P09221: Innovative Composite Parts for a Formula SAE Racecar

Team Members:
David Holland
Theodore Kusnierz
Anthony Salvo
Ryan Baldi
Charles Thomas
Martin Iwanowicz

Project Overview

- Mission Statement:
  - To build an easily manufactured, lightweight, stiff, high performance composite chassis, aerodynamics package, and pedal box for the RIT Formula SAE racecar.
- Primary Market:
  - R•I•T Formula SAE Team
- Secondary Market:
  - Weekend Autocrossers
- Stakeholders:
  - RIT FSAE Team
  - Dr. Alan Nye
- Start Date/End Date:
  - 2008-2/2008-3

Components for Redesign

Customers Interviewed:
- Formula SAE Driver, Project Manager, Chassis Designer, & Chief Engineer
- SCCA Autocrosser

Customer Needs (Pedal Box):
- Stiff
- Lightweight
- Adjustable
- Easily Manufactured

Customer Needs (Chassis):
- Torsionally Stiff
- Lightweight
- Ergonomic
- Test Procedure for Correlation
- Works with F16's other parts

Customer Needs (Undertray):
- Center of pressure near CG of car
- Lightweight
- Easily manufactured
- Makes Downforce
- Does not interfere with car operation

Engineering Specifications

Chassis

- Weight < 55lbs
- Cone impact @ 75mph
- Bump, accel, brake, corner loads: 3g/2g/2g
- Torsional Stiffness: 2500lb*ft/degree

Undertray

- Lift: 30+lb @ 25mph
- Weight: < 25lb
- Must mount to chassis and not interfere with suspension geometry.

Pedal Box

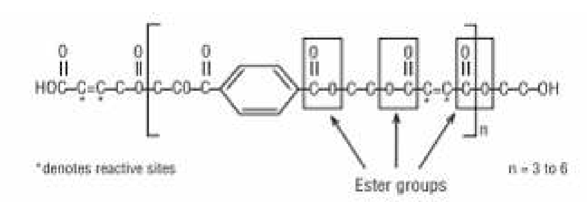
- 3g bump loading, 2g braking load
- Pedal load = 200lb
- Deflection < .010”
- Adjustable for driver height: 5’4”<h< 6’6”
- Weight: < 1.5lb

Resin Selection

Polyester:

Pros:
- Cheap
- Low viscosity
- Properties can be tailored

Cons:
- Poor adhesive characteristics
- Relatively brittle and weak
- Large number of ester groups means water has significant effect on properties due to hydrolysis
- High degree of shrinkage

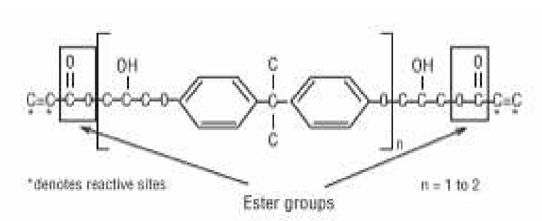


Idealized Polyester Molecule
(Isophthalic)

Vinylester

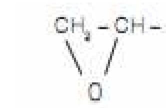
Pros:
- Relatively cheap
- Low viscosity
- Good mechanical properties
- Fewer ester groups than polyester, more resistant to ingress of water
- High toughness because active sites are at ends of molecular chains

Cons:
- High degree of shrinkage
- Relatively poor adhesive qualities



Idealized Vinylester Molecule

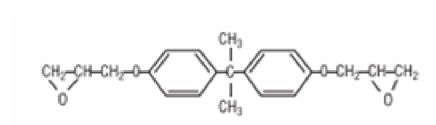
Epoxy



Idealized Ethylene Oxide Group (Epoxy)

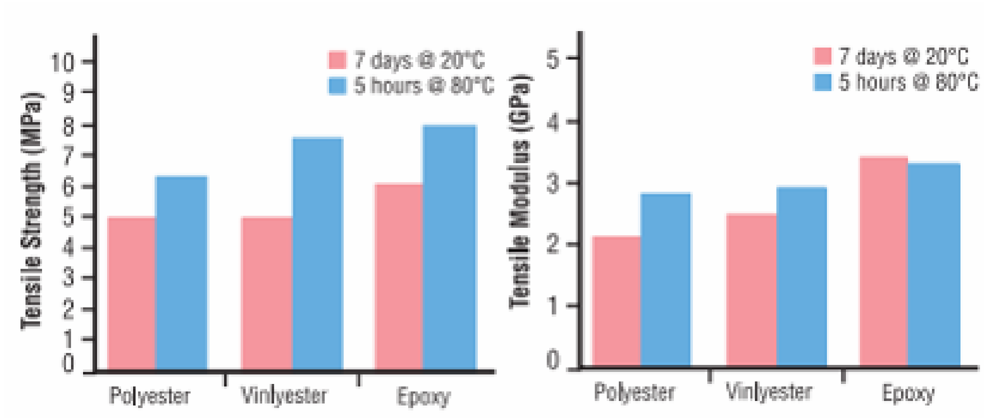
Pros:
- Excellent thermal and mechanical properties due to cyclic groups (instead of linear chains)
- Ethylene Oxide groups instead of ester groups – high resistance to water
- Reaction sites are at ends of molecular chains – high toughness
- Excellent adhesive properties

Cons:
- High viscosity
- Cost



Idealized Epoxy Molecule
(Bisphenol A)

Resin Selection



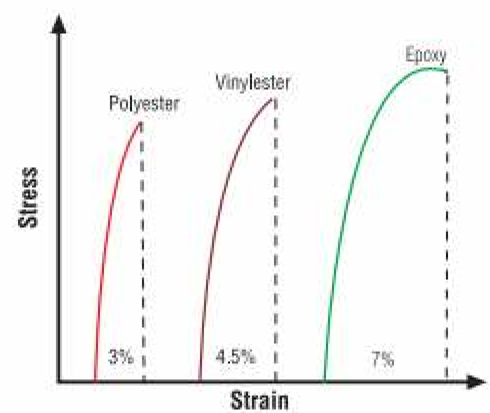


Figure 6 -Typical Resin Stress/Strain Curves (Post-Cured for 5 hrs @ 80°C

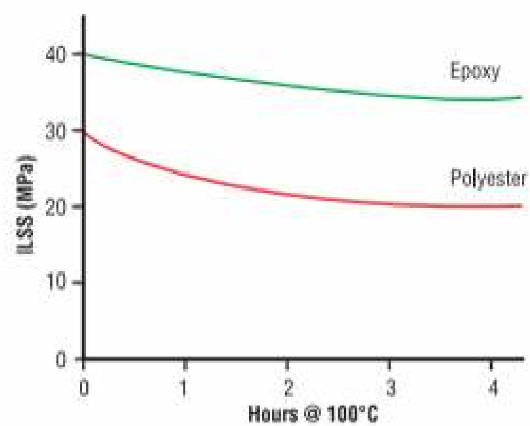


Figure 23 - Effect of Periods of Water Soak at 100°C on Resin Inter-Laminar Shear Strength

Resin Selection

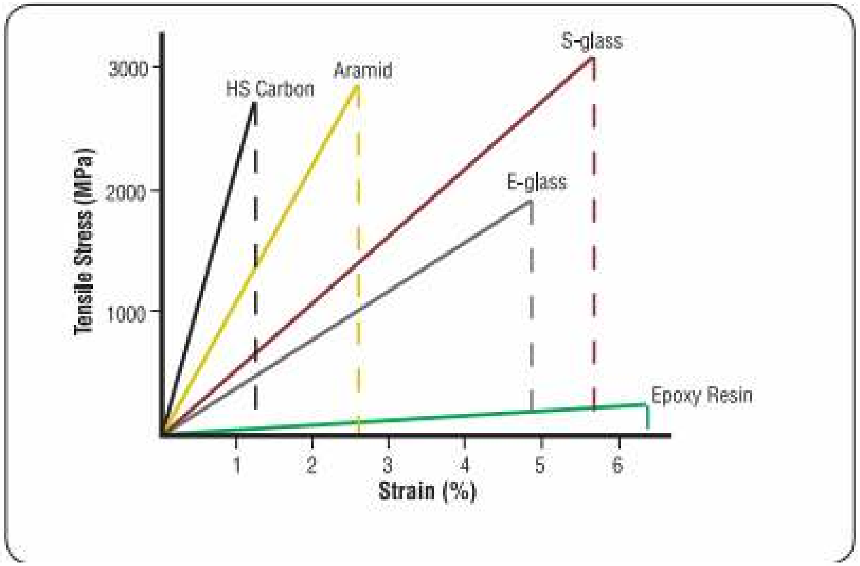
Selection Criteria:
- Elasticity/Toughness
- Adhesion Properties
- Strength
- Water Degradation
- Resistance to Corrosives
- Viscosity
- Cost

