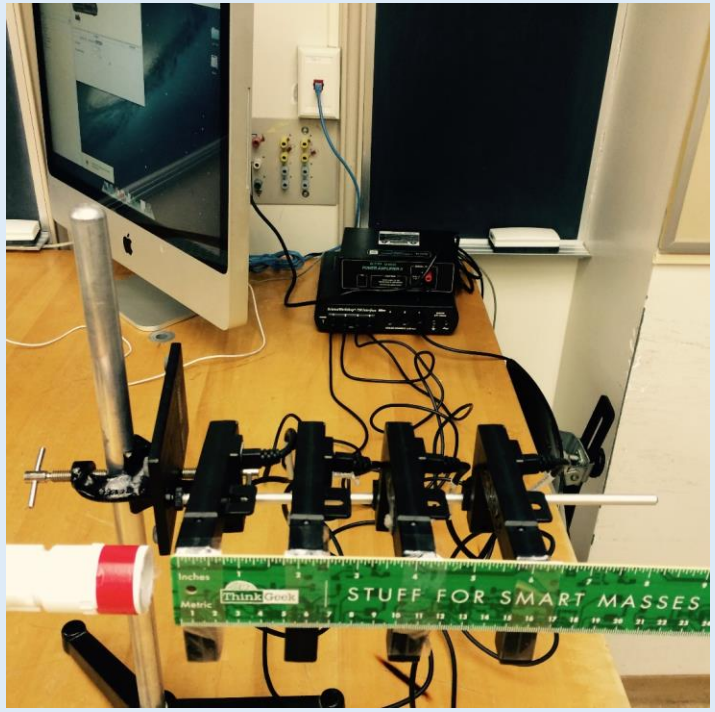
Oh my hail



John Metcalf

Wasatch Aerospace & Systems Engineering Conference

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Oh my hail – Test method

Environmental condition requirement from specification

3.2.5.7	Hail	The non-operating and operating hail environment consists of frozen water pellets from 0.2 inches to 1.0 inch diameter, with density of 0.032 lb/in3 maximum and falling at a speed of 164 ft/s maximum. The instantaneous rate of hail is 4 inches per hour maximum where exposed.

- MIL-STD-810 Test Method Standard, Environmental Engineering Considerations and Laboratory Tests

Hailstones	Size	Location	Date
Canada – Heaviest	290 g (10.23)	Cedoux, Saskatchewan	27 August 1973
US – Largest Circumference	47.6 cm (18.75 in)	Aurora, Nebraska	22 June 2003
World – Heaviest	1.02 kg (2.25 lb)	Gopalganj District, Bangladesh	14 April 1986

- Recognized environment
- But no test method!

