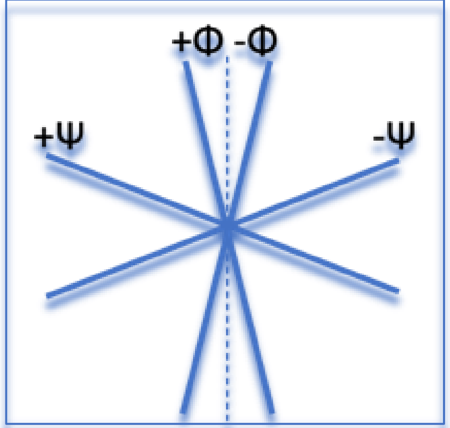
Stanford University



STANFORD AERONAUTICS & ASTRONAUTICS

Double Double (DD)

Opening the frontiers between manufacturing, materials and optimum design of composite structures

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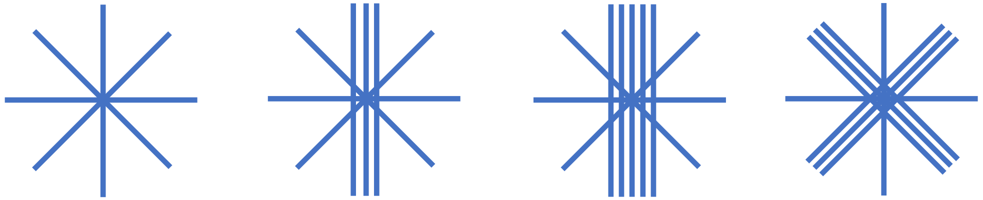
2 - Nashero
3 - Univ Porto
4 - Niar Wichita
5 - Univ. Budapest
6 -Nus Singapore
7 - Univ. Dayton
8- Whycomposites.com
9- Federal University of Rio Grande do Norte
10 – CSU Long Beach
11 - Universidade Federal de Minas Gerais
12 – NASA/Marshal Space Flight Center
13 - Univ. Campania
14 – Italian Center for Aerospace Research
15 - US Air Force Research Laboratory
16 - Queen’s University, Belfast
17 - Otto Aviation
18– IIT Kanpur

Double Double Performance vs Quad

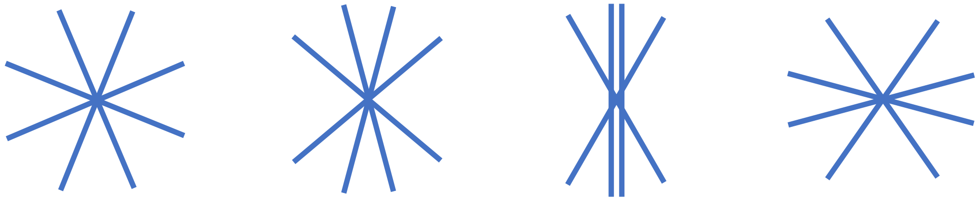
Quad performance is managed by adding 0°, ±45° or 90° plies. Quad is discrete.



π/4: 4 Hard1: 6 Hard2: 8 Soft: 8

Must add number of plies: 4 to 6, 8, 10, …
Thousands of stacking permutations
Cannot drops must be in pairs
Cannot maintain same properties

Double Double performance is managed by tuning Φ & Ψ. DD is continuous, adjustible.



π/4: 4 Hard1: 4 Hard2: 4 Soft: 4

DD is always 4 plies, easier homogenization
Ply drop simple and one at a time
Keep same properties and save weight

What is your name?