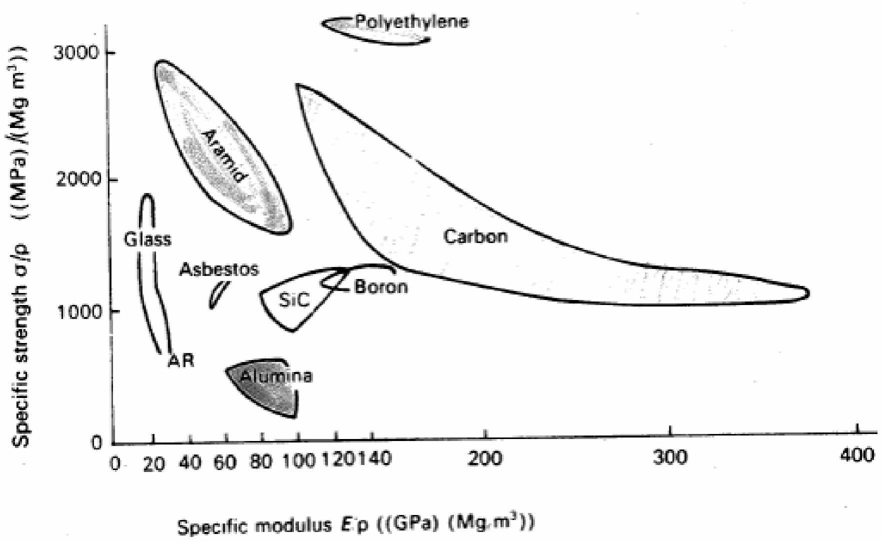
	Adhesion	Ductility	Strength	Shrinkage While Curing	Water Degredation	Chemical Resistance	Low Viscosity	Cost
Polyester	-	-	0	-	0	0	+	+
Vinylester	0	+	+	-	+	+	+	+
Epoxy	+	+	+	+	+	+	0	-

*Analysis performed based on general material properties.

Selected Matrix: Epoxy
- Highest Fatigue/Creep Resistance
- Highest Resistance to Water & Corrosives

Fiber Selection





	Stiffness	Strength	Cost	Environmental Resistance	Chemical Resistance
Carbon Fiber	+	+	-	+	+
S-Glass	0	+	0	+	+
E-Glass	-	-	+	+	-

*Analysis performed based on general material properties.

Selected Fiber: Carbon Fiber

- Highest specific stiffness
- Very little sacrifice in strength
- More experience with CF

Composite Monocoque

Monocoque Style

Above: Partial Monocoque
(TU Graz)

Above: Partial Monocoque Roll Hoop Mounting
(ETS)

Above: Full Monocoque
(RMIT)

Composite Monocoque

Monocoque Style

Partial Monocoque:

Pros:

- Less carbon = cheaper
- Ease of manufacturing
    - Smaller monocoque footprint means easier time finding oven/autoclave
    - Fewer molds and less lay-up time
- Easy engine mounting scheme

Cons:

- Different suspension mounting scheme front and rear
- Extensive welding required

Full Monocoque:

Pros:

- Solutions for suspension mounting can be applied to both front and rear
- Continuous fabric rear box is likely stiffer and stronger than steel rear
- Less time, if any, spent welding

Cons:

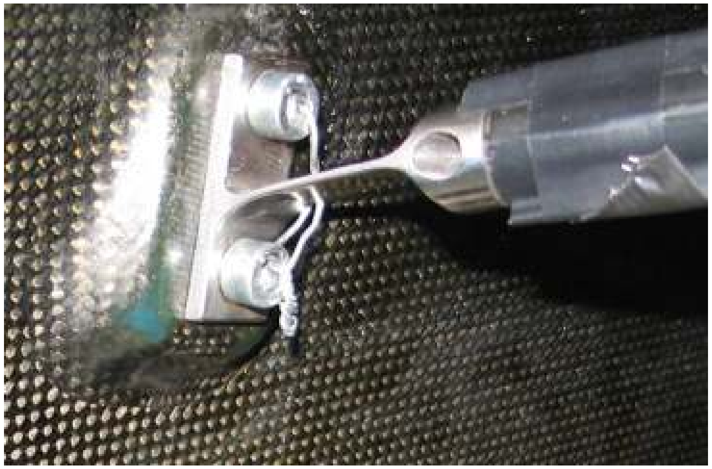
- More expensive
- Difficult to transition to steel roll hoop, then back to carbon
- Difficulty in engine mounting
- Larger footprint restricts oven choices

Concept Selected: Partial Monocoque

Composite Monocoque
A-Arm Mounting

Metal Tabs Bolted to Chassis
(KU)

Composite Tab Bolted to Chassis
(RMIT)



Flex Plate Bolted to Chassis

Composite Monocoque
A-Arm Mounting

Tabs (carbon or metal):

Pros:
- Minimal alteration of vehicle’s kinematics
- Longer lifetime (no reversing flexural loads)

Cons:
- Heavy
- Expensive bearings
- Subject to bearing supplier’s lead times

Flex Plates:

Pros:
- Lightweight
- Simple design with very few parts

Cons:
- Changes spring rate of vehicle
- Reversing flexural loads decrease fatigue life

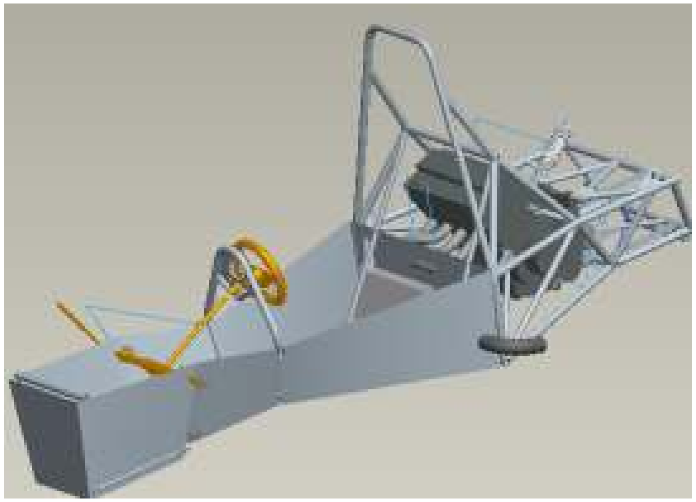
Concept Selected: Tabs Bolted to Chassis

Composite Monocoque

Shock/Bell Crank Mounting Style

Above: Bolted/bonded “box” to pick up shock points
(KU)

Above: Move point locations to accommodate packaging
(RMIT)



Above: Run bell crank through side of monocoque to preserve old points.
(RIT)

Composite Monocoque

Shock/Bell Crank Mounting Style

Cut large hole in side of monocoque:

Pros:

- Minimal alteration of vehicle's kinematics
- Previous year's bell cranks can be used
- Lightweight

Cons:

- Large stress concentrations created
- Results in small radii in the floor of the chassis – difficult to manufacture

Create Mounting Box

Pros:

- Maintains previous year's kinematics

Cons:

- Heavy
- Numerous small stress concentrations created for bolt holes
- More components to fabricate

Move Bell Cranks

Pros:

- Lightweight
- Can create simple, efficient design with few extraneous parts

Cons:

- Changes kinematics relative to previous year's vehicle

Concept Selected: Cut hole in monocoque

Composite Monocoque

Chassis Analysis

Governing Equation of Finite Element Analysis:

• Garbage In = Garbage Out

FEM must:

• Have quickly traced and resolved errors
• Run “quickly” on school computers
• Be robust enough to easily run multiple load cases
• Comprehend composite-to-steel interface at roll hoop mounts
• Be easily modified
• Be accurate

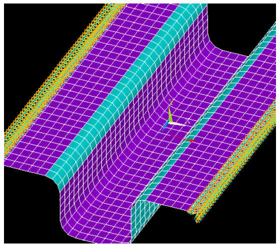
FEA Package Chosen: ANSYS

Composite Monocoque

Chassis Analysis

Steps for Building Model

(Note: All steps will be completed first by modeling composite components with equivalent isotropic properties. After successful runs, full laminate will be modeled)



• Model a channel with min & max chassis radii.

• Model front half of chassis, apply arbitrary loads and constraints.

• "Bond" both steel roll hoops (beam elements) to monocoque (shell elements). Apply arbitrary loads and constraints

• Increase roll hoop element count, connect nodes from roll hoop elements to shell elements. Use beam elements with fastener material & geometric properties.

• Add rear of chassis as beam elements. Run model with realistic loads/constraints (coarse mesh)

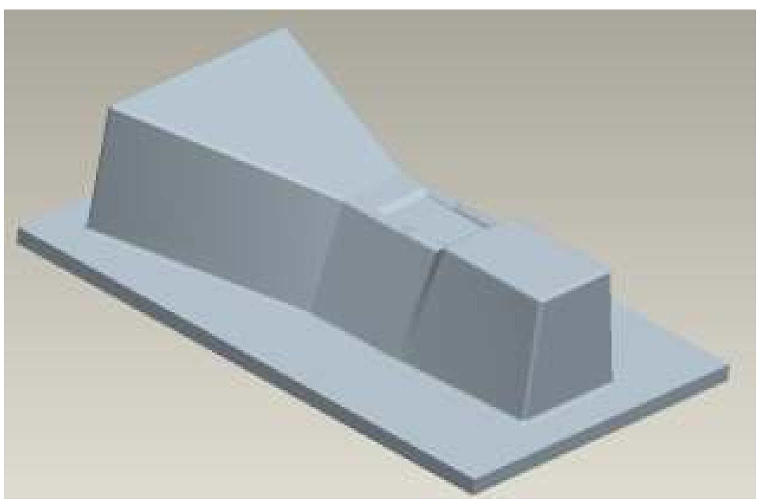
• Model small chassis segments w/ very fine mesh. Apply displacements (taken from global coarse grid model) at boundaries. Check for strain, stress, buckling, etc..

