



Monocoque Hardpoint Design

By Nick Garber



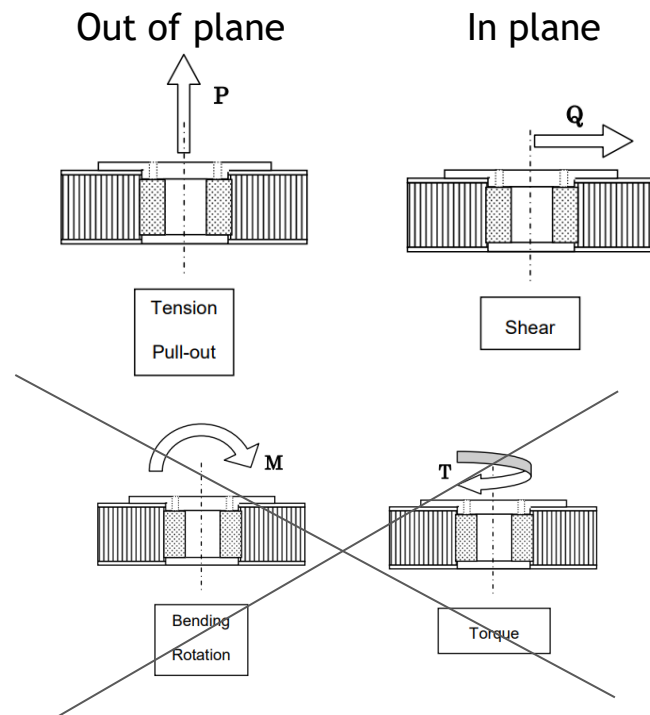
Load introduction principles

Out of plane loads

- Core is driving factor
 - Density & height
- Insert radius typical design variable
 - Linear capability relationship but mass increases with square of radius

In plane loads

- Local ply builds usually ideal for increased capability
 - Bearing typical failure mode unless small edge distance





Analytical Capability Determination

- Loads derived from driver input forces (pedals, steering wheel, etc.) as well as maximum driving forces (braking, lateral acceleration, etc.)
- Equations from ECSS Insert Design Handbook
 - Derived for fully-potted, cold-bonded inserts but equations shown to be generally applicable for hot bonded inserts too (<https://wiki.uwracing.com/images/3/31/10.1.1.934.2853.pdf>)
- Calculations include knockdown factors for edge proximity and proximity to other inserts
- Margins tracked in excel document including tabs for each category
 - (Next slide)



Excel Document

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1	READ ME																								
2																									
3	Lapup Region	Lower FBHS																							
4	Bolt Type	AN3																							
5																									
6	Peak In-Plane (Q)	254	lbf																						
7	Peak Out-of-Plane	113	lbf																						
8	SF	2	[-]																						
9	eta_total	1	[-]																						
10	Closest edge	999	in																						
11																									
12																									
13	Local core thickness	0.875	in																						
14	Bolt diameter	0.1875	in																						
15	Facesheet type	3 Ply	[-]																						
16	Num Bolts	1	[-]																						
17	Core type	18-5052-0010	[-]																						
18																									
19																									
20																									
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33																									
34																									
35																									
36																									
37	Laminate Properties (use CLT tab)																								
38	Facesheet E	4.55E+06	psi																						
39	Facesheet G	240114	psi																						
40	Facesheet nu	0.271	[-]																						
41	Facesheet thickness	0.0285	in																						
42																									
43	Core Properties																								
44	Core Gc	1.03E+04	psi																						
45	Core E	1.55E+04	psi																						
46	Core cell size	0.125	in																						
47	Core foil thickness	0.001	in																						
48	Core density	2.60E-03	lb/in ³																						
49	Core nu	0.33																							
50																									
51	3d-Printed of nylon Properties																								
52	Print G	56729	psi																						
53	Print E	1.82E+05	psi																						
54	Print density	3.83E-02	lb/in ³																						

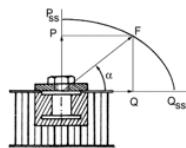


Figure 17-1: Insert submitted to an inclined load

Region	c	ply count
FBHS		1 4 Ply
Lower FBHS	0.875	3 Ply
MHS		1 3 Ply
Lower MHS	0.875	3 Ply
AP/FLF	0.875	6 Ply
Diff Crossbar	0.875	3 Ply

