2016 Impact Attenuator Data Report

This form must be completed and submitted by **all teams no later than the date specified in the Action Deadlines on Formula Hybrid website**. The Formula Hybrid Technical Committee will review all submissions which deviate from the Formula Hybrid® rules and reply with a decision about the requested deviation. All requests will have a confirmation of receipt sent to the team. Impact Attenuator Data (IAD) and supporting calculations must be submitted electronically in Adobe Acrobat Format (*.pdf). The submissions must be named as follows: schoolname_IAD.pdf using the complete school name. **Submit the IAD report as instructed on the event website.**

*In the event that the Formula Hybrid Technical Committee requests additional information or calculations, teams have **one week from the date of the request** to submit the requested information or ask for a deadline extension.

University Name: ____Yale Univeristy_____ Car Number: ________________213__________

Team Contact: ___Taha Ramazanoglu______ E-mail Address: _____taha.ramazanoglu@yale.edu______

Faculty Advisor: _______Joseph Zinter_____ E-mail Address:_____joseph.zinter@yale.edu__________

Material(s) Used	Aluminum	
Description of form/shape	Honeycomb 5052 5.7pcf 3/16” 4”x8”x10.7”	
IA to Anti-Intrusion Plate mounting method	WEST SYSTEM® Six10® Thickened Epoxy Adhesive	
Anti-Intrusion Plate to Front Bulkhead mounting method	4, 5/16 Grade 8 Bolts	
Peak deceleration (<= 40 g's)	18.8 g’s	
Average deceleration (<= 20 g's)	16.3g’s	
Vehicle Mass	Amount = 700 lbs	Please Circle: Measured or **Estimate**

Confirm that the attenuator contains the minimum volume 200mm wide x 100mm high x 200mm long [X]

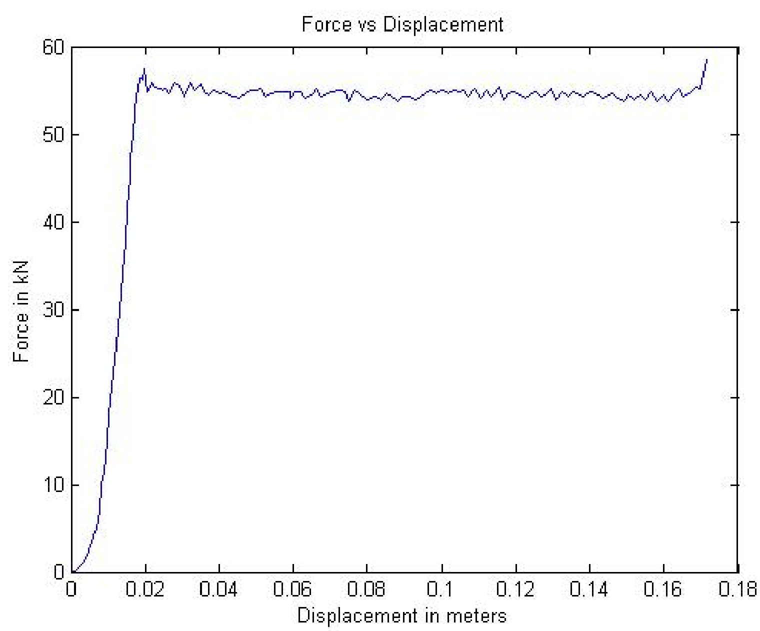

Figure 1: Force-Displacement Curve (dynamic tests must show displacement during collision and after the point v=0 and until force becomes = 0)

ATTACH PROOF OF EQUIVALENCY

TECHNICAL COMMITTEE DECISION/COMMENTS

Approved by______________Joseph Zinter__________________________________ Date______2/5/16_______

NOTE: THIS FORM AND THE APPROVED COPY OF THE SUBMISSION MUST BE PRESENTED AT TECHNICAL INSPECTION

University Name: _______Yale University______ Car Number(s) & Event(s): __#213, Formula Hybrid 2016