Composite Monocoque

Chassis Plug

- Chassis plug used as accurate base for chassis manufacture
- 2 plugs will be made, one representing top half geometry, one representing bottom half geometry
- Plugs will be CNC manufactured out of MDF primarily for accuracy, but also to minimize manufacturing time
- MDF cost (~$400) is a major concern
- Surface will be finished with sanded/polished paint and coated with mold release

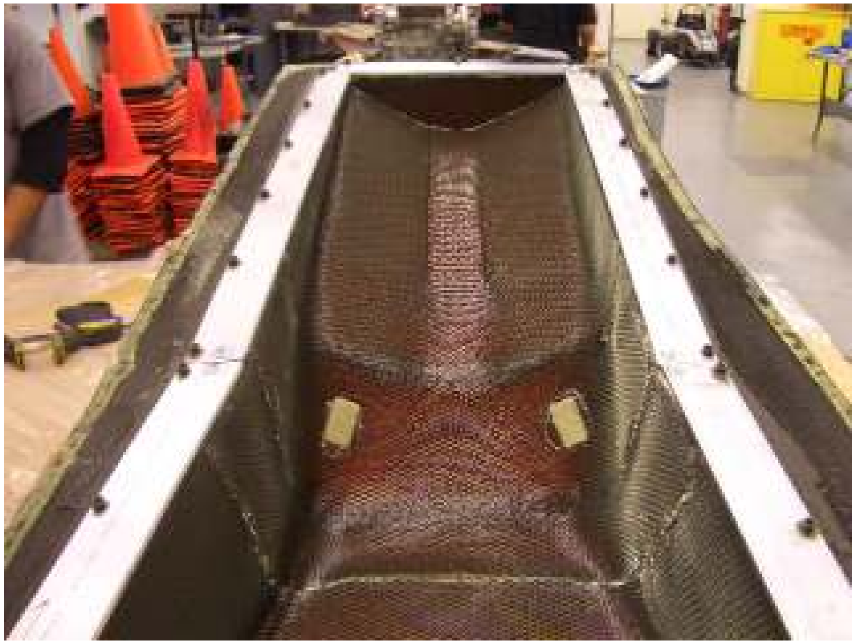
Top and Bottom Plugs (CSU Northridge)



Initial Bottom Plug Design

Composite Monocoque
Chassis Mold

- Mold will be produced from finished plug
- Material will likely be low temperature cure/high temperate post-cure prepreg
- Prepreg will allow for good dimensional stability at a wide variety of temperatures, as well as quick manufacturing and high quality surface finish
- Major downside is cost of materials, though prepreg will hopefully be donated
- Other options include wet layup, infusion, or manufacture of a female "plug"



Layup in Mold (CSU Northridge)

Layup in Mold (CSU Northridge)

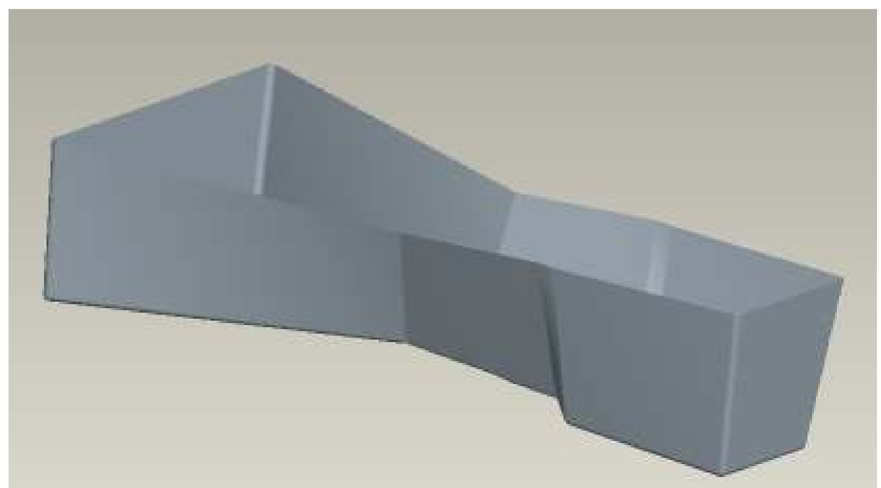
Composite Monocoque

Final Part

- Aerospace prepreg will be cured in an autoclave at high temperature and pressure
- Process assures very high quality, consistent part and allows use of high performance resins
- Cost of materials is very high, but they will hopefully be donated

Autoclave Cure of Components (CSU Northridge)

Lower Chassis Half
(CSU Northridge)



Lower Chassis Model

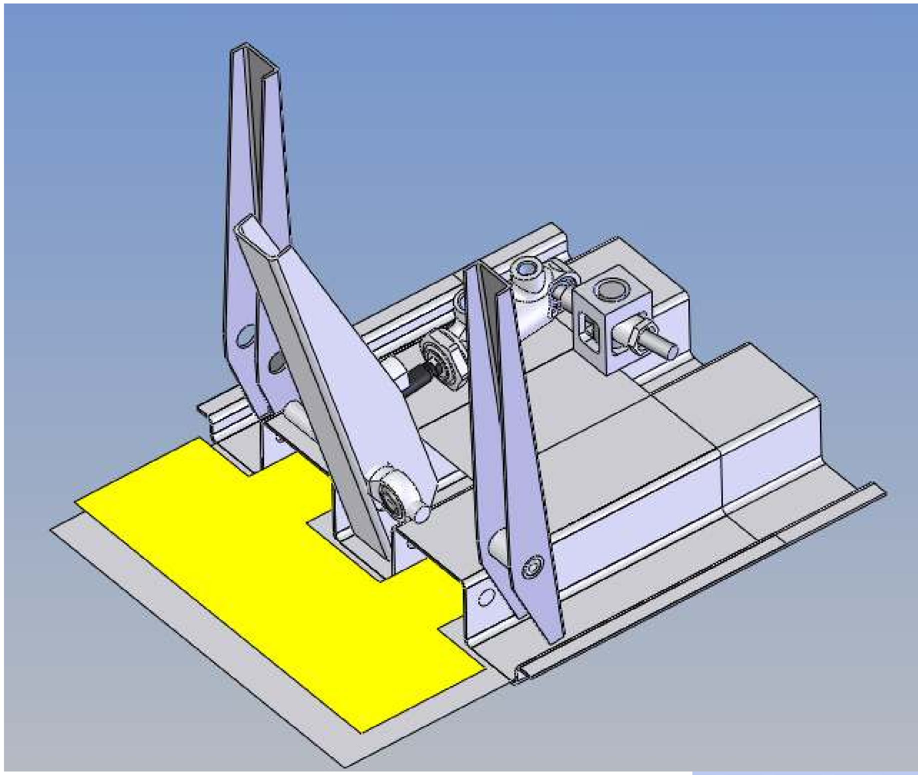
Composite Monocoque

Overall Cost

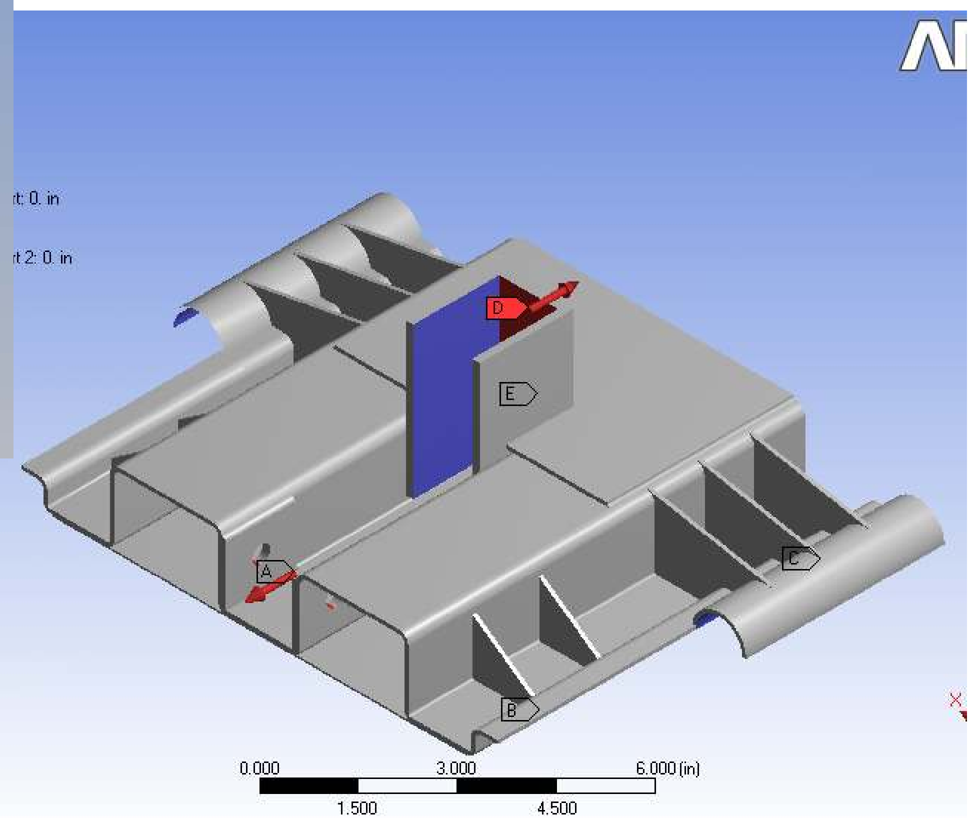
Chassis:				
Item	**Quantity**	**Per Unit Cost ($)**	**Dollars per:**	**Total Cost**
Assorted tools, supplies, cleaners, saf	1	75	per pack	75
Carbon Fiber (Prepreg)	150	50	per yd	7500
MDF	15	27	per sheet	405
Core	2	350	per 4'X8' sheet	700
Plug Machining Time	6	150	per hour	900
Plug Secondary Operations	36	60	per hour	2160
Mold Layup Time	5	60	per hour	300
Mold Prep Time	15	60	per hour	900
Chassis Layup Time	50	60	per hour	3000
Oven/Autoclave Curing Time	4	50	per hour	200
Oven/Autoclave Post Curing Time	4	50	per hour	200
Part Trimming	10	60	per hour	600
Final Assembly	105	60	per hour	6300
			Total Chassis Cost	23240