Quad: my name is $[45/90/-45_2/90/-45/90/-45/0_2/45/0_2/45_2/0]_S$,

my siblings: $[90/45/-45_2/90/$…

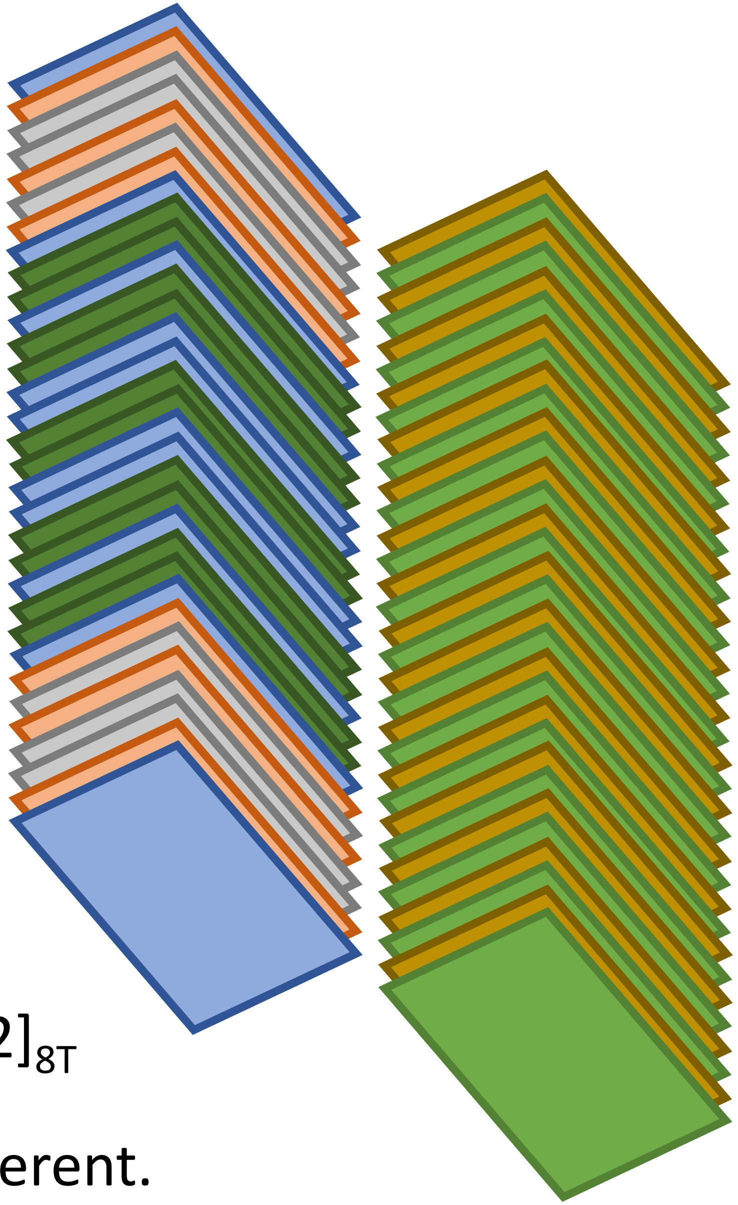
$[90/-45/-45_2/90/$…

$[45_2/90/-45_2/90/$…

…

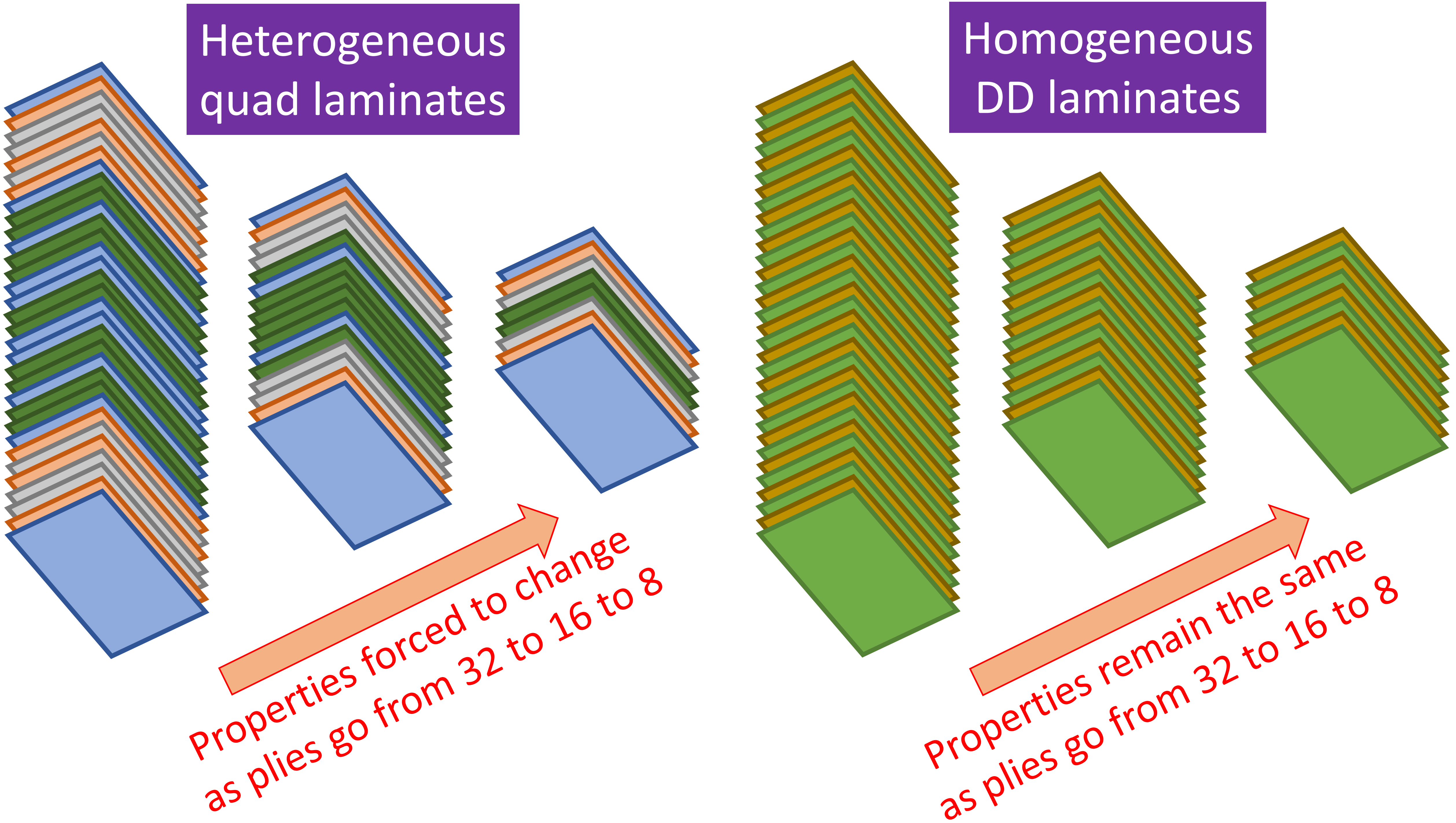
and over 100,000 of us!