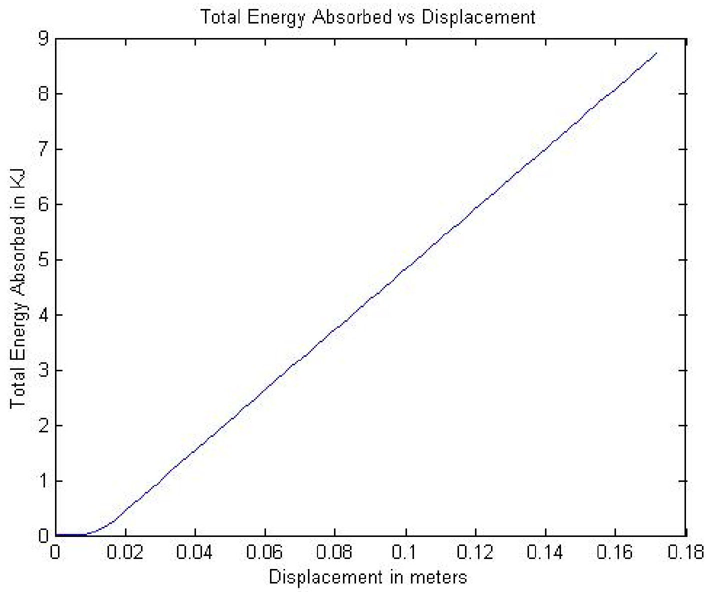

Figure 2: Energy-Displacement Curve (dynamic tests must show displacement during collision and after v=0)


Figure 3: Attenuator as Constructed

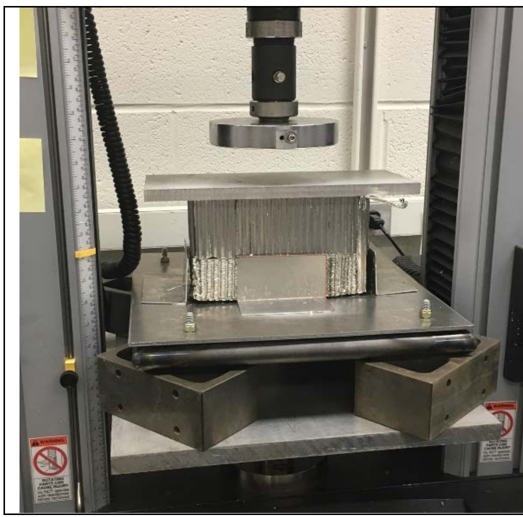
Figure 4: Attenuator after Impact

*See appended photos for Anti-intrusion plate deformation measurement

Energy Absorbed (J):	8,720	Vehicle includes front wing in front of front bulkhead?	Yes/**No**
IA Max. Crushed Displacement (mm):	171.5	Wing structure included in test?	N/A
IA Post Crush Displacement - demonstrating any return (mm):	-18.0	Test Type: (e.g. barrier test, drop test, quasi-static crush)	Quasi-static crush
Anti-Intrusion Plate Deformation (mm)	9	Test Site: (must be from approved test site list on website for dynamic tests)	Yale University, Schroers's Lab Instron 5569