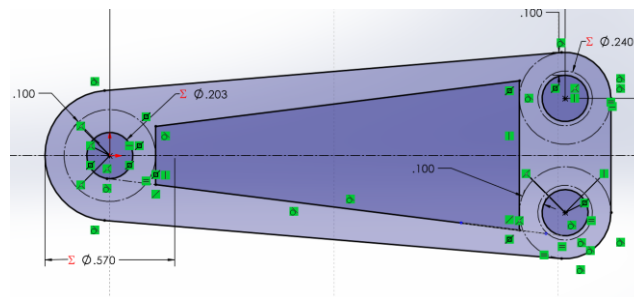
AN3	0.1875
AN4	0.25
AN5	0.3125

Lower FBHS

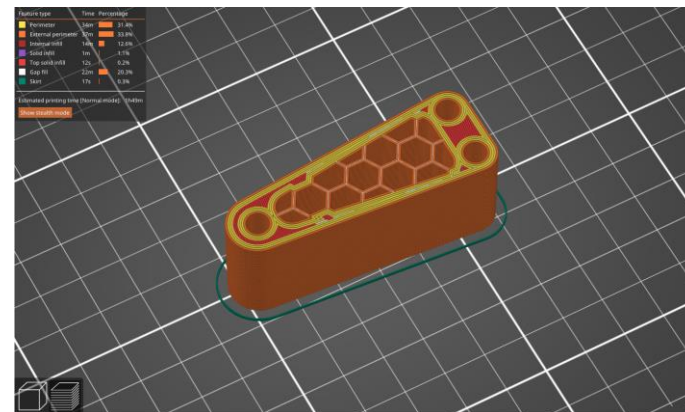


Block Insert Design

- Stress interactions between inserts in close proximity drive significantly larger inserts
 - It can become advantageous to combine multiple inserts into a single block insert
 - Manufacturability
 - Weight savings
- Block inserts often contain a significant amount of structurally unnecessary material (dark blue region) due to manufacturing constraints
 - Cannot be removed or face sheets would sag (pillowing) during cure



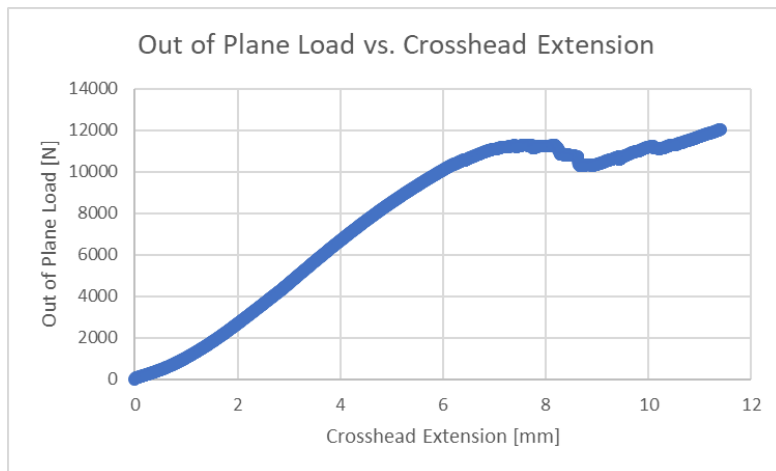
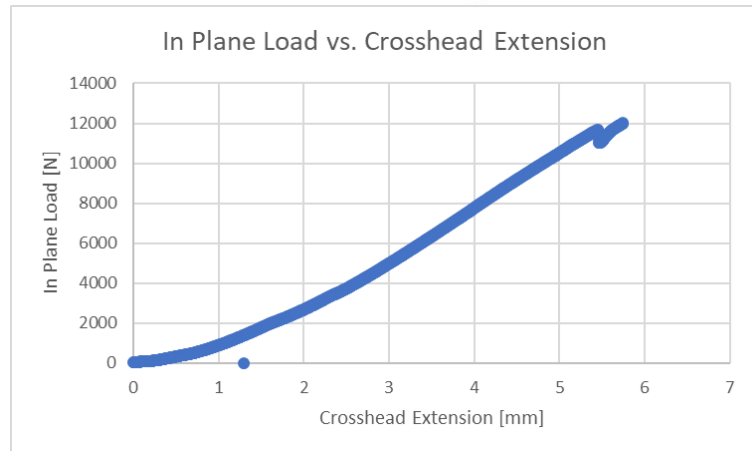
- Dead space gets filled with “pseudo core”
 - Greatly reduces mass while supporting face sheets during cure and satisfying structural requirements