How to choose the best. Humanly impossible.



DD: my name is $[\pm18/\pm62/\pm18/\pm62/\pm18/\pm62/…/\pm18/\pm62]_T$, or $[\pm18/\pm62]_{8T}$, for short. I have 3 siblings: $[\pm62/\pm18]_{8T}$, $[18/62/-62/-18]_{8T}$, $[62/-18/18/-62]_{8T}$

Me and siblings are all the same inside. Only our faces are different.
Any one of us will do well. Same as the quad but much cleaner.


Heterogeneous quad laminates
Homogeneous DD laminates
Properties forced to change as plies go from 32 to 16 to 8
Properties remain the same as plies go from 32 to 16 to 8

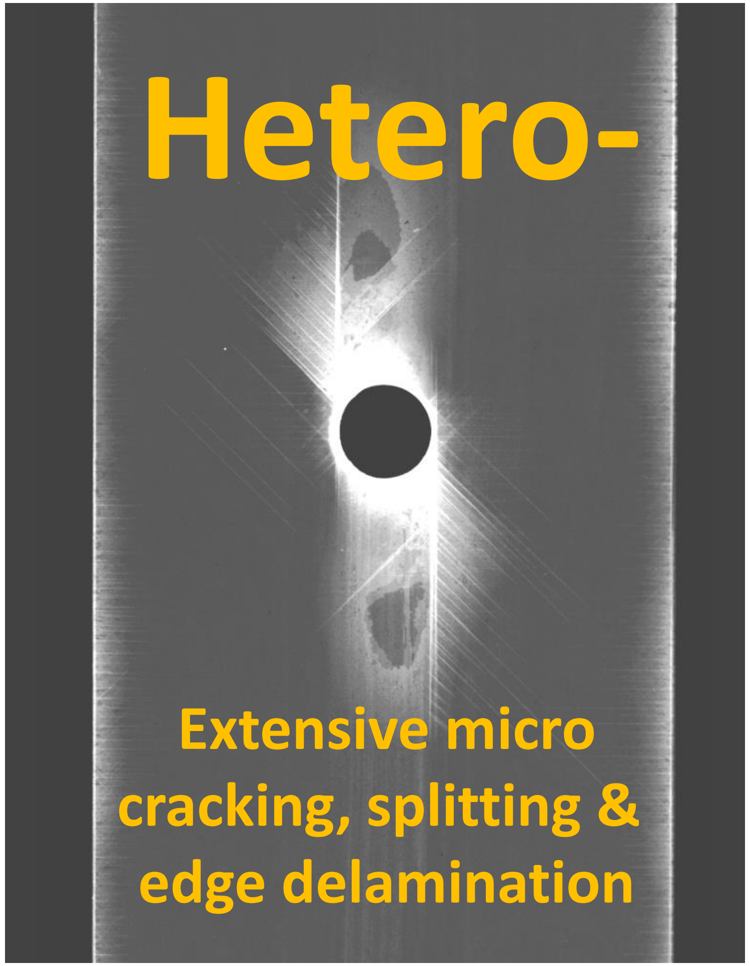
Hetero- vs homo-geneous hard laminate

Sangwook Sihn

σ_{max} = 70 ksi (70% static), R = 0.1, f = 5 Hz, after 73,000 cycles

Ply thickness = 0.04 mm, Laminate thickness = 3.2 mm

$[45_5/0_{10}/-45_5/90_5/45_5/0_{10}/-45_5/0_5]_S$

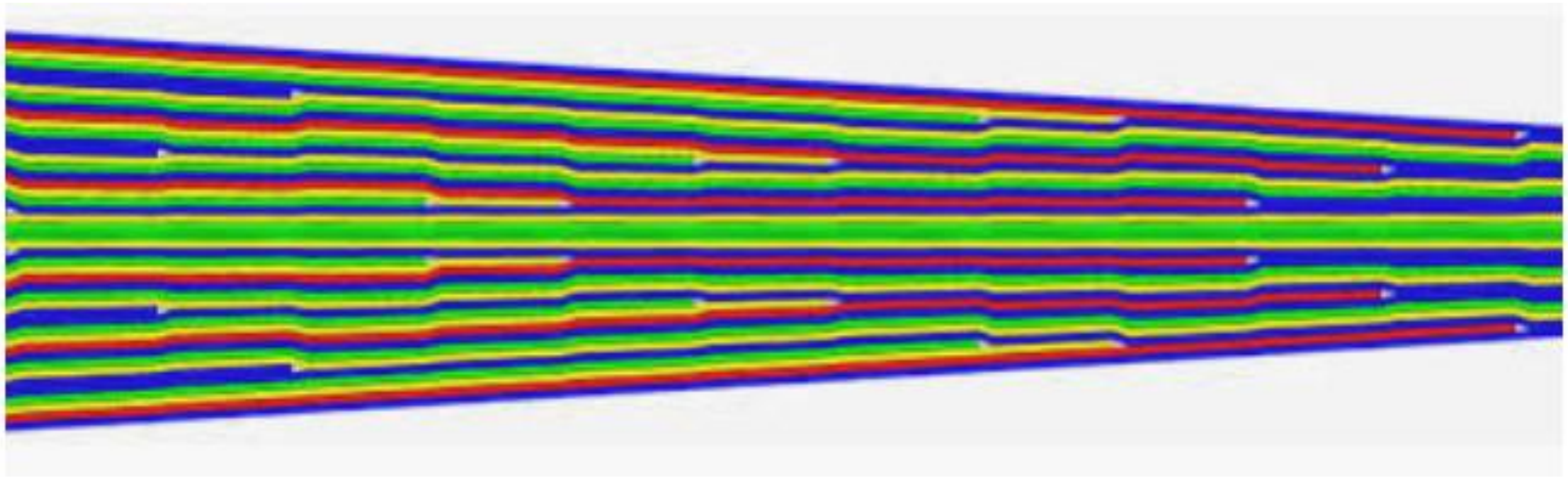


$[45/0_2/-45/90/45/0_2/-45/0]_{5S}$

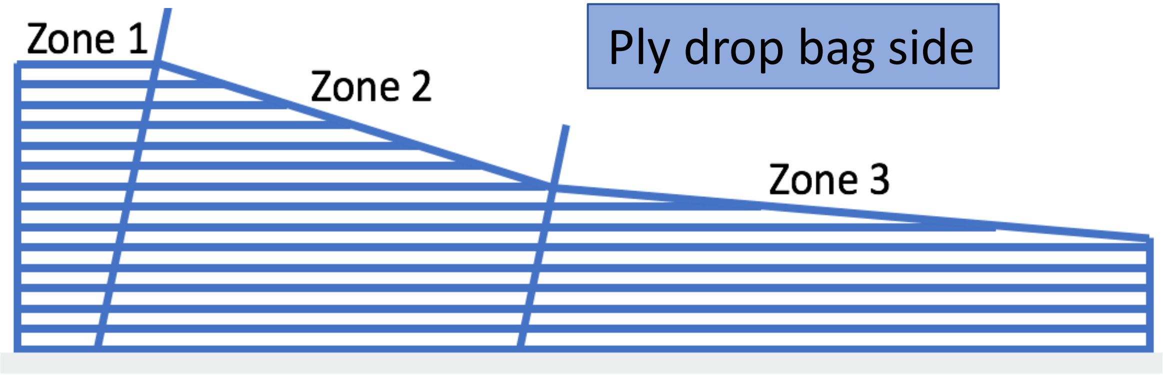
Legacy quad vs double-double: homogenization