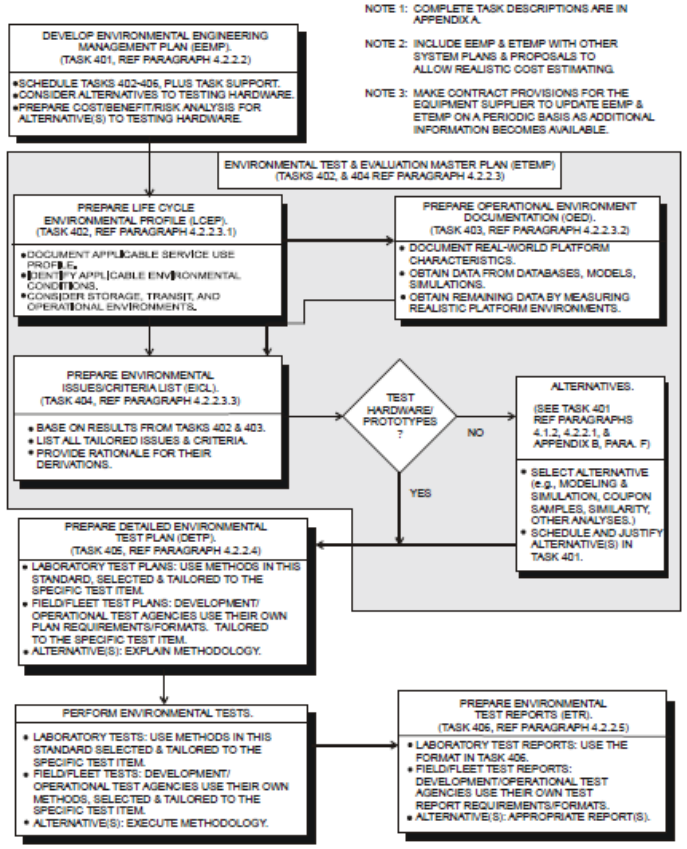

Figure 1-1. Environmental engineering program guide.

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Oh my hail - Background

- All of the kinetic energy of the hail in the requirement is being transferred into the surfaces of the Unit Under Test (UUT)
- Most objects will deform 10% thickness before reaching permanent deformation
- Any object can be used for the requirements test, as long as size, density, and Young's modulus are provided
  - This is the ability of an object to undergo compressive or tensile forces before reaching permanent deformation
  - The ratio of the Young's modulus of hail to the Young's modulus of the test projectile will provide a ratio of transferred kinetic energy on impact with a PT surface

Hailstone Characteristics

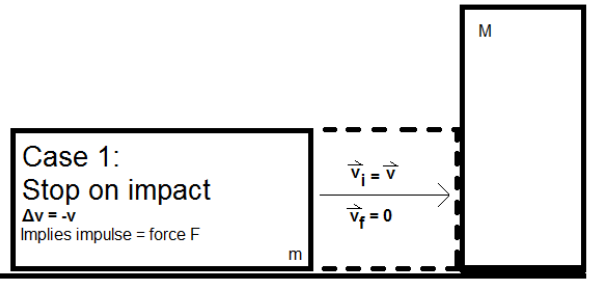
- Diameter: 0.2" – 1.0" = 0.508 cm – 2.54 cm
- Radius: 0.254 cm – 1.27 cm
- Projected Area: 0.203 cm^2 – 5.07 cm^2
- Volume: 0.0686 cm^3 – 8.58 cm^3
- Density: 0.032 lbs./in^3 = 0.886 g/cm^3
- Velocity: 164 ft./s = 50 m/s
- Mass: 0.061 g – 7.598 g
- Young's Modulus: 9 GPa

Impluse:

F = -m*(Δv/Δt)

The stated assumption is that Δv is -v for a collision which stops on impact, and Δv = -2v fro a collision which rebounds. Frictionless environment, immovable wall. The entire setup is identical except for the collision type. The question of the unstated assumption(s) in the intro physics text book:

Is Δt the same for both equations?
Or, Does Case 2 take 2Δ t to complete?
Which collision is more damaging to the wall?

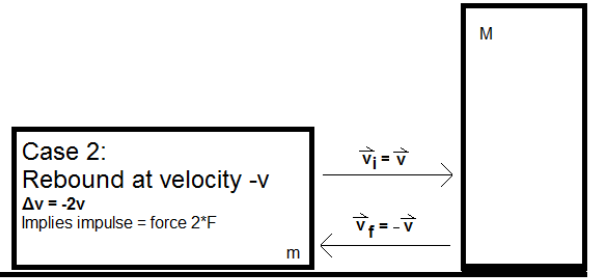


My intuition:

Δt can be treated the same for both cases.

The inelastic collision, stopping on impact, is more damaging, as all of the kinetic energy is being transferred into the surface of the wall.

I don't have any strong justification of this, nor is it explicitely stated in my intro textbook.



