2^2}{Y_tY_c}+2F_{12}\sigma_1\sigma_2+\frac{\tau_{12}^2}{S^2}\right]SR^2+\left[\sigma_1\left[\frac{1}{X_t}-\frac{1}{X_c}\right]+\sigma_2\left[\frac{1}{Y_t}-\frac{1}{Y_c}\right]\right]SR=1$$

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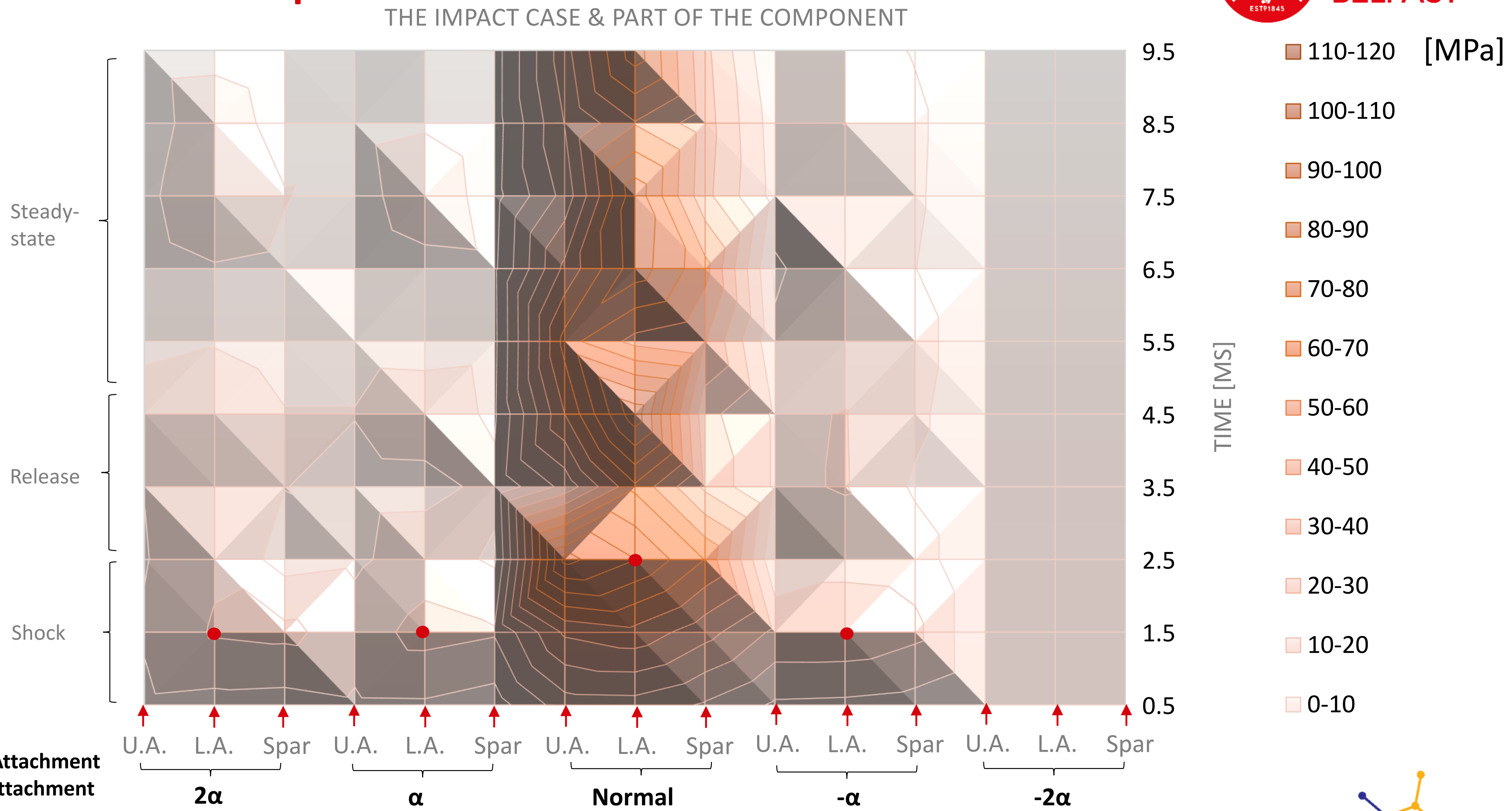
FEA Results 1st Principal Stress Distribution



U.A.: Upper Attachment
L.A.: Lower Attachment

Figure – 16 1st Principal Stress Distribution of Upper, Lower Attachment Parts and The Spar for Oblique and Normal Impact Cases (2α, α, Normal, -α, -2α)

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FEA Results 1st Principal Stress Distribution, Lower Attachment