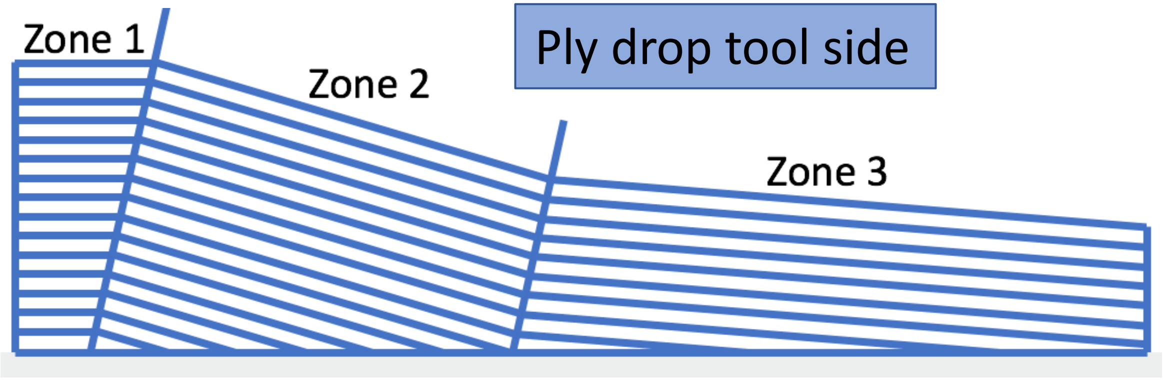
Legacy quad

Thousands of discontinuities



DD



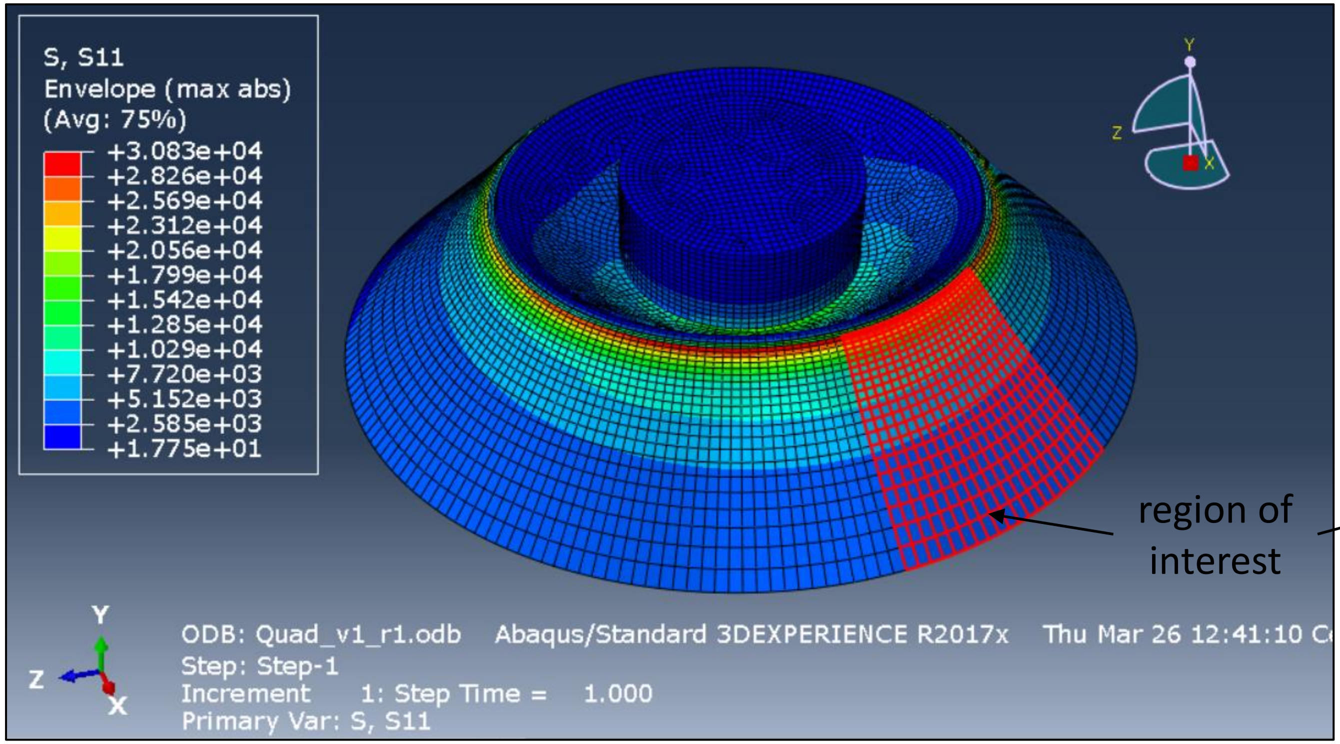


Homogenized body: no internal discontinuities

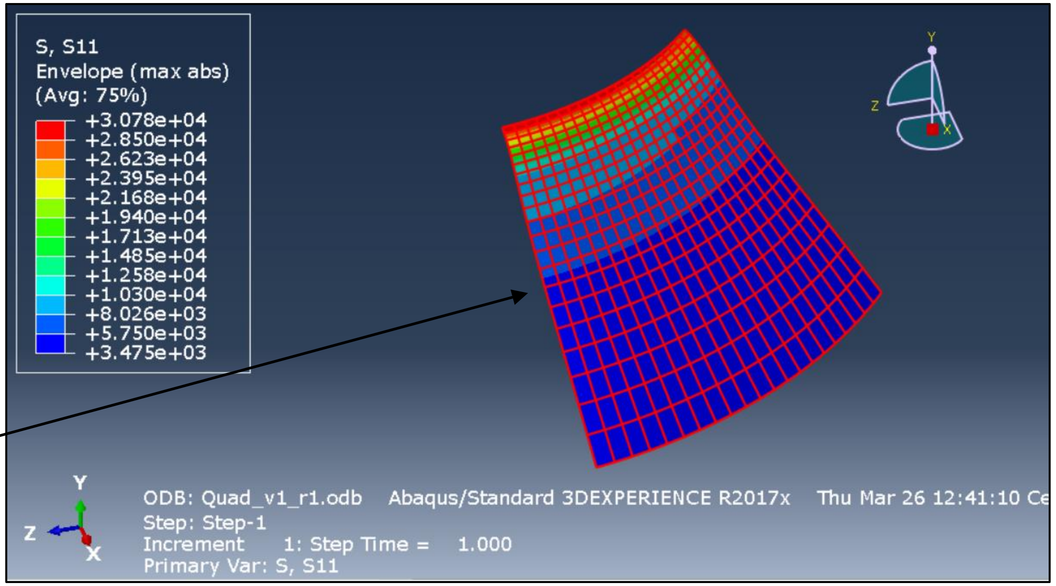
Post-processing

Stresses

- 21x21 mesh in worst-case location on adapter considered; stresses averaged over 49 regions (each region includes 9 elements)
- Local stresses (S11, S22, S12) for each ply extracted from Abaqus, then used to calculate Tsai-Wu stress ratios (R-values) over 49 regions in each ply