Chassis:				
Item	**Quantity**	**Per Unit Cost ($)**	**Dollars:**	**Total Cost**
Assorted tools, supplies, cleaners, saf	1	75	per pack	75
Carbon Fiber (Prepreg)	150	0	per yd	0
MDF	15	27	per sheet	405
Core	2	0	per 4'X8' sheet	0
Plug Machining Time	6	0	per hour	0
Plug Secondary Operations	36	0	per hour	0
Mold Layup Time	5	0	per hour	0
Mold Prep Time	15	0	per hour	0
Chassis Layup Time	50	0	per hour	0
Oven/Autoclave Curing Time	4	0	per hour	0
Oven/Autoclave Post Curing Time	4	0	per hour	0
Part Trimming	10	0	per hour	0
Final Assembly	105	0	per hour	0
			Total Chassis Cost	480

Composite Pedal Box
Concept Development



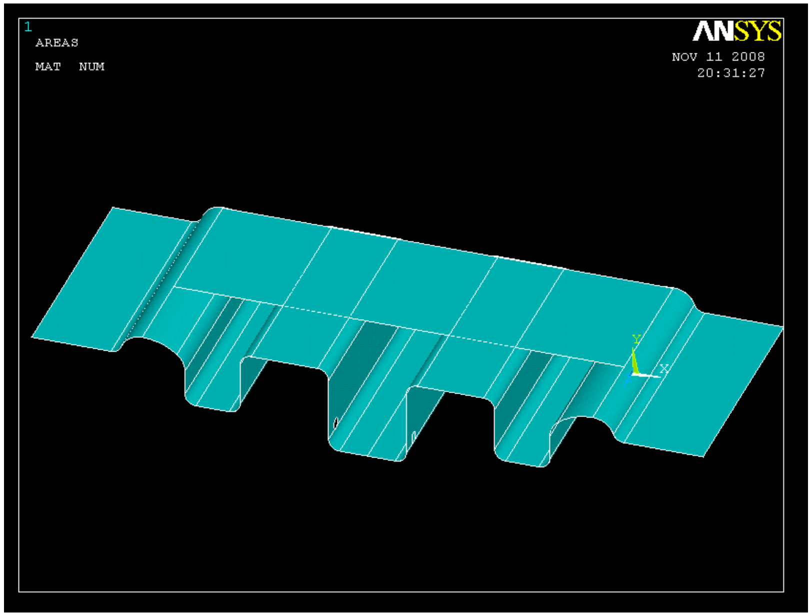
Left: Concept pedal box assembly including:
- Pedals
- Bias block
- Footrest

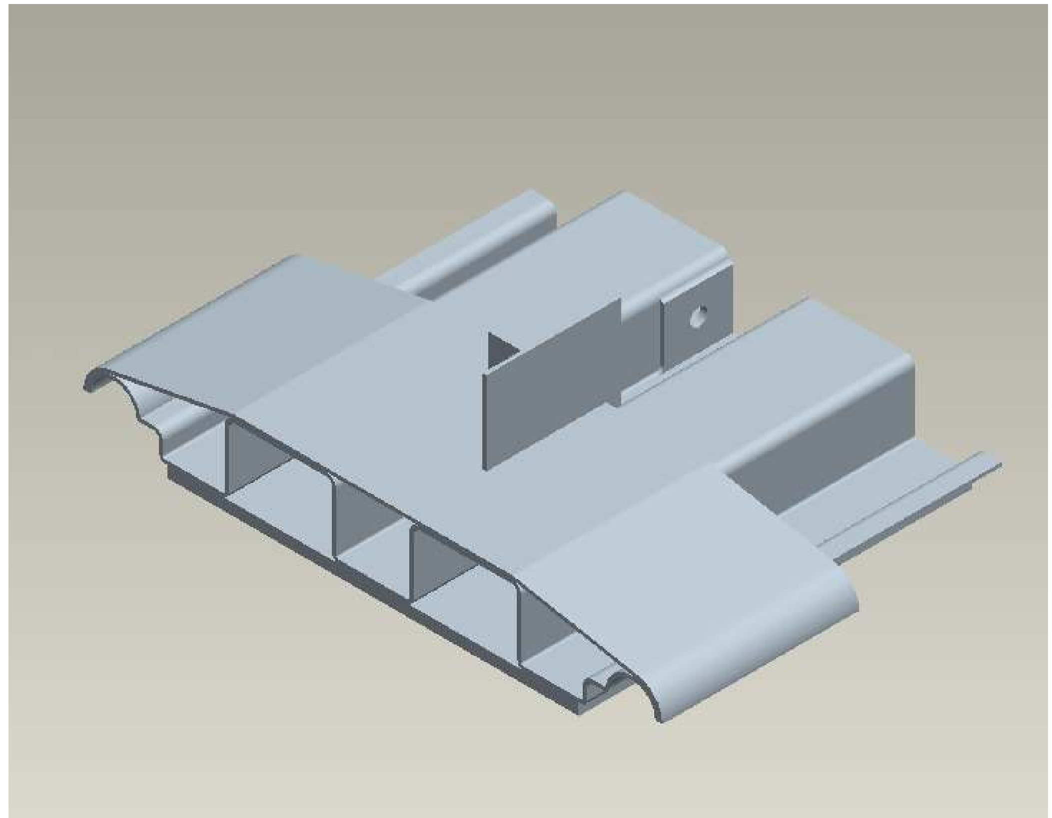


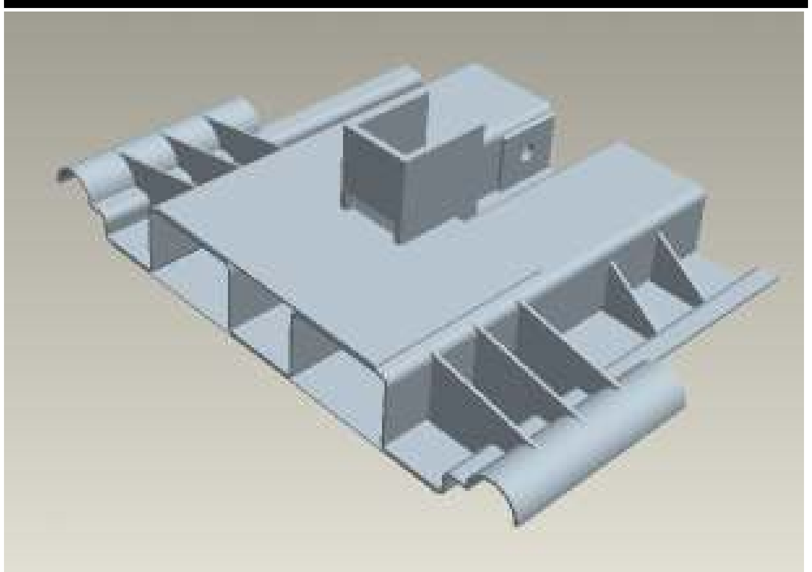
Right: Load cases to be considered:
- Driver input reactions
- Bump loading

Composite Pedal Box

Stiffening Concepts







Above: Design combing flat plate and rib-style concepts (in progress)