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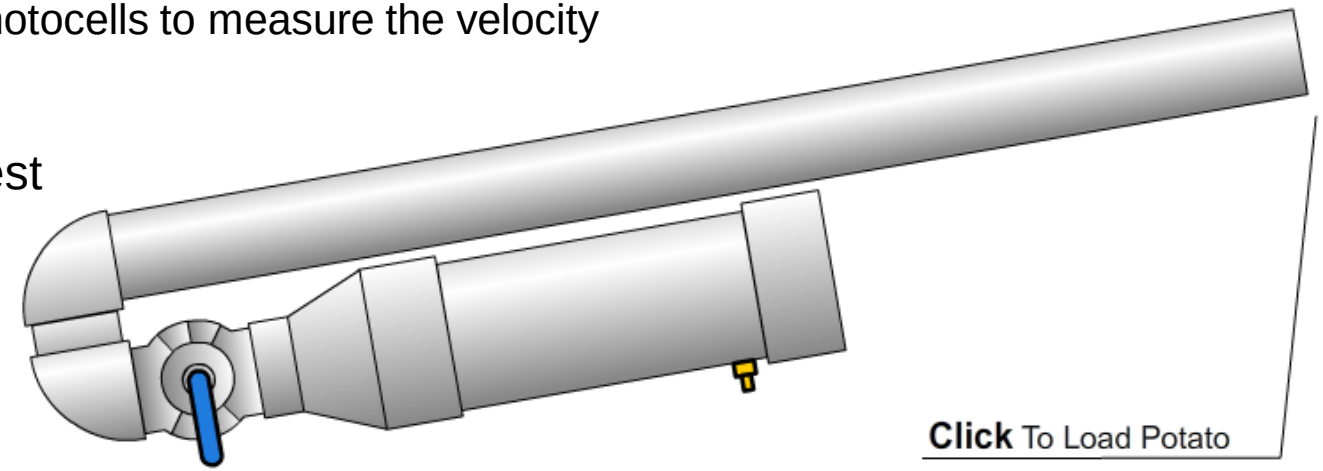
Oh my hail – WSMR hail approach

- White Sands Missile Range (WSMR) ‘Pneumatic Spud Gun’
- Generic air tank
- Air compressor
- 3 inch pipe for barrel
  - Must build a different barrel for each size
- Projectile - 2.75” diameter Williams Sonoma ice
  - Weigh to give density
  - *I don't believe we could call them "calibrated”*
  - Build something using photocells to measure the velocity
- One shot at a time
- 2 days setup and 2 days test
- Cost ~$17k



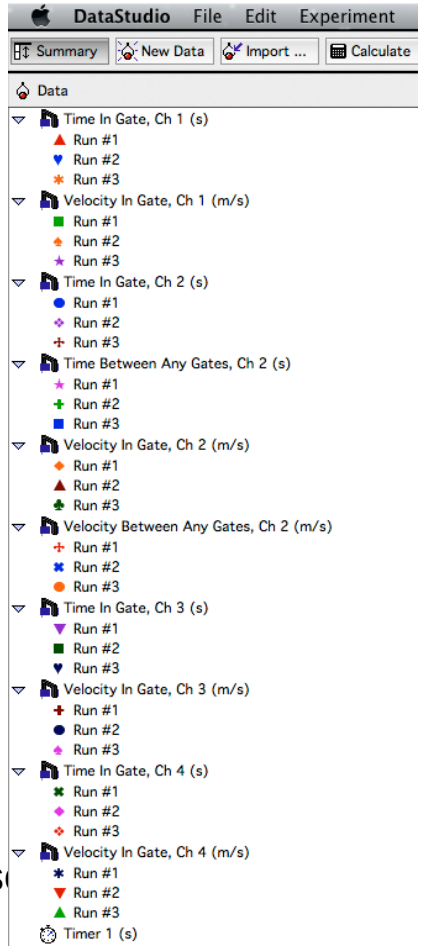
Oh my hail – My hail approach

- Projectile - Ice
  - 1” diameter 24 ct spherical ice cube tray - $11
  - Or regular paintballs (.68”)
- Launcher
  - Paintball marker w/CO2 ~$150
    - Up to 300 fps (typical)
  - Barrel - $15
    - of 1” (1.029” ID) PVC pip
    - 3/4” to 1” reducer (to fit to existing barrel)
    - Single shot at a time
- Velocity
  - Chronometer/Chronograph ~ $100
  - 1” diameter ice balls @ 162 fps
  - .68” diameter paintballs @ 275 fps
- Few weeks to validate approach
  - One University Science Lab with conservation of energy/momentum lab equipment (photogates and s
- Cost <$300 in materials