- Critical R-values and corresponding ply locations identified from ply-by-ply data



577 lb reduced to 302 lb: -48%

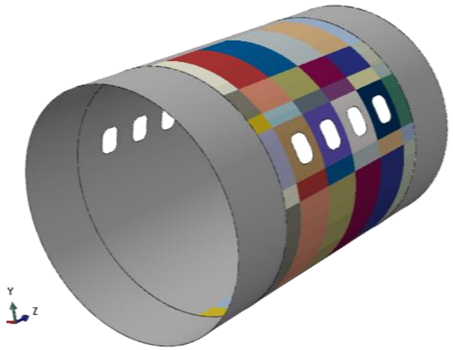


Universita
degli Studi
della Campania
Luigi Vanvitelli

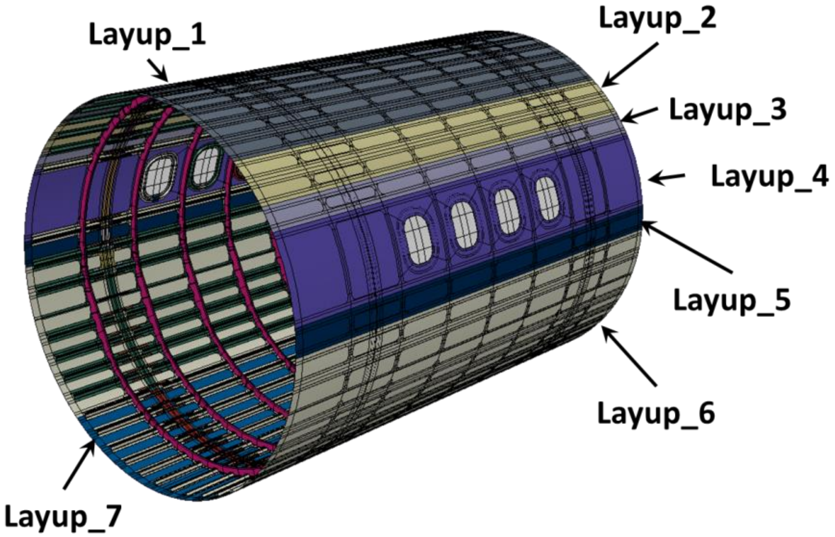
Cell Definition

- The Fuselage barrel has been divided in 7 x 6 = 42 cells
- The stacking sequence has been set constant within each cell
- The starting skin has been divided in 7 regions with the same layup