Upper-left: Flat plate concept

Left: Rib-style concept

Composite Pedal Box

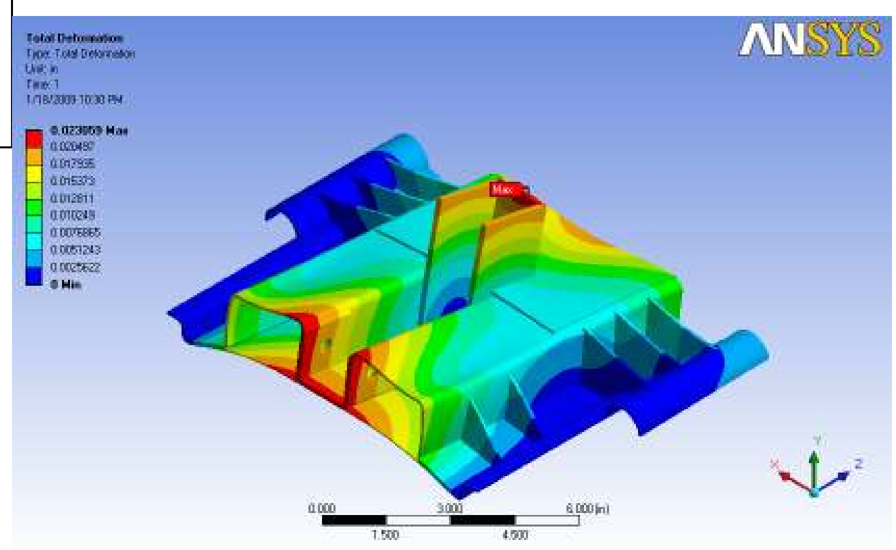
Analysis & Testing

Analysis Plan:

- ANSYS Workbench
  - “Iso” properties
  - Estimate deflection
  - Estimate thickness
- ANSYS Classic
  - Refine thickness & ply orientation
  - Ply stress analysis
- ANSYS Workbench
  - Bond-line analysis
  - Determine suitable structural adhesive

Test Plan:

- Destructive testing to verify**:**
  - Fabric/matrix properties
  - Pin pull-out
  - Bias-block tabs
- Determine required material thicknesses

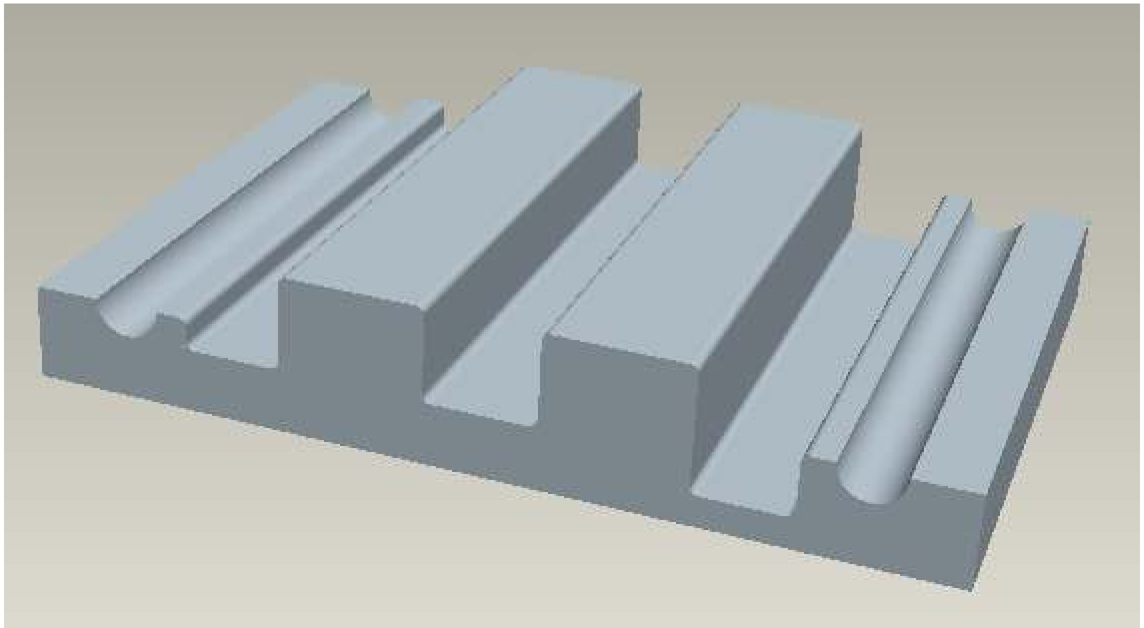


Composite Pedal Box

Manufacturing

Mold Concept:

- Two piece compression-molding:
  - Tray
  - Bias block tabs
  - Stiffening plates
- Possible materials include:
  - MDF
  - Plastic
  - Aluminum



Above: Lower mold concept

Composite Pedal Box

Overall Cost

Pedal Box:				
Item	**Quantity**	**Per Unit Cost ($)**	**Dollars per:**	**Total Cost**
Assorted tools, supplies, cleaners, s	1	75	per pack	75
Carbon Fiber	2	50	per yd	100
Epoxy	0.3	100	per gallon	30
Structural Adhesive	0.025	50	per qt	1.25
Tooling Board	0.1	75	per 4'X8' sheet	7.5
Core	0.05	350	per 4'X8' sheet	17.5
Mold Machining Time	1.5	150	per hour	225
Mold Prep Time	1.5	60	per hour	90
Pedal Box Layup Time	1.5	60	per hour	90
Stiffener/Tab Fabrication	3	60	per hour	180
Part Trimming	1	60	per hour	60
Final Assembly	2	60	per hour	120
			Total Pedal Box Cost	996.25

Pedal Box:				
Item	**Quantity**	**Per Unit Cost ($)**	**Dollars per:**	**Total Cost**
Assorted tools, supplies, cleaners, s	1	75	per pack	75
Carbon Fiber	2	0	per yd	0
Epoxy	0.3	0	per gallon	0
Structural Adhesive	0.025	0	per qt	0
Tooling Board	0.1	0	per 4'X8' sheet	0
Core	0.05	0	per 4'X8' sheet	0
Mold Machining Time	1.5	0	per hour	0
Mold Prep Time	1.5	0	per hour	0
Pedal Box Layup Time	1.5	0	per hour	0
Stiffener/Tab Fabrication	3	0	per hour	0
Part Trimming	1	0	per hour	0
Final Assembly	2	0	per hour	0
			Total Pedal Box Cost	75

Composite Undertray

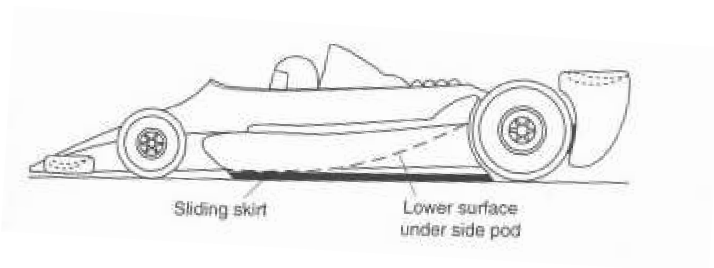
Undertray Images

Rear Tunnels of TU Graz's Undertray

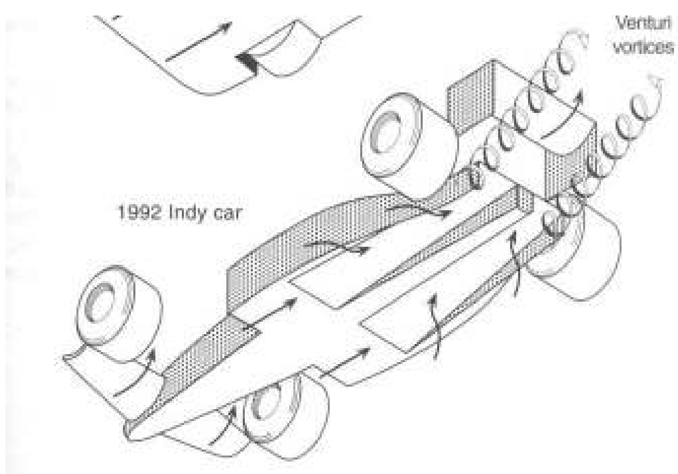
Side view of TU Graz's Undertray

Underside of TU Graz's Undertray

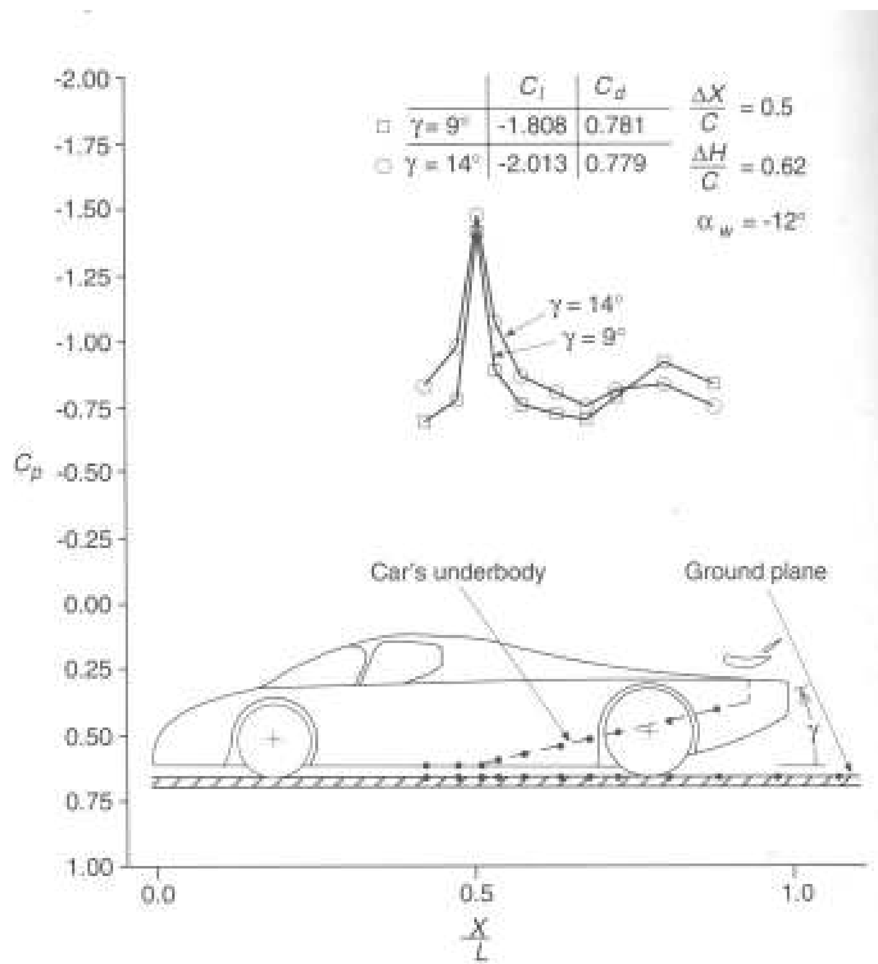
Composite Undertray
Underwing vs. Tunnels