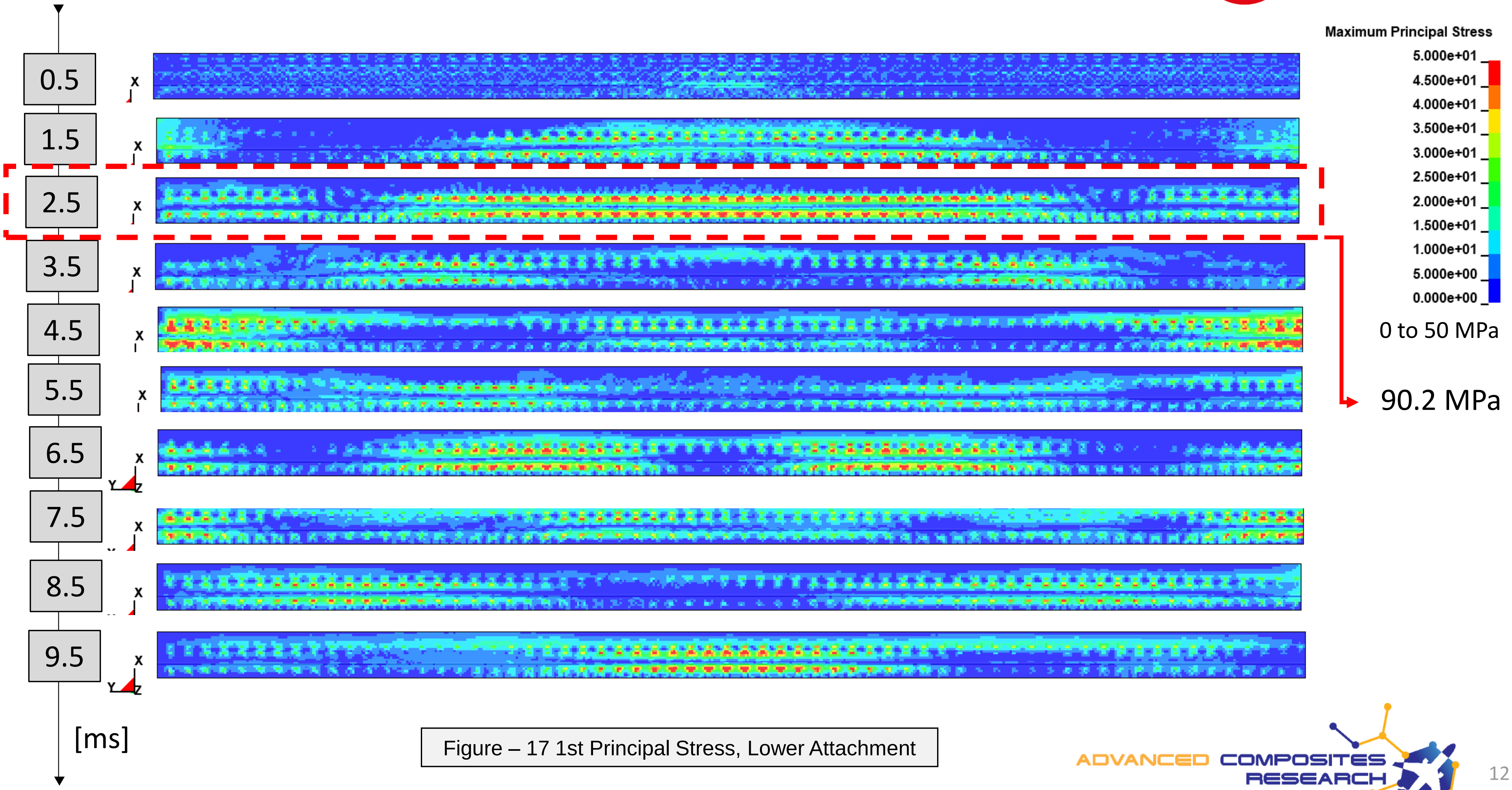

Figure – 17 1st Principal Stress, Lower Attachment

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FEA Results 1st Principal Stress Distribution, Lower Attachment