Tippmann Stormer Basic .68 Caliber Paintball Marker Black 14911

★★★★★ 26

$139.95



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Oh my hail – Trade study result

- Recommend performing ‘in-house’ (let John do it)
- Pros
  - Significant cost savings
  - More representative of environment
  - Highly repeatable
  - Frees 4 days of environmental facility test schedule
  - More engineer eyes available to evaluate performance
- Cons
  - Untested setup
    - Spend 1 day on test setup to validate procedure

Oh my hail – My hail

- Spheres closer to 1.1”
- ID of barrel is 1”
- Polish/melt
- Vaseline/udder butter/bag balm as a gap fill

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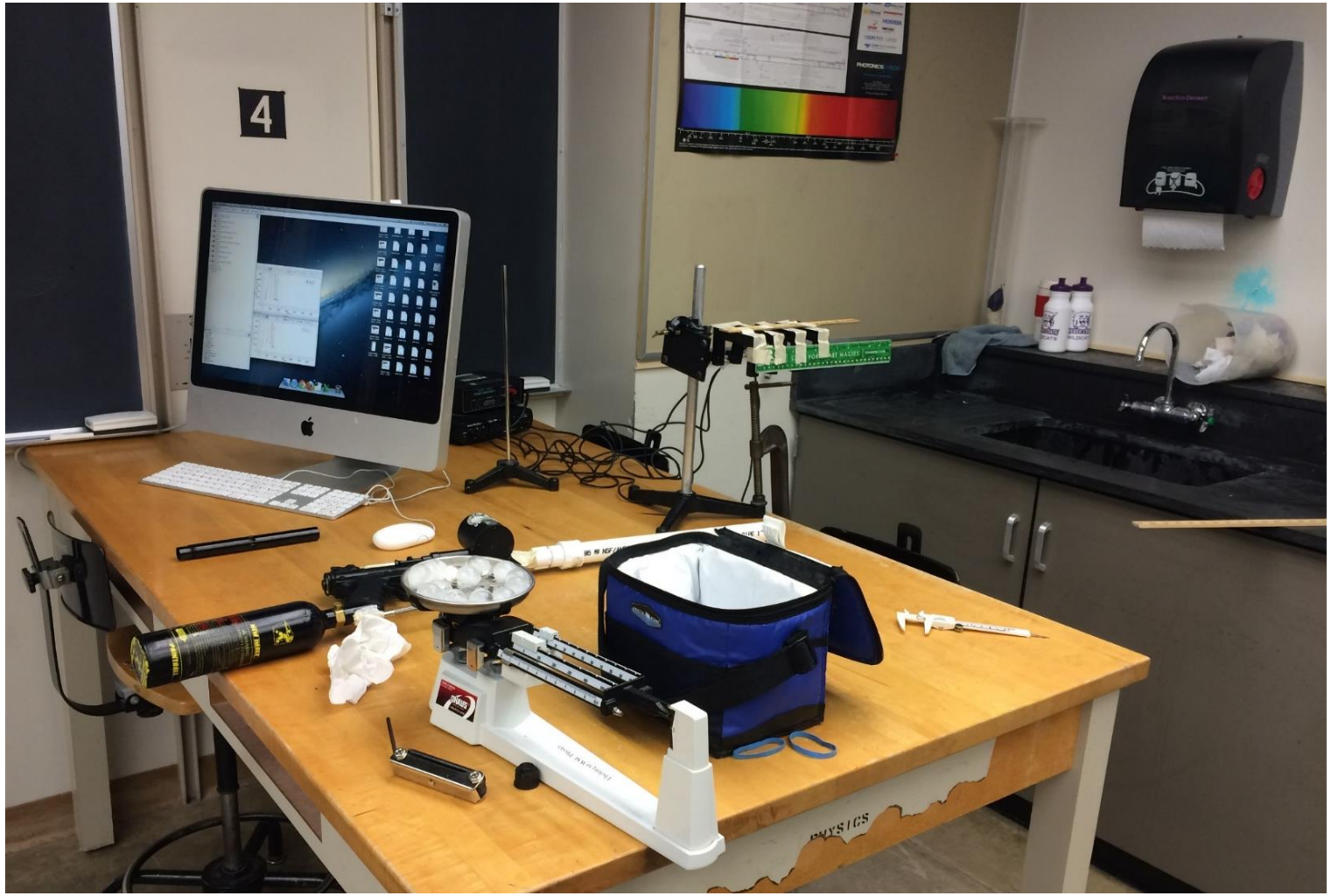
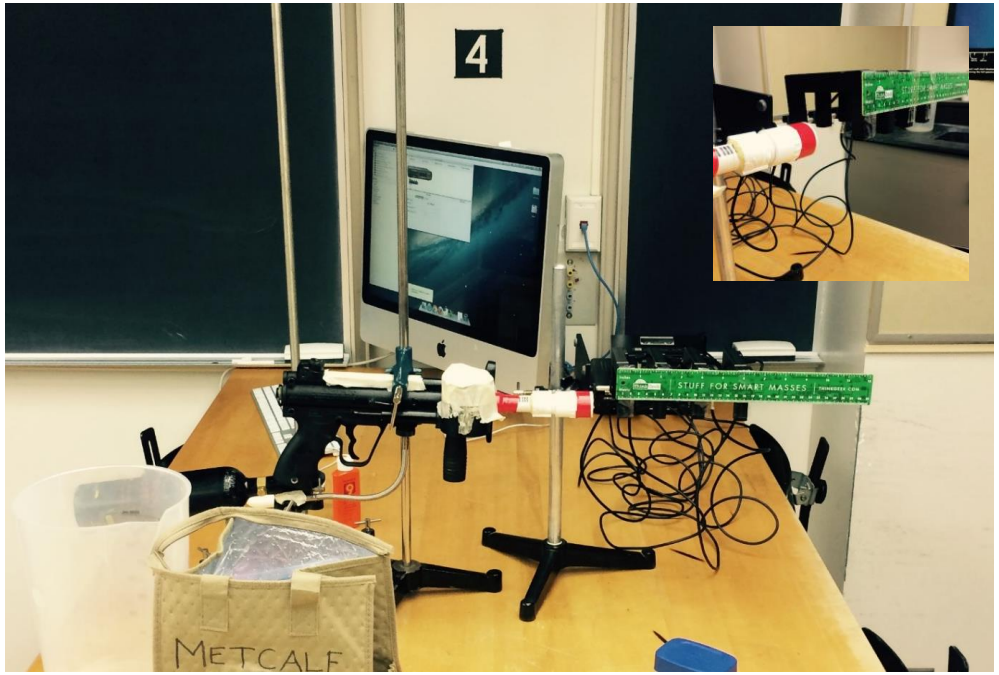
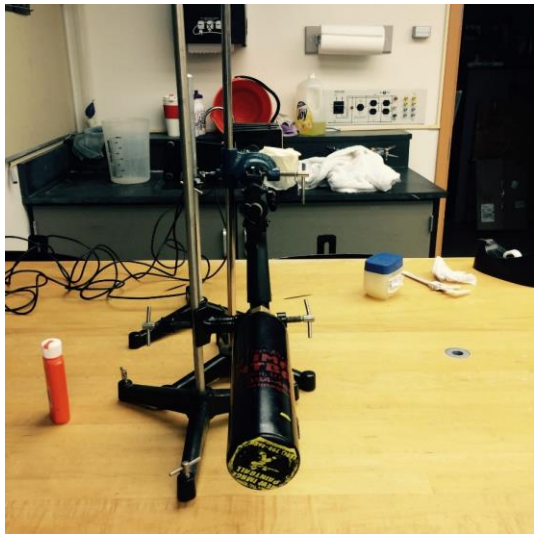
Oh my hail – Validate approach