Above: Underwing Concept



Above: "Venturi" Tunnel Concept

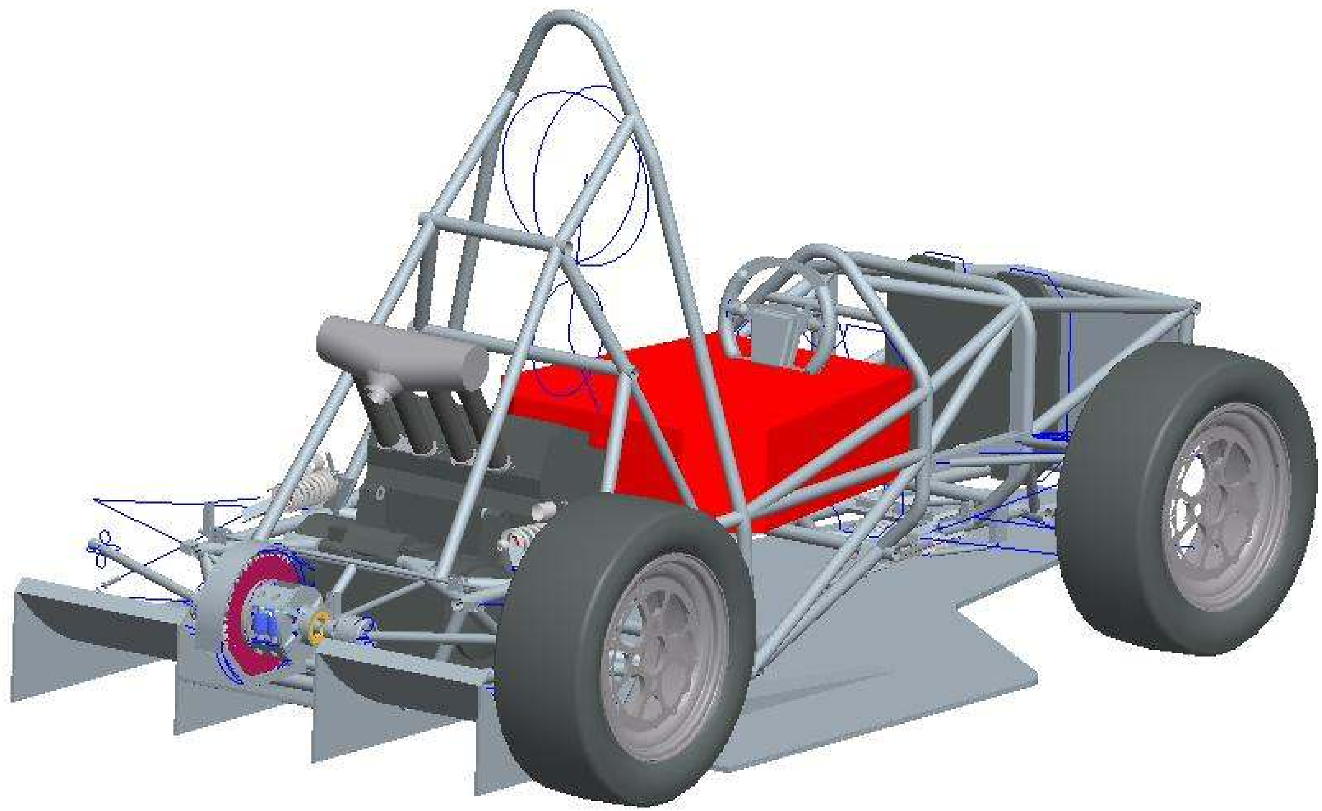


	C_l	C_d
□ γ = 9°	-1.808	0.781
○ γ = 14°	-2.013	0.779

Above: Cp vs. Longitudinal Distance

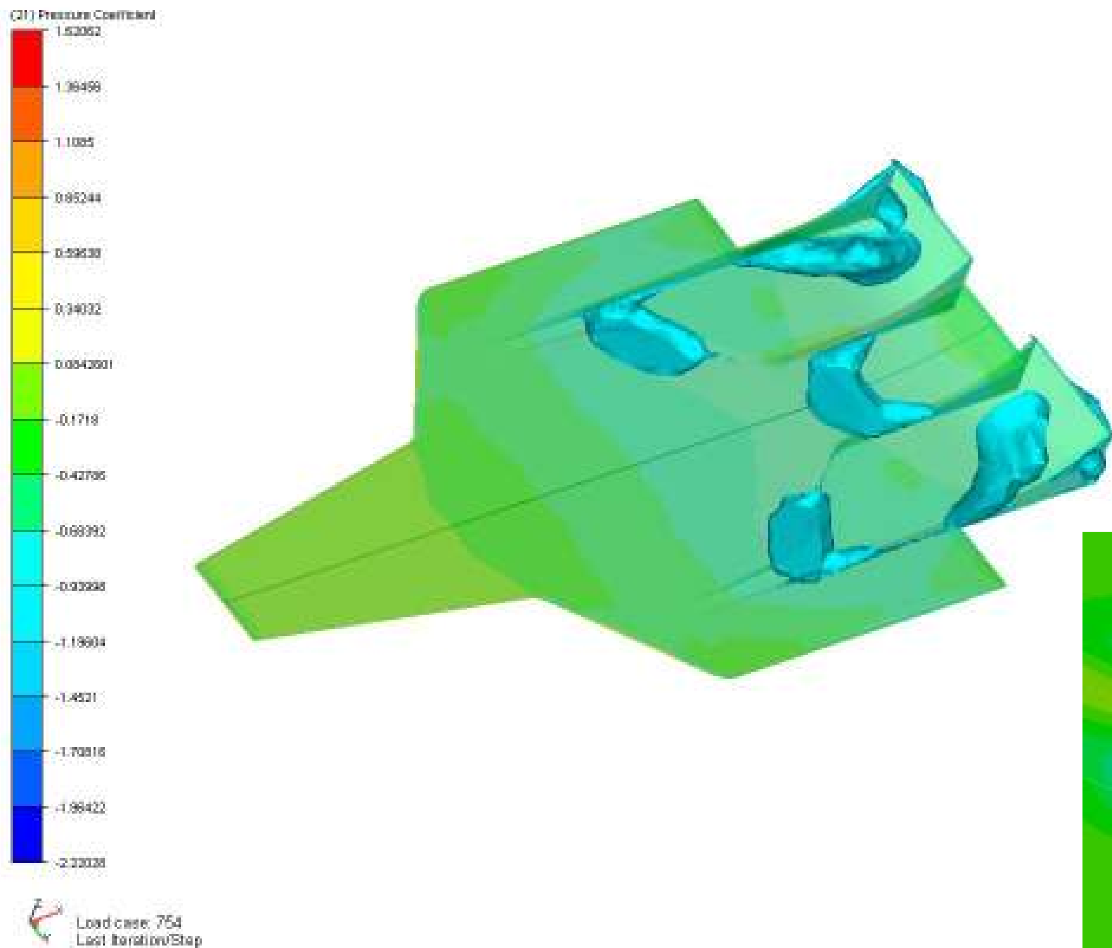
Composite Undertray