2016 Impact Attenuator Data Report

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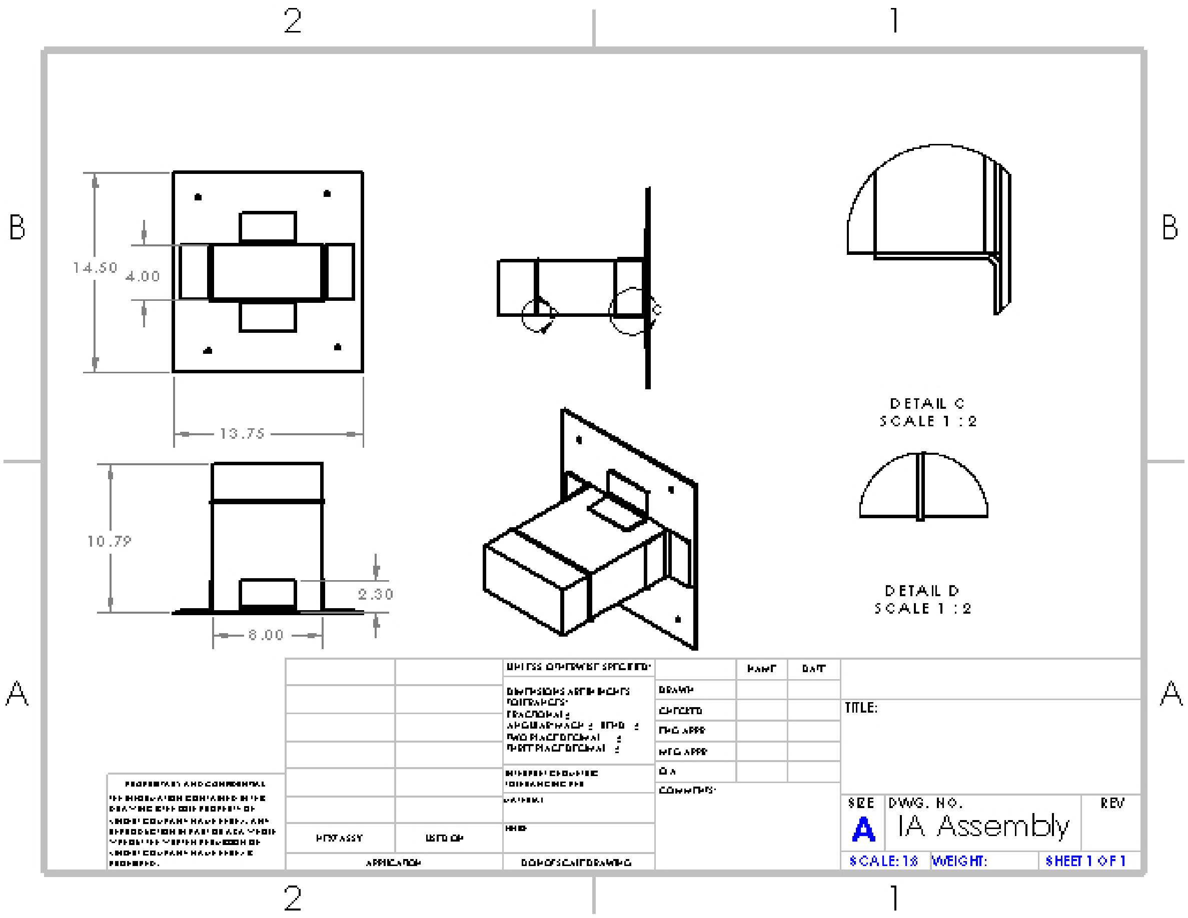


See attached drawings for improved size and quality.

Length (fore/aft direction): __274.1_ mm (>=200mm)
Width (lateral direction): _203.2__ mm (>=200mm)
Height (vertical direction): __101.6_ mm (>=100mm)
Attenuator is at least 200mm wide by 100mm high for at least 200mm: **Yes**/No
Attach additional information below this point and/or on additional sheets

Test schematic, photos of test, design report including reasons for selection and advantages/disadvantages, etc. Additional information shall be kept concise and relevant.

Test Data Calculations:

The Rules require that our impact attenuator, "when mounted on the front of their vehicle and run into a solid, non-yielding impact barrier with a velocity of impact of 7.0 meters/second, would give an average deceleration of the vehicle not to exceed 20 g, with a peak deceleration less than or equal to 40 g's."

Weight:

We estimate our vehicle will have a mass of mass of about 683 lbs. According to rule T3.21.3, we round this weight up to 700 lbs, or 317.5 kg.

Peak deceleration:
Our compression testing yielded a maximum force of 58.5 kN. Generally, acceleration may be calculated as:

$$1.\ a = F/m$$

For a Force "F" and Mass "m"
For our mass of 317.5 kg, this yields a maximum acceleration:

$$a_{max} = \frac{F_{max}}{m} = \frac{58{,}500N}{317.5\,kg} = 184.3\,\frac{m}{s^2} = 18.8\,g's$$

Clearly, $a_{max} < 40$ g's.

Average deceleration:
We used Matlab to calculate a displacement-averaged-force of 50.7 kN over our testing curve. For each displacement unit, we multiplied the differential displacement by the average force over that distance. Finally, we summed each of these products and divided by total displacement to generate a total average force.

For our mass of 317.5 kg, this yields an average acceleration:

$$a_{average} = \frac{F_{average}}{m} = \frac{50{,}700\,N}{317.5\,kg} = 159.7.3\,\frac{m}{s^2} = 16.3\,g's$$

Again, $a_{average} < 20$ g's.

Total Absorbed Energy:

The Rules require that our impact attenuator decelerate our vehicle from 7 m/s.