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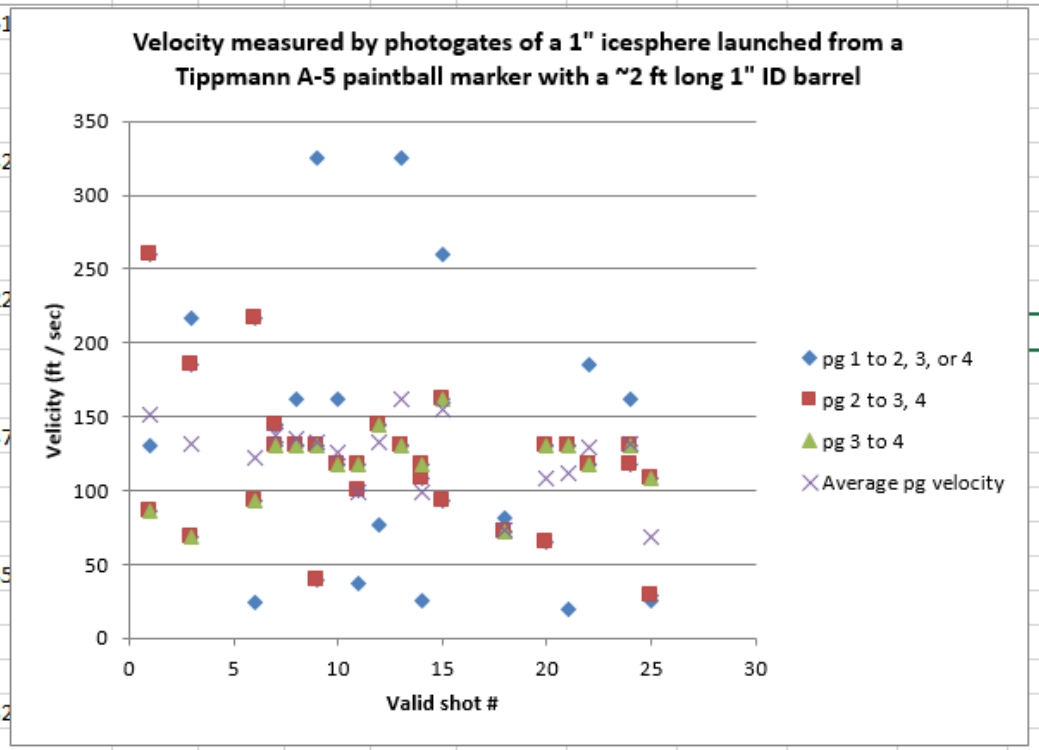
Oh my hail – Fortuitous result

							Distance between photogates in cm
							pg 2 - 1
Time pg tripped (S)	Time in pg (s)	velocity between pg (cm/s)	#	pg 1 to 2, 3, 4	pg 2 to 3,	pg 3 to	Ave Shot v
172.6369	1.00E-04	No Gate	1				151
172.6379	2.00E-04	5000	3	129.9376299			
172.6384	1.00E-04	10000	4	259.8752599	259.8753		
172.6399	1.00E-04	3333.333333	7	86.62508662	86.62509	86.625	
469.0478	3.00E-04	Following Gate	22				132
469.0484	1.00E-04	8333.333333	24	216.5627166			
469.0491	1.00E-04	7142.857143	26	185.6251856	185.6252		
469.0510	2.00E-04	2631.578947	32	68.38822628	68.38823	68.388	
730.4601	7.00E-04	Following Gate	68				122
730.4654	2.00E-04	943.3962264	73	24.51653395			
730.4660	1.00E-04	8333.333334	77	216.5627166	216.5627		
730.4674	2.00E-04	3571.428571	82	92.81259281	92.81259	92.813	
772.0410	5.00E-04	Following Gate	107				137
772.0419	5.00E-04	5555.555556	108	144.3751444			
772.0428	5.00E-04	5555.555556	109	144.3751444	144.3751		
772.0438	6.00E-04	5000	110	129.9376299	129.9376	129.94	
825.4209	5.00E-04	Following Gate	111				135
825.4217	5.00E-04	6250	112	162.4220374			
825.4227	5.00E-04	5000	113	129.9376299	129.9376		
825.4237	5.00E-04	5000	114	129.9376299	129.9376	129.94	
854.9218	1.00E-04	Following Gate	115				132
854.9222	1.00E-04	12500	117	324.8440748			
854.9255	1.00E-04	1515.151515	122	39.37503937	39.37504		

pg 3 - 1	pg 4 - 1	pg 3 - 2	pg 4 - 2	pg 4 - 3
10	15	5	10	5



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Oh my hail – Paintball and hailstone energy analysis