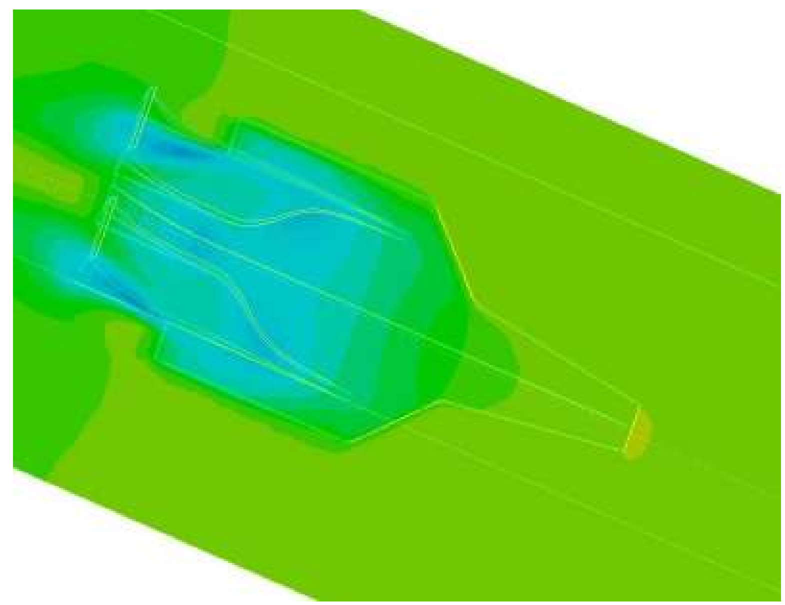
Current Model



Composite Undertray

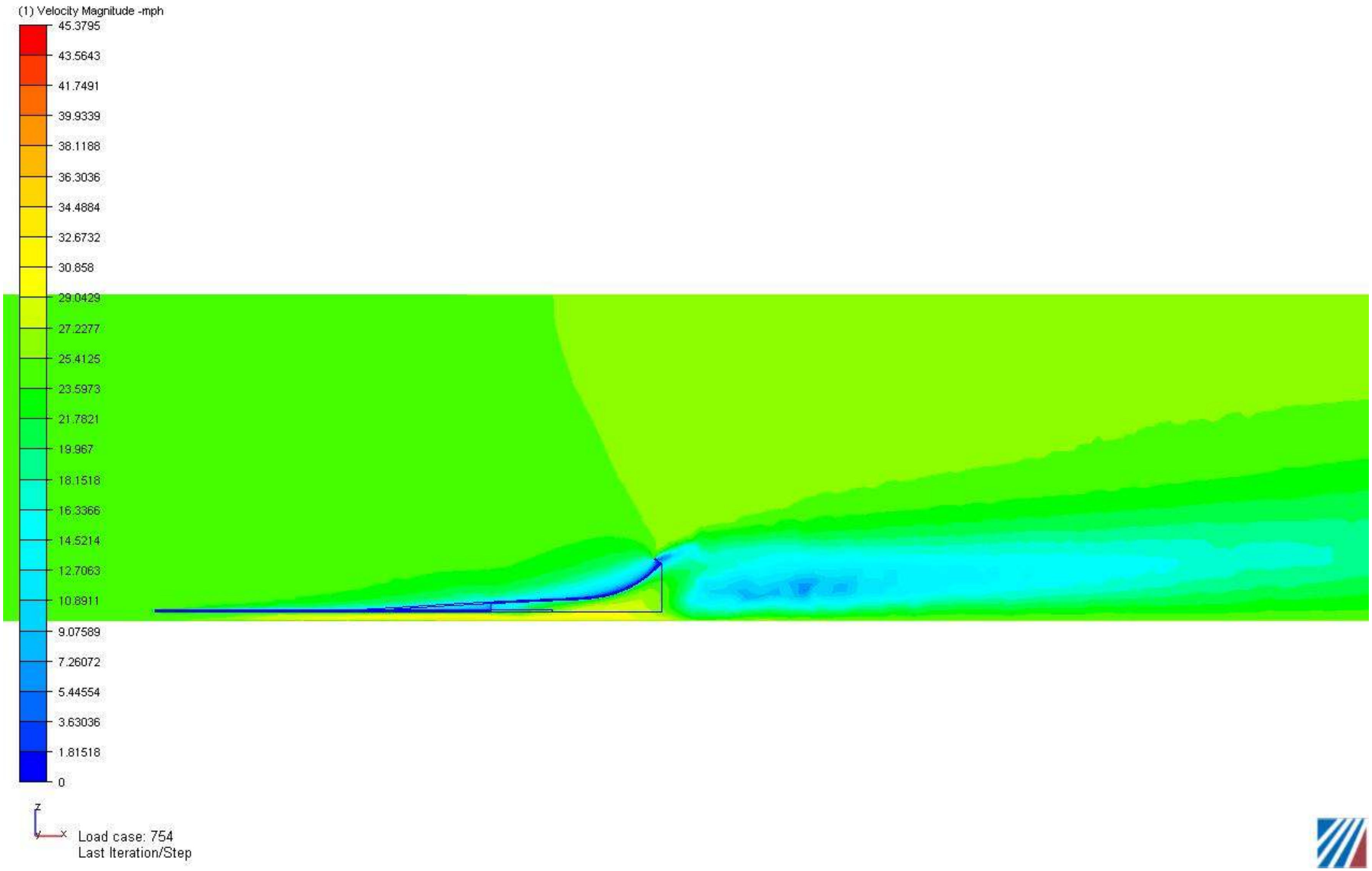
Plots of Pressure Coefficient (50mph)



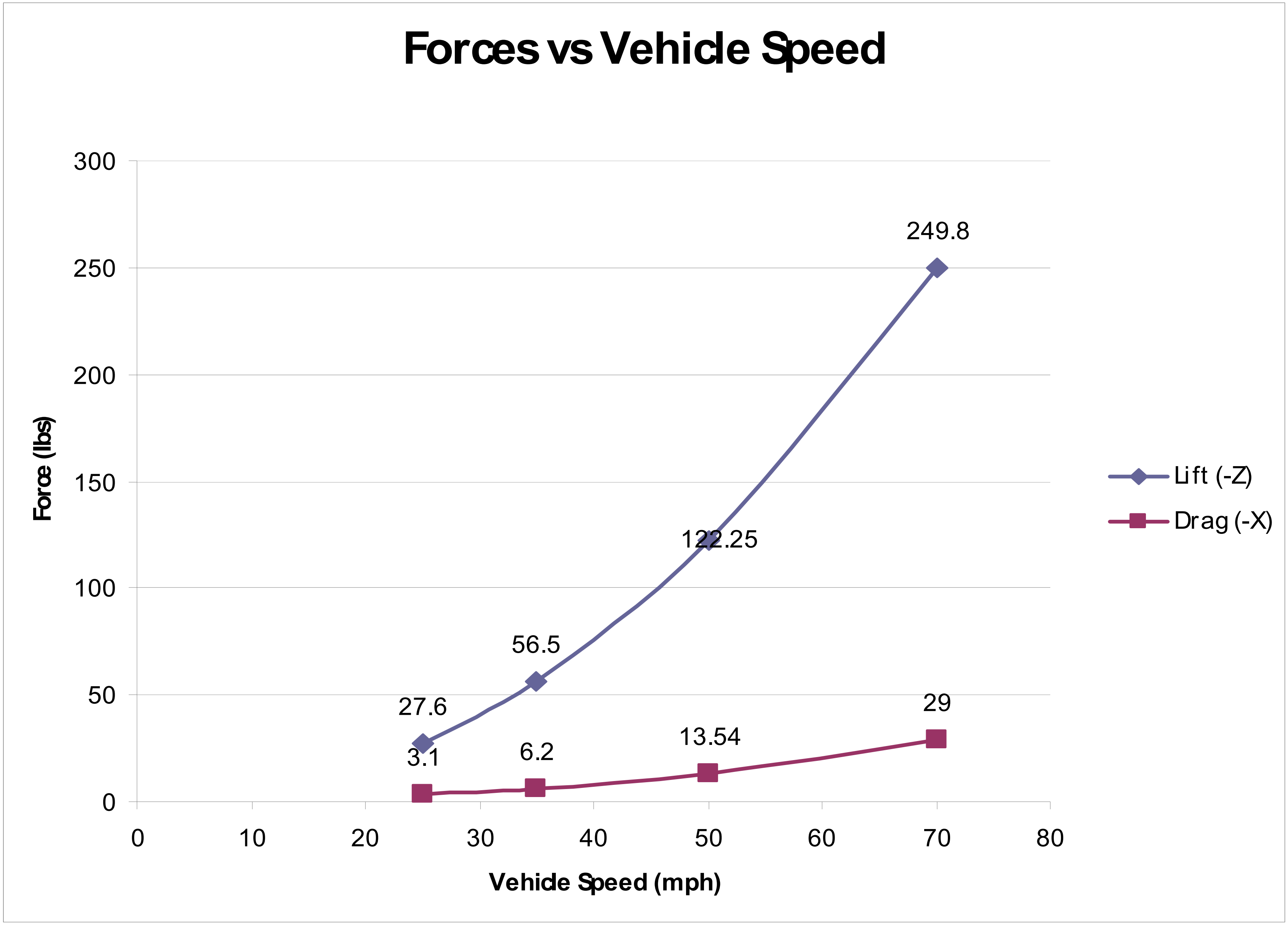


Composite Undertray

Plot of Velocity Gradient (25mph)