At 317.5 kg, our vehicle has Kinetic Energy given by:

$$2.\, KE = \frac{1}{2}mv^2 = \frac{1}{2}(317.5\ kg)\left(7\frac{m}{s}\right)^2 = 7{,}779\ Joules.$$

Work done on a system at is given by:

$$3.\ W = F * D$$

for a force "F", over a distance "D".

Thus, for a Force vs. Displacement curve, the work done on the attenuator is equivalent to the area under the curve. By conservation of energy, this total work is equivalent to total absorbed KE. We used Matlab to approximate this area as a sum of trapezoidal areas. For our total test displacement of 0.17 meters, we calculated:

Total Energy absorbed = 8,720 Joules

And 8,720J > 7779J.

Design Calculations:

The pre-crushed honeycomb that we purchased nominally compresses at 375 psi +/- 10% (2,586,000 +/- 258,600 Pa) and has a cross sectional area of 8x4 inches (see attached data sheets). We designed for both pressure extremes.

For our design, we used the additional equations to calculate Force "F":

$$4.\ F = P * A$$

for an average Pressure "P" and Cross-sectional Area "A," and:

$$5.\ D = \frac{v_f^2 - v_i^2}{(2 * a)}$$

to calculate Displacement "D" during a constant acceleration "a."

University Name: _______Yale University______ Car Number(s) & Event(s): __#213, Formula Hybrid 2016

Our quasi-static compression test found that after an initial elastic deformation, the honeycomb crushed at an average pressure:

$$P_{crush} = \frac{F_{average}}{A} = \frac{55\ kN}{(0.203m * 0.102m)} = 2{,}556{,}000\ Pa$$

This falls at the middle of the predicted range of pressures, but for safety our impact attenuator needed to perform at both the top and bottom of that pressure range.

Case 1: Honeycomb crushes at 2.844 MPa

In this case, higher pressure leads to greater force on the car by equation 4, and shorter displacement during deceleration by equation 5. Therefore, the limiting parameter for a high pressure crush is the 20 g's maximum average acceleration mandated by rule T3.21.

For this pressure and our cross-sectional area, equation 4 gives:

$$F_{high} = 2{,}844{,}000\ Pa * 0.021\ m^2 = 59.7\ kN$$

By equation 1, this corresponds to a deceleration of about 19.1 g's, which is less than 20 g's.

Case 2: Honeycomb crushes at 2.327 MPa

In this case, lower pressure leads to lower force on the car by equation 4, and a larger displacement during deceleration by equation 5. Here, the limiting parameter for a low pressure crush is the total ability to absorb KE.

By equation 3, KE absorption is directly proportional to displacement, which means that we need a sufficiently long attenuator for our cross-sectional area. For this pressure, equation 4 tells us that:

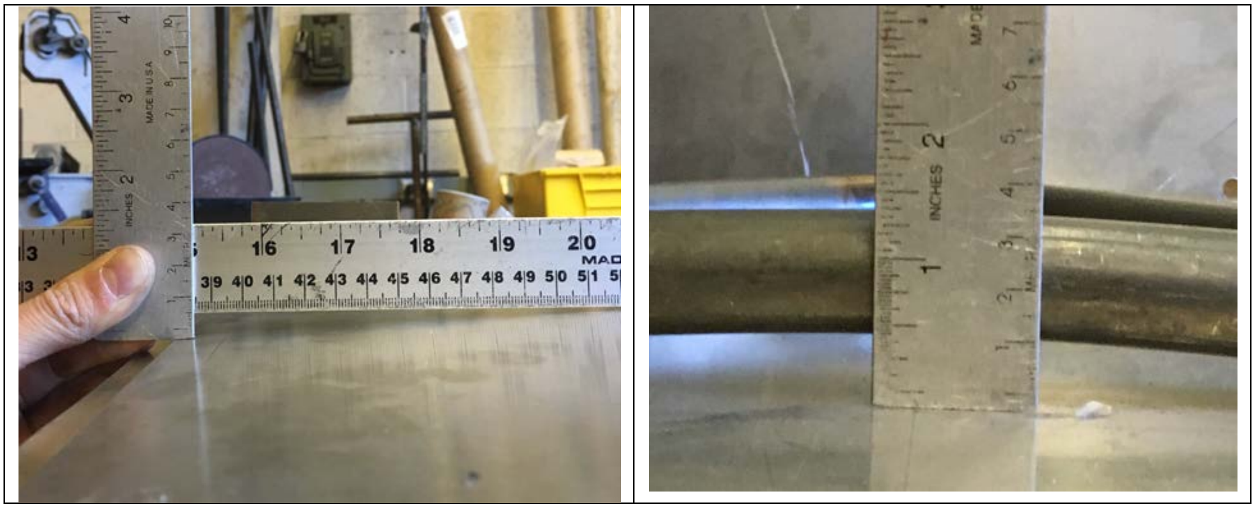
$$F = 2{,}327{,}000\ Pa * 0.021\ m^2 = 48.9\ kN$$