Material Comparrison to Hail, Michael Shaw, 12/11/2014

This table will tell you how fast you need to shoot each object in order to match impact characteristics with hail. All that is needed is the young's modulus of each projectile object, Follow code a bit to solve.

Object Name	Mass (kg)	Diameter (m)	Radius (m)	Volume (m^3)	Density (kg/m^3)	Projected Area (m^2)
Hail Small	6.08E-05	5.08E-03	2.54E-03	6.86E-08	8.86E+02	2.03E-05
Hail Large	7.60E-03	2.54E-02	1.27E-02	8.58E-06	8.86E+02	5.07E-04
Paintball	3.20E-03	1.73E-02	8.64E-03	2.70E-06	1.19E+03	2.34E-04
Iceball Paintball Sized	2.70E-03	1.73E-02	8.64E-03	2.70E-06	1.00E+03	2.34E-04
Iceball 0.74"	3.48E-03	1.88E-02	9.40E-03	3.48E-06	1.00E+03	2.77E-04
Iceball 1"	8.58E-03	2.54E-02	1.27E-02	8.58E-06	1.00E+03	5.07E-04

Object Name	Velocity (m/s)	Kinetic Energy (J)	Momentum (kg*m/s)	Projectile Deformation (m	Impact Force (N	Stress, σ (N/m^2)
Hail Small @ KE = 7.60E-02	5.00E+01	7.60E-02	3.04E-03	5.08E-04	1.50E+02	7.38E+06
Hail Large @ KE = 9.50E+00	5.00E+01	9.50E+00	3.80E-01	2.54E-03	3.74E+03	7.38E+06
Paintball @ KE = 7.60E-02	#DIV/0!	#DIV/0!	#DIV/0!	1.73E-03	#DIV/0!	#DIV/0!
Iceball Paintball-Sized @ KE = 7.60E	4.47E+00	7.60E-02	1.21E-02	1.73E-03	4.40E+01	1.88E+05
Iceball 0.74" @ KE = 7.60E-02	6.89E+00	7.60E-02	2.40E-02	1.88E-03	4.04E+01	1.46E+05
Iceball 1" @ KE = 7.60E-02	7.51E+00	7.60E-02	6.44E-02	2.54E-03	2.99E+01	5.91E+04
Paintball @ KE = 9.50E+00	#DIV/0!	#DIV/0!	#DIV/0!	1.73E-03	#DIV/0!	#DIV/0!
Iceball Paintball-Sized @ KE = 9.50E	8.39E+01	9.50E+00	2.26E-01	1.73E-03	5.50E+03	2.35E+07
Iceball 0.74" @ KE = 9.50E+00	7.39E+01	9.50E+00	2.57E-01	1.88E-03	5.06E+03	1.82E+07
Iceball 1" @ KE = 9.50E+00	4.71E+01	9.50E+00	4.04E-01	2.54E-03	3.74E+03	7.38E+06