Final insert testing

Reinforced clevis used because projected insert capability exceeded that of the clevis





Final insert testing

Out of plane:

- +50% Error
 - Conservative calculation 10-60% due to lack of literature*
- Core shear failure

In plane:

- Called at 2700 lbf due to fixture strength concerns, 12% over predicted

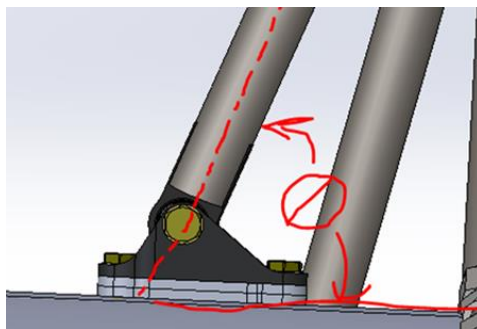
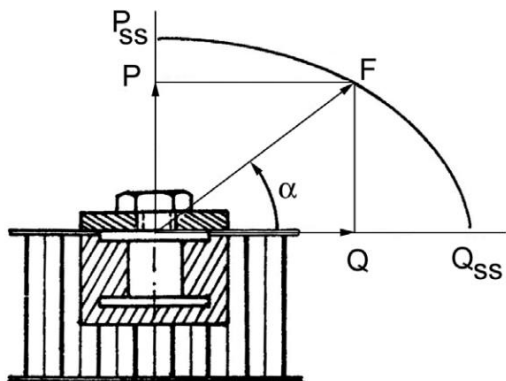


*See directional layups slide for more information

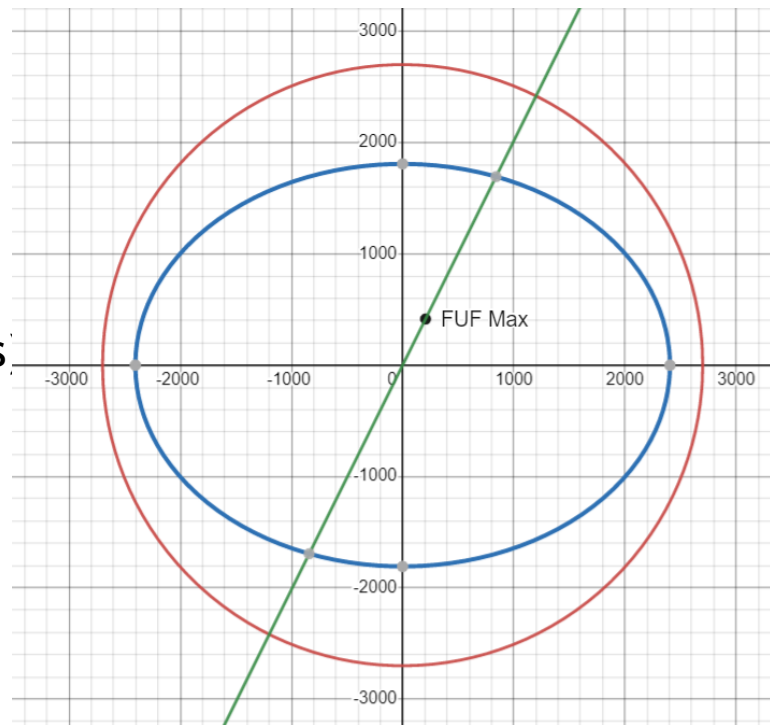
Relating test results to real-world performance

Combined loading capability

- Ellipse used for calculations
 - Akin to the traction ellipse
- 53g -> 20g, 62% weight reduction
- Tested MoS of 4.83 (driven by mfg. constraints)



$$|F_{ss}| = \frac{P_{ss}Q_{ss}}{\sqrt{P_{ss}^2 \cos^2 \alpha + Q_{ss}^2 \sin^2 \alpha}}$$