By equation 1, this gives us an deceleration of about 153.9 m/s^2. For this minimum deceleration, equation 5 predicts a maximum displacement of about 0.17 meters. After accounting for the roughly 75% stroke efficiency of the honeycomb (see attached data sheet) and 1 cm pre-crushed region, we concluded that we our impact attenuator must be at least 0.236 meters, or 9.3 inches long. Design considerations discussed below led us to build an impact attenuator that was longer, at about 10.7 inches.

Conclusions:

Our quasi-static compression test showed that our IA design met all regulations in rule T3.21. Additionally, our impact attenuator design meets these regulations over the entire range of crush-pressures supplied by the honeycomb manufacturer.

Additional Post-Test Photos



Figures 4a and 4b: (left) Deflection of Anti-intrusion plate, (right) Deflection of Bulkhead Diagonal Member

Design Selection:

We decided to use the same Aluminum honeycomb from our 2014 vehicle, as that attenuator performed well. Again, we opted for the industry standard pre-crushed 8*8*4 in aluminum 5052 5.7pcf 3/16” honeycomb because of its abundance and low-cost compared to a custom-built honeycomb.

To dissipate the kinetic energy of our 317.5 kg car in the event of a crash at 7 m/s, we needed at least 9.3 in in the fore/aft direction. After adding a 15% safety margin we decided to stack another 2.6 in honeycomb with identical properties on top of the 8*8*4 block, thereby giving rise to our new impact attenuator with dimensions 10.6*8*4. This safety margin allows our car to strike a wall at 20 degrees and still absorb all of the vehicle’s Kinetic Energy.

We bonded these pieces with WEST SYSTEM® Six10® Thickened Epoxy Adhesive. To increase surface area and improve resistance to shearing forces, we placed a 0.06 inch thick aluminum plate between the honeycomb pieces. Detailed information regarding the equivalency of the epoxy to the (4) 5/16 Grade 5 bolts stated in the rules T3.20.3 can be found in our SES rev1.

To attach the honeycomb system and the aluminum L brackets that help support the honeycomb on the anti-intrusion plate we again used WEST SYSTEM® Six10® Thickened Epoxy Adhesive. The aluminum L brackets provide an additional level of protection against shearing forces and enhances stability in the event of a linear impact.

We used 4 mm-thick aluminum for our anti-intrusion plate to facilitate bonding with the honeycomb and the L brackets, since they are aluminum as well.

In summary, the impact attenuator we designed for our 2016 car was optimized in terms of cost, weight and use of materials. We emphasized safety as a key point and thus over-engineered both our honeycomb system and our anti-intrusion plate to outperform the criteria of Formula Hybrid, as we believe that a few pounds and a few dollars are well spent to protect a human life.

PLASCORE®

CERTIFICATE OF CONFORMANCE

Date: February 28, 2011

PURCHASE ORDER INFORMATION

Work Order Number:	276806
Size:	8.000" x 8.000" x 4.000"
Plascore Part Number:	IMPACT_ATTENUATOR

CORE INFORMATION

Core Type:	PAMG-XR1-5.7-3/16-P-5052
Foil Type:	0.0020"
Measured Cell Size:	0.1875 inches
Measured Density:	5.7 pcf

Block Number: 005B0307

SAMPLE ONLY

(ACTUAL TEST RESULTS MAY VARY)

This is to certify that the aluminum honeycomb core supplied, meets the crush requirements of 375 psi +/- 10% per ASTM D 7336.