Object Name	'oung's Modulus (N/m^2	Elastic/Inelastic %?	'otal Transferred Energy (J	Impact Distance (m)	Strain	alculated Young's of PT
Hail Small @ KE = 7.60E-02	9.00E+06	1.00E+00	7.60E-02	1.30E-04	6.50E-02	3.12E-04
Hail Large @ KE = 9.50E+00	9.00E+06	1.00E+00	9.50E+00	1.45E-03	7.27E-01	6.97E-04
Paintball @ KE = 7.60E-02		0.00E+00	7.60E-02	#DIV/0!	#DIV/0!	#DIV/0!
Iceball Paintball-Sized @ KE = 7.60E	9.00E+06	1.00E+00	7.60E-02	1.30E-04	6.50E-02	3.60E-03
Iceball 0.74" @ KE = 7.60E-02	9.00E+06	1.00E+00	7.60E-02	1.30E-04	6.50E-02	4.27E-03
Iceball 1" @ KE = 7.60E-02	9.00E+06	1.00E+00	7.60E-02	1.30E-04	6.50E-02	7.80E-03
Paintball @ KE = 9.50E+00		0.00E+00	9.50E+00	#DIV/0!	#DIV/0!	#DIV/0!
Iceball Paintball-Sized @ KE = 9.50E	9.00E+06	1.00E+00	9.50E+00	1.45E-03	7.27E-01	3.22E-04
Iceball 0.74" @ KE = 9.50E+00	9.00E+06	1.00E+00	9.50E+00	1.45E-03	7.27E-01	3.82E-04
Iceball 1" @ KE = 9.50E+00	9.00E+06	1.00E+00	9.50E+00	1.45E-03	7.27E-01	6.97E-04

Object Name	Velocity (ft/s)	'T Material Thickness (m)
Hail Small @ KE = 7.60E-02	164.04	0.002
Hail Large @ KE = 9.50E+00	164.04	
Paintball @ KE = 7.60E-02	#DIV/0!	
Iceball Paintball-Sized @ KE = 7.60E	14.67	
Iceball 0.74" @ KE = 7.60E-02	22.61	
Iceball 1" @ KE = 7.60E-02	24.63	
Paintball @ KE = 9.50E+00	#DIV/0!	
Iceball Paintball-Sized @ KE = 9.50E	275.41	
Iceball 0.74" @ KE = 9.50E+00	242.56	
Iceball 1" @ KE = 9.50E+00	154.41	

- In order to use the table created for this requirement, all that needs to be known about the material is the Young's modulus, the density, and object size. The table will calculated projected area, kinetic energy and momentum, and will output a projectile velocity required to make a comparable impact on the various payload transporter surfaces for that specific projectile.
- Because it was not explicitly stated, we will assume the worst case scenario – that all (100%) of the kinetic energy of the particle will be transferred into the various surfaces of the payload transporter. This means a perfectly inelastic collision. In reality, most collisions are on a spectrum of elastic to inelastic (this is referring to the amount of kinetic energy lost – not conserved – in the collision, and how much of it is transferred back into the rebounding object).
- A rough estimate was made that the impacting object could deform 10% of its diameter before having permanent deformation, and thus 100% kinetic energy transfer into the impacted surface.

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Oh my hail – Obtain stakeholder consensus

- 0.2 to 1” hail at 164 fps (111 mph)
  - Material composition (0.033 lb/in^3, Youngs modulus = hail)
  - Spherical ice cube size is about 1.1”
  - Hail shape not very repeatable (2 out of 5 are good)
    - Distilled water seemed to work better
  - Velocity varies greatly (~30 fps estimated), about ~ 45% error in KE
    - Could not measure with a chronometer
  - Repeat shots to get to ensure that correct velocity was obtained
    - Need to measure the velocity using a more elaborate setup
- 0.68” Paintball at 275 fps (188 mph)
  - Material composition (0.0428 lb/in^3, Youngs modulus < hail)
  - Consistent size and shape
  - Would perform 6 shots per location (4.08” total)
  - Consistent velocity (~5 fps), ~4% error in kinetic energy (KE)
    - Velocity of each shot measured and recorded

Oh my hail – Test execution and results

- Results: Unsurprising… a few barely noticeable dime size dimples
- Lessons learned: chronometers/chronographs size/shape and location can pick up vapor and packing material as well as the projectile which can result in an inaccurate velocity
- Try measuring a foot or two away from the barrel to get only the hail stone but not before to much velocity is lost
- You can probably find all of the materials and equipment if you ask around
- Distilled water for ice ball mold
- Brief and involve internal and external stakeholders along the way, present in a trade study format
- Questions?

Oh my hail – A bonafide test setup

- https://www.youtube.com/watch?v=59kRY9-Crws

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