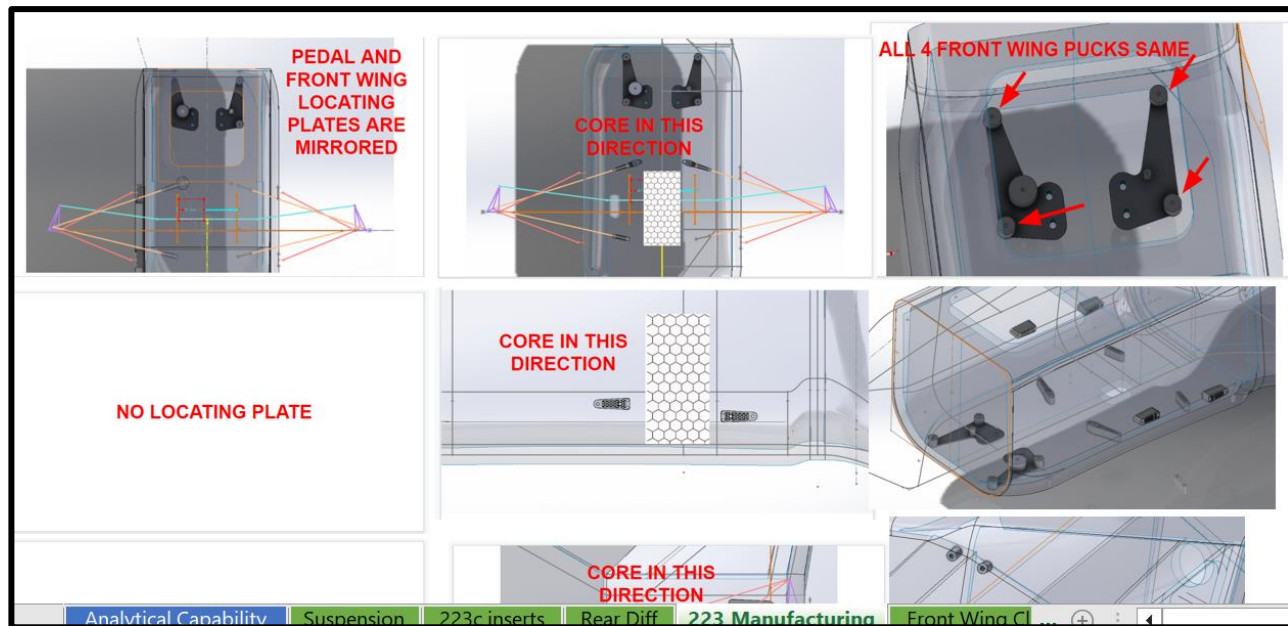
Material and manufacturing considerations

- FDM 3D-Printed PA-12 with 15% discontinuous carbon fiber reinforcement
 - Easy to print with compared to other high-performance thermoplastics
 - Can be printed on team members' 3d printers whenever needed
- Great chemical resistance characteristics
 - Don't have to worry about hardpoints dissolving from various solvents present in the shop
- Fiber reinforcement improves compression set qualities and reduces CTE to minimize delamination during cure
- Can survive the temperature and pressure of a monocoque cure



Manufacturing

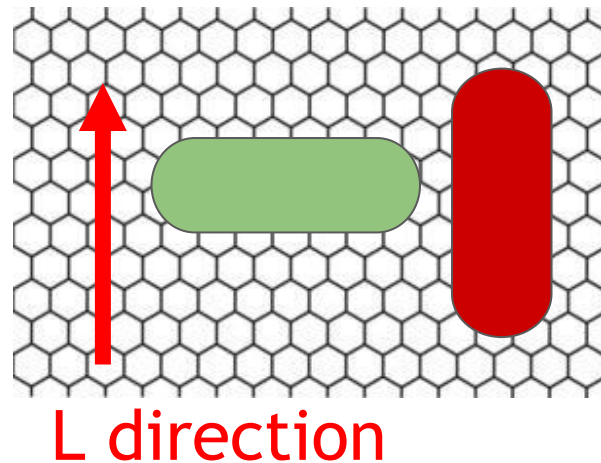
- Thorough manufacturing plan created to avoid errors during physically/mentally exhausting monocoque layups





Directional layups for block inserts

- ECSS calculations derived using Bessel functions which rely on rotational symmetry and are invalid for block inserts
 - Final block insert uses conservative first order shear deformation theory which significantly underpredicts capability
- Conservative shear strength values used due to lack of literature
 - Shear strength a factor of strength in both L and W directions
 - Experimental data has shown $1.36\tau_w$ to correlate well for rotational symmetry bc's
 - Pure L direction approaches $1.54\tau_w$ whereas pure W direction approaches $1.0\tau_w$





Areas for future development

- Room for optimization of standard spool style inserts
 - Reduce through-the-thickness height as shear perimeter increases, full in remaining height with pseudo core
- Characterize the shear strength value based on geometry/direction of the insert
 - Likely not worth the testing/validation on FSAE timelines but a fun thought experiment



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