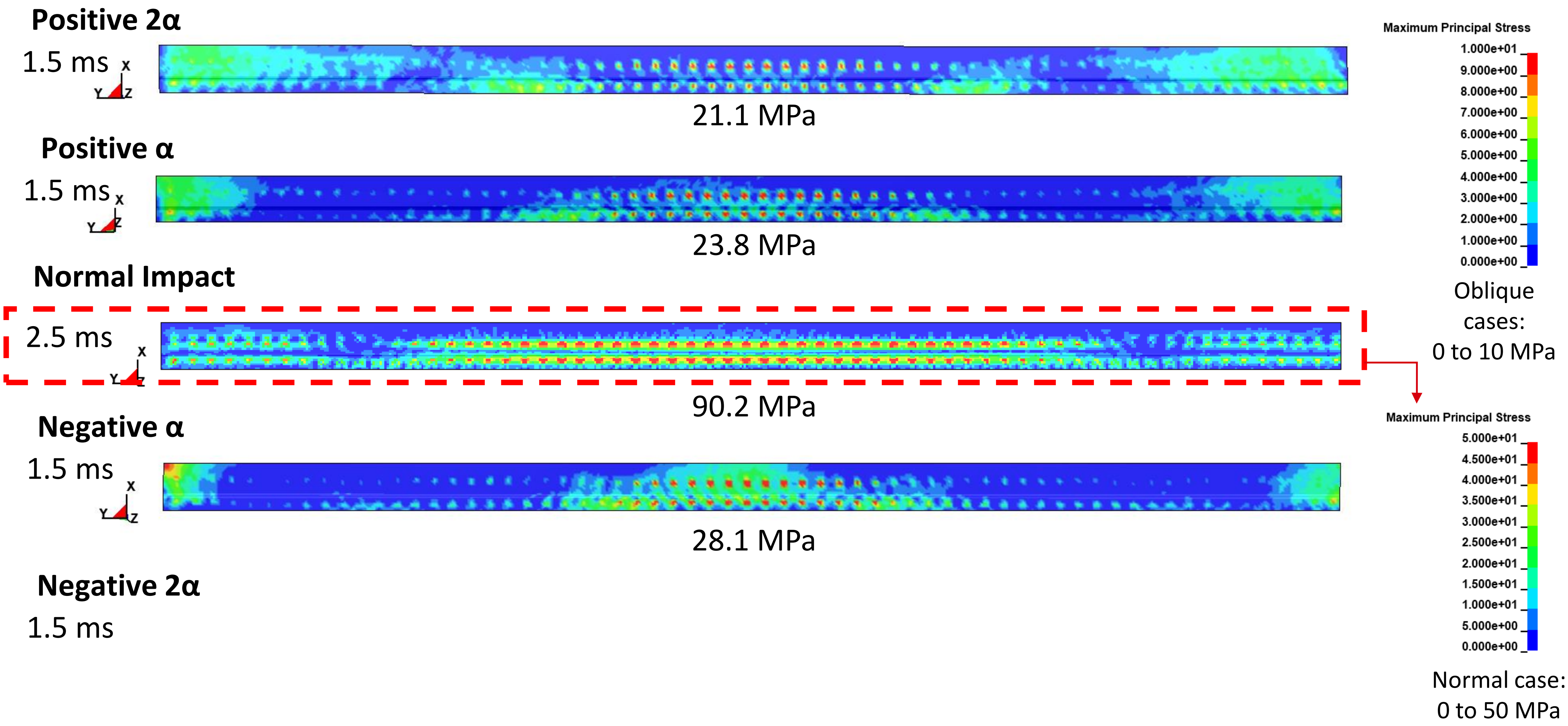

Figure – 18 1st Principal Stress, Lower Attachment

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Shear Stress & Safety Reserve Results

Table – 1 Shear Stress Results of The Lower & Upper Attachment Parts for 2α, α, Normal, -α and -2α

Time [ms]	Lower A. Pos 2α	Upper A. Pos 2α	Lower A. Pos α	Upper A. Pos α	Lower A. Normal	Upper A. Normal	Lower A. Neg α	Upper A. Neg α	Lower A. Neg 2α	Upper A. Neg 2α
1.5	21.2	10.9	23.5	14.5	25.0	19.7	27.7	28.7		
2.5	14.0	9.8	13.8	8.2	51.3	52.9	17.5	7.9		

[MPa]

Table – 2 Safety Reserve Results of The Lower & Upper Attachment Parts for 2α, α, Normal, -α and -2α

Time [ms]	Lower A. Pos 2α	Upper A. Pos 2α	Lower A. Pos α	Upper A. Pos α	Lower A. Normal	Upper A. Normal	Lower A. Neg α	Upper A. Neg α	Lower A. Neg 2α	Upper A. Neg 2α
1.5	3.84 E-03	1.97 E-03	4.26 E-03	2.63 E-03	-	-	5.02 E-03	5.20 E-03		
2.5	-	-	-	-	9.27 E-03	9.56 E-03	-	-	-	-

Safety Reserve

>1 Safe

≤1 Not safe

[Unitless]

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Concluding Remarks & Future Work

- Lower principal stress and shear stress results are evaluated for the oblique impact cases. Moreover, the safety reserve results are lower than the normal impact case. The shock phase takes 2.5 ms for normal impact case. However, it takes 1.5 ms for oblique impact cases. The following tasks will be performed as a future work to compare these cases and make a reliable comment;

- Results under various stacking configurations
- Investigation of connector fails (i.e Pull-through mode)

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Thank you!
Questions & Answers