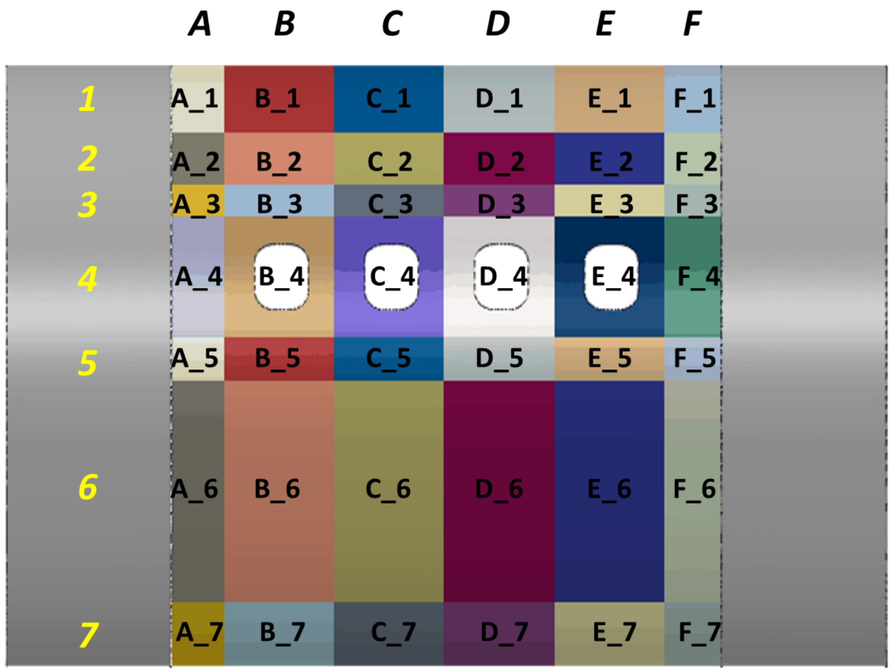
Weight reduced: 48%



Defined cells

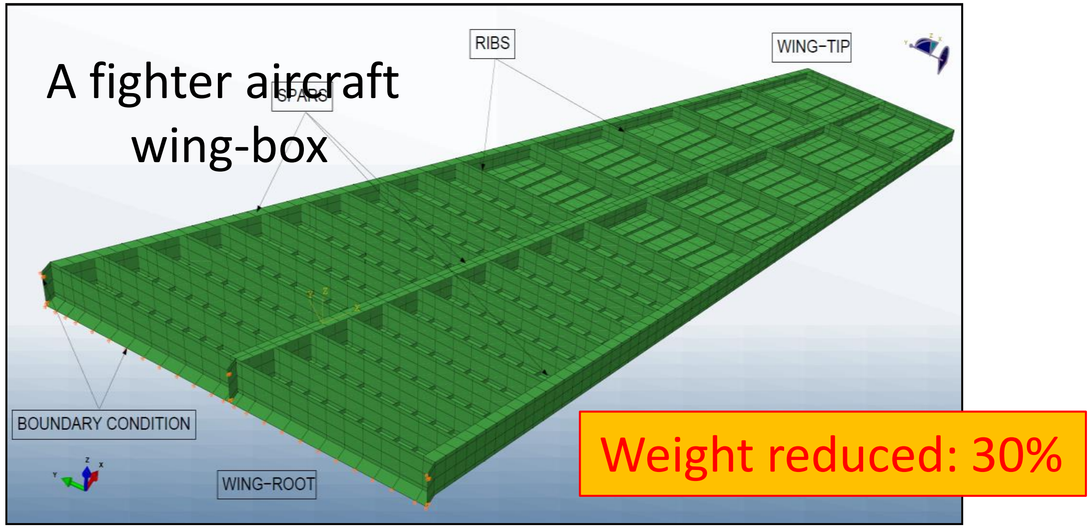


Regions with the same layup



Cell ID

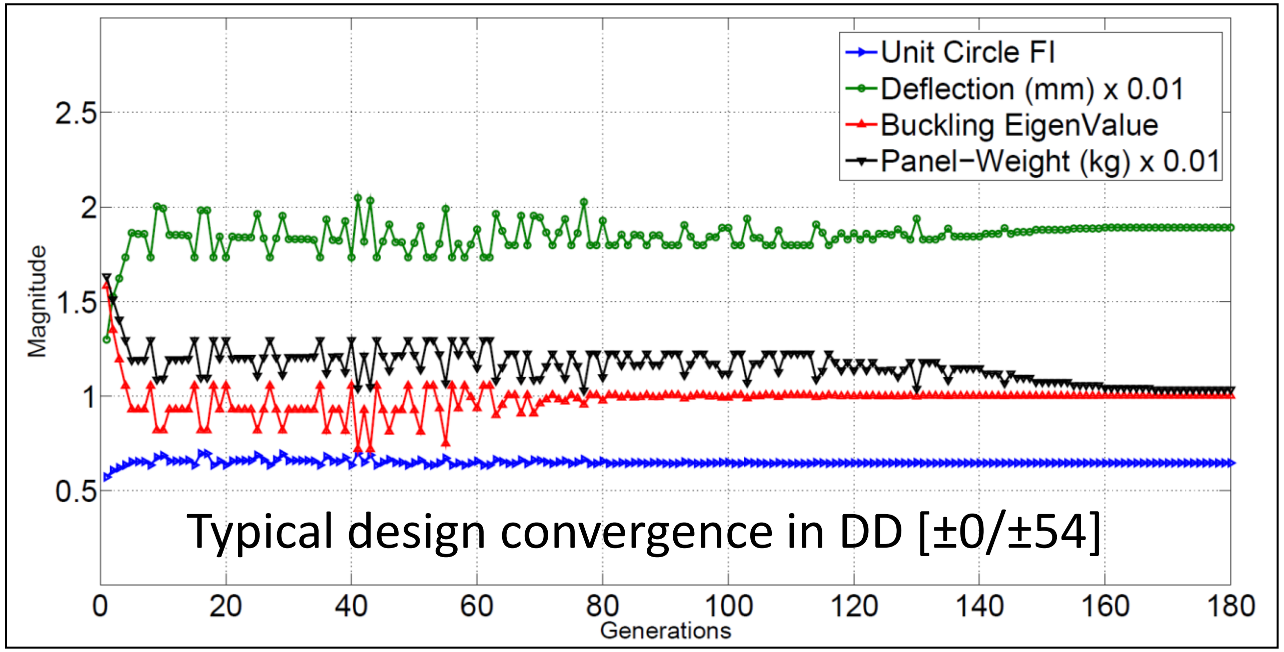
Double-double optimized wing box



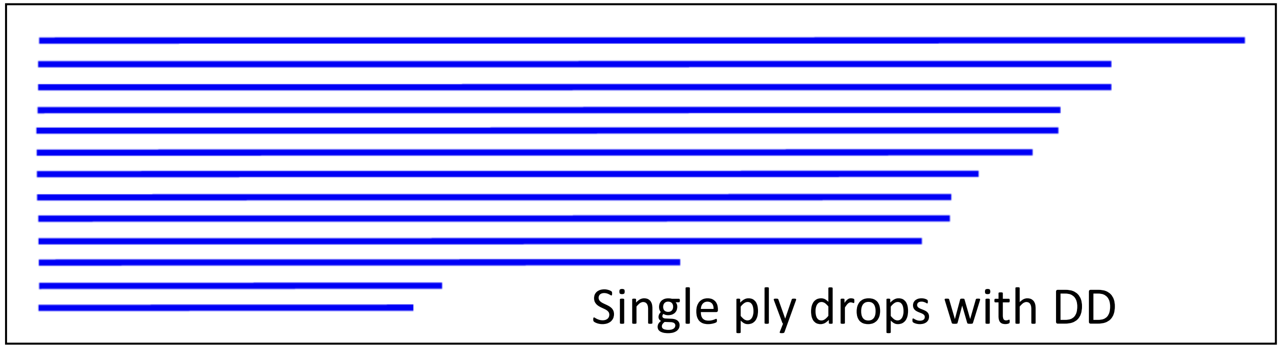
Weight reduction of 30 percent with use of DD $[\pm0/\pm54]_T$ over an optimized quad in $[0/45/0/90/-45/0/90/45]_S$

Homogenized DD profile with highly tapered profile showed no adverse warping during curing at simulated elevated temperature – a very important asset of DD

One-axis layup is fast, less-prone to error and wrinkling, no internal resin pockets and fiber breaks; all leading to high quality and low cost manufacturing unique with DD



Typical design convergence in DD [±0/±54]



Single ply drops with DD

Otto Aviation Celera 500L

Measure Up

A real world flight test of the chase plane, Piper 350 and our Celera 500L

	PIPER NAVAJO 350	CELERA 500L
Gallons consumed	129	27
Cabin volume	180 ft^3	448 ft^3
Max power	700 hp	500 hp
Flight duration	1:53 hour	1.53 hour

https://www.youtube.com/watch?v=zD1kFSvhq_k&feature=youtu.be

Proprietary Notice: All information is the property of Otto Aviation and considered confidential

Features

Laminar flow surfaces reduce drag

Turbo-diesel engine is fuel efficient with low Carbon emissions

High aspect ratio wing is very efficient

DD carbon fiber layup reduces weight

Performance

460 mph
5,600 mi range
20-25 mpg fuel efficiency
5x reduction in Carbon emissions

Double-double (DD) Key Benefits

DD leads to lighter parts

- DD **optimization is continuous** (quad is discrete)
- 4 plies minimum gage allows fine **thickness tuning**
- **Simple Ply drop** strategy

DD optimization by zone is achieved by **thickness variation with a unique DD, better than metal**

DD laminate is homogeneous : If sufficient repeat is achieved and thus requiring **no symmetry, not stacking dependent, and aggressive taper to save weight not possible with traditional quad**

Efficient manufacturing and easier repair

- Always the same simple 4-ply [±Φ/±Ψ] with no challenge of blending with quad
- DD can be tapered to reduce weight by additive lay up or subtractive ply drop
- [±Φ], [±Ψ], and/or [Φ/-Ψ] can be prebuilt to speed up deposition rate using Non Crimp Fabrics C-Ply™ with 1-axis layup that reduce time, error, and scrap
- High compaction/wrinkle-free product made possible with no internal ply drops