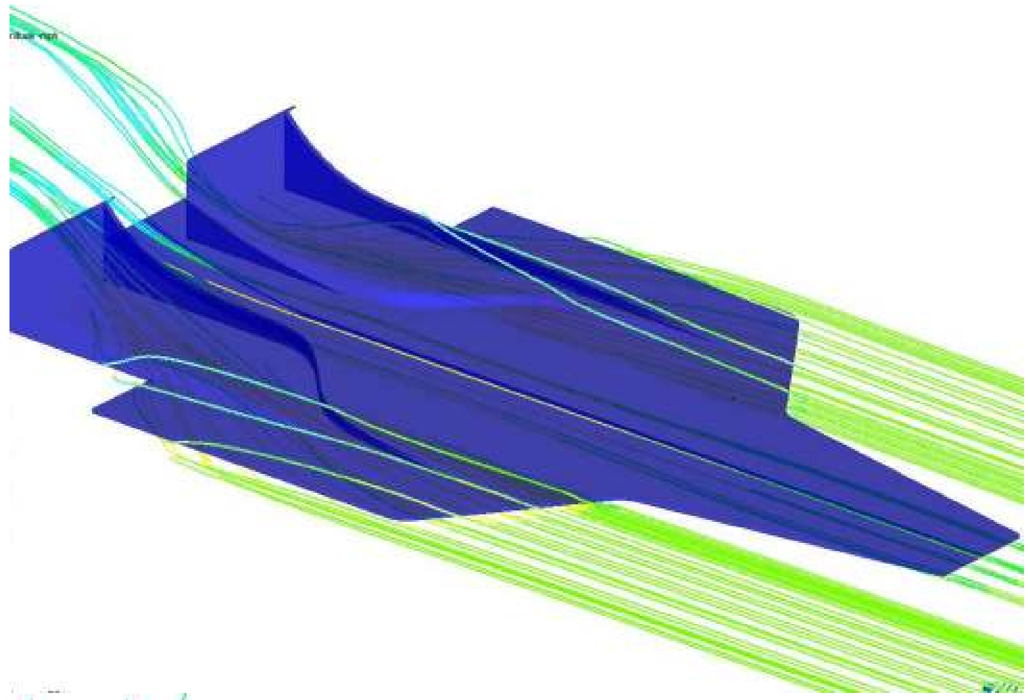


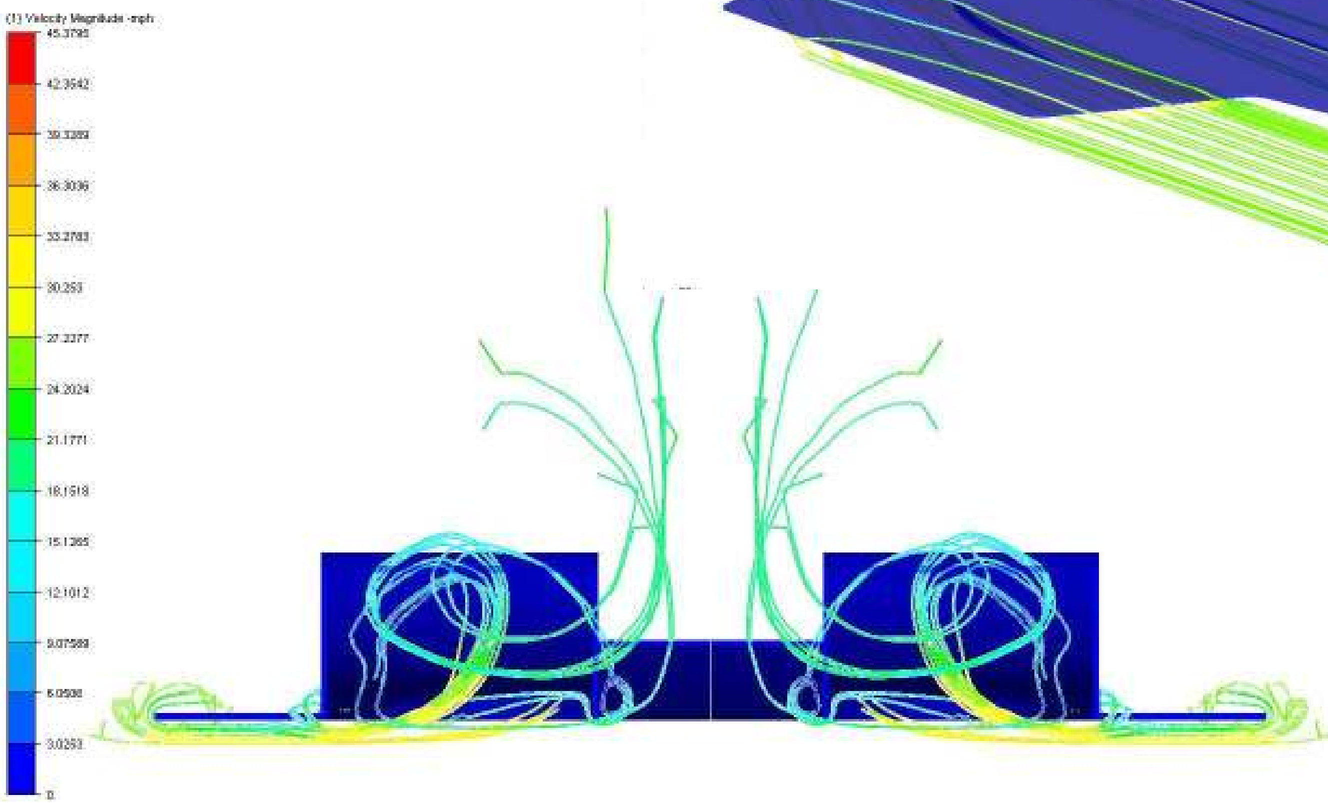
Composite Undertray



Composite Undertray

Flow stream Plots (25mph)





Composite Undertray
Manufacturing

Undertray Manufacturing Process:

- Mold “roughed out” with a hot wire and foam block
- “Rough” mold bonded to wooden base
- Fiberglass overlaid onto foam
- Bond-o applied over fiberglass
- Final prep for mold (painting, wet sanding, fine bond-o work, etc…)
- Wet lay-up performed
- Vacuum bag applied.

Composite Undertray

Overall Cost

Undertray:				
Item	**Quantity**	**Per Unit Cost ($)**	**Dollars per:**	**Total Cost**
Carbon Fiber	12	50	per yd	600
Epoxy	2	100	per gallon	200
Bond-O	2	25	per gallon	50
Assorted tools, supplies, cleaners, safety equipment	1	75	per pack	75
Fiber Glass	15	2	per pound	30
Foam	1	80	per block	80
Plug Hot-Wire Time	4	80	per hour	320
Plug Secondary Operations	60	60	per hour	3600
Part Lay-Up Time	3	60	per hour	180
Part Trimming	3	60	per hour	180
Final Assembly	2	60	per hour	120
			Total Undertray Cost	5435

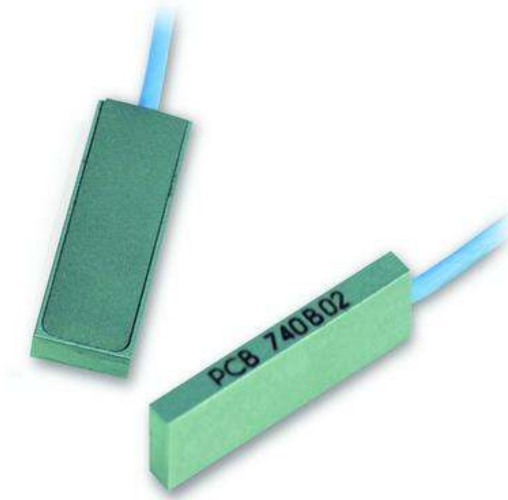
Undertray:				
Item	**Quantity**	**Per Unit Cost ($)**	**Dollars per:**	**Total Cost**
Carbon Fiber	12	0	per yd	0
Epoxy	2	0	per gallon	0
Bond-O	2	25	per gallon	50
Assorted tools, supplies, cleaners, safety equipment	1	75	per pack	75
Fiber Glass	15	0	per pound	0
Foam	1	0	per block	0
Plug Hot-Wire Time	4	0	per hour	0
Plug Secondary Operations	60	0	per hour	0
Part Lay-Up Time	3	0	per hour	0
Part Trimming	3	0	per hour	0
Final Assembly	2	0	per hour	0
			Total Undertray Cost	125

Verification of Components

- Had meeting with PCB Piezotronics
  - January 9th, 2009
- Looking for sensors to validate designs
  - Decided upon strain gages and load cells
- Sent in “wish list” for desired sensors
  - Waiting on pricing quote

Verification of Components

- Strain gage
  - Model 740B02 – Dynamic ICP Strain Sensor
    - 50 mV/με sensitivity
    - 0.5Hz to 100kHz frequency range
    - 0.02 oz in weight
    - 0.6 nε resolution
    - Integral 10ft cable with 10-32 coaxial plug
    - Reusable
    - Used for strain measurement at various locations on the chassis
    - Four units requested



Verification of Components

- Load Cells
  - Model 222B
    - Used for pullrod force measurement
    - 2500 lb tension range
    - 2.00 oz in weight
    - 0.9 mV/lb
    - Two units requested
  - Model 221B05
    - Used for pushrod force measurement
    - 5000lb compression range
    - 1.1 oz in weight
    - 1 mV/lb
    - Two units requested

Verification of Components

- Undertray verification uses load cells
  - A load cell in each pushrod and pullrod will allow for direct measurements of downforce and pressure center.
- Chassis verification uses strain gages
  - Strain gages distributed about the chassis will allow for FEA Model verification
  - Coupling with loads gathered with load cells and accelerometers will allow for FEA analysis using empirically measured loads and compare measured strain to theoretical strain.

Sources

- Gurit's Guide to Composites: www.gurit.com
- Introduction to Composite Materials Design by Ever J. Barbero
- Race Car Aerodynamics by Joseph Katz