Quality Assurance Representative

QA Plascore Accept 023

PLASCORE, INC. • 615 N. FAIRVIEW ST. • ZEELAND, MI 49464-0170 • PHONE: (616) 772-1220 • FAX: (616) 772-1289
WEBSITE: www.plascore.com • EMAIL: info@plascore.com

PLASCORE®
615 N Fairview, Zeeland MI, 49464

AM

ASTM D7336

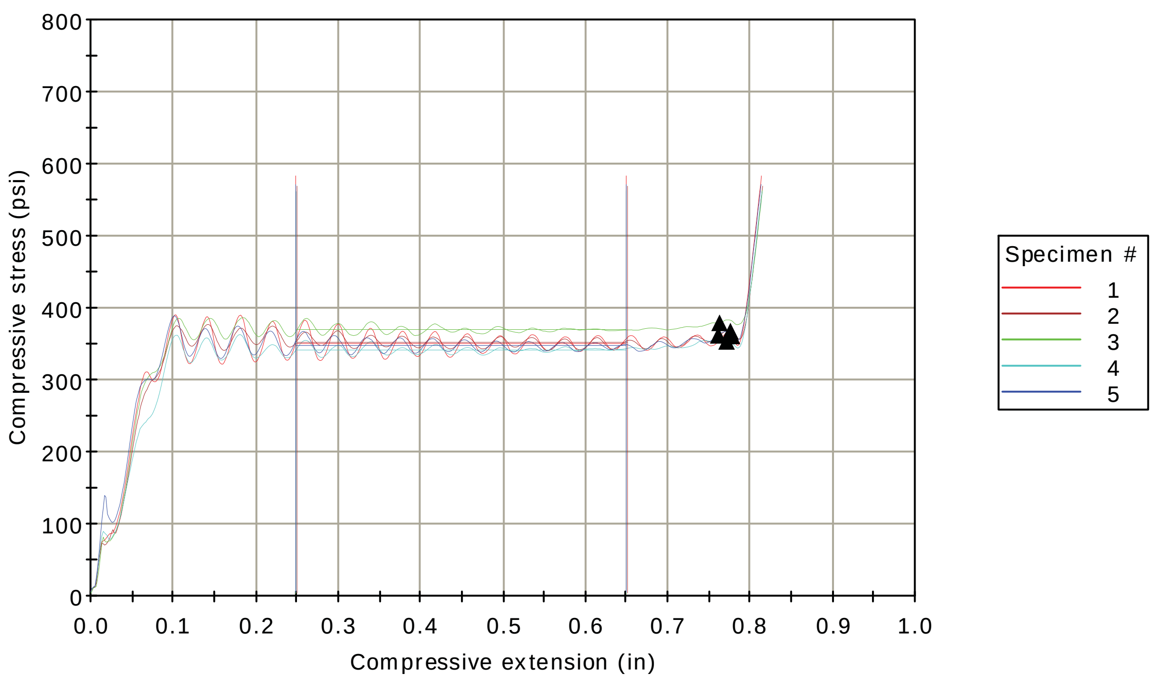
Sample file name: QC005B0307_CR

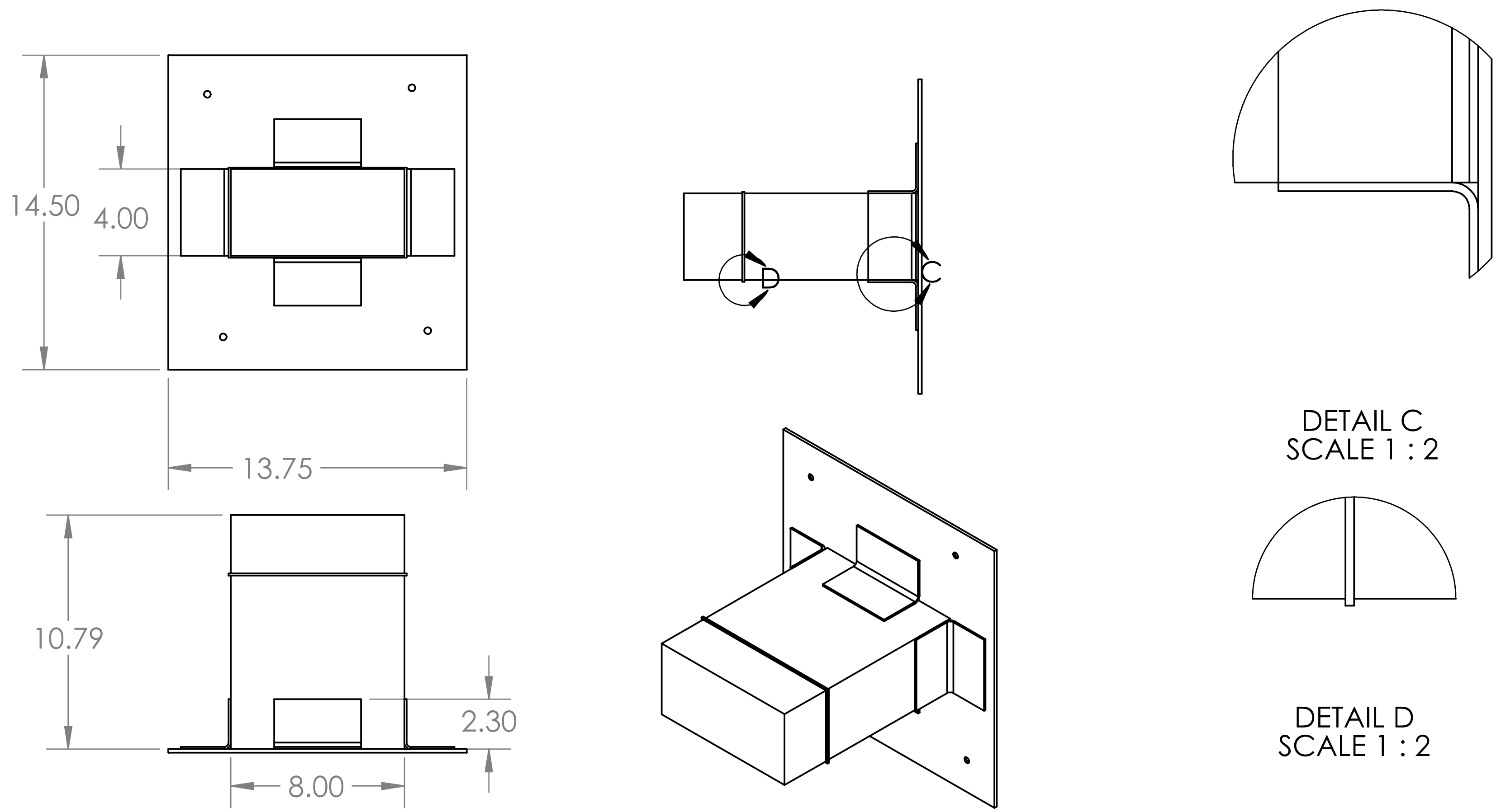
Honeycomb Type	Aluminum
Part Number	A57316P5052
Block Number	005B0307
Slice Location	27.750
Plascore Visual	Yes
Instron	1
Operator	JT
Room Temp (F)	70.0
Humidity (%)	50.0
Rate 1	1.00 in/min

	Measured Cell (in)	Average Crush Strength (psi)	Stroke (%)	Test Result
1	0.203	351.0	77.7	Pass
2	0.196	352.8	77.5	Pass
3	0.190	370.5	76.2	Pass
4	0.210	342.3	77.0	Pass
5	0.200	348.3	76.0	Pass

Sample note 1
0.190"-0.210"

Stress vs Displacement Curve (English)





DETAIL C
SCALE 1 : 2

DETAIL D
SCALE 1 : 2

PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

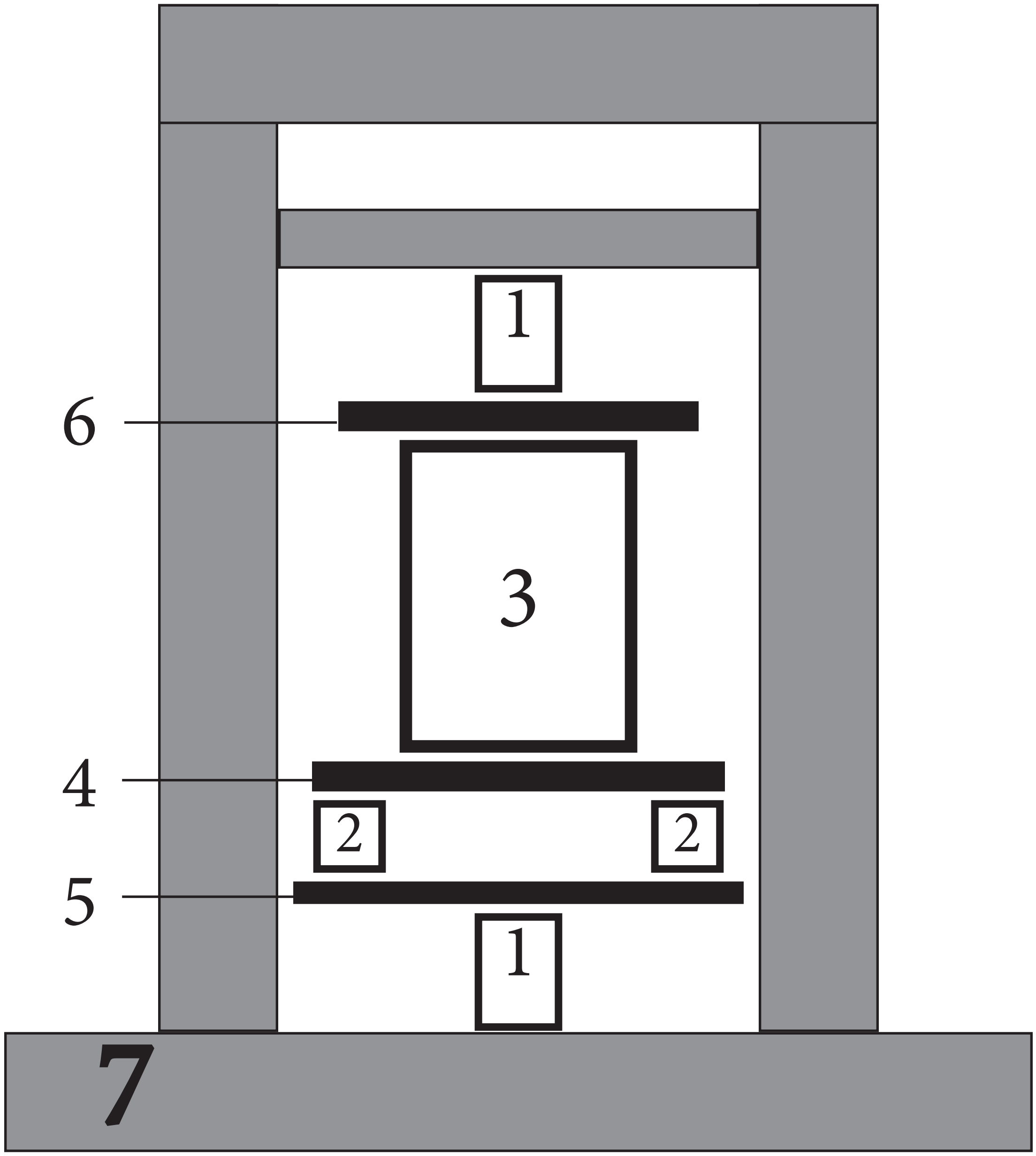
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE	DWG. NO.	REV
A	IA Assembly	

SCALE: 1:8 WEIGHT: SHEET 1 OF 1



1: Platens
2: Spacers with h>2” to raise the IA system
3: IA Aluminum Honeycomb
4: Mock-up of Front Bulkhead
5: 0.75” thick T6 6061 aluminum support plate
6: Precision ground 1” thick aluminum plate to homogenize the force
7: Instron 5569 Dual Column Tabletop Universal Testing System

*Parts 3, 4, 5, 6 drawn to 1:6 scale

Matlab Scripts: Test Data Processing

```
name = 'ImpactAttenuatorTestData.xlsx';
Data=xlsread(name);

%Displacement in meters, force in kN
Disp = Data(:,1)*.001;
Force = Data(:,2);

%totalE in kJ
TotalE=zeros(length(Force),1);
for i = 2:length(Force)
    TotalE(i)= TotalE(i-1) + ((Disp(i)-Disp(i-1))*((Force(i)+Force(i-
1))/2));
end

%distance averaged force
sumForce=0;
for i=1:length(Force)-1
    sumForce=sumForce+(Force(i)*(Disp(i+1)-Disp(i)));
end

%Fav in kN
Fav=sumForce/Disp(i+1);

figure
plot(Disp,Force);
title('Force vs Displacement')
xlabel('Displacement in meters')
ylabel('Force in kN')
figure
plot(Disp,TotalE);
title('Total Energy Absorbed vs Displacement')
xlabel('Displacement in meters')
ylabel('Total Energy Absorbed in KJ')
```