Construction of a Hail Gun for Solar PV Module Testing

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ABSTRACT

Solar modules sold in the United States do not have to be tested for resistance to hail impact. Our customers expressed concern about the possibility of their significant investment in solar modules being lost due to a hail storm. After reviewing the scientific literature, we decided we could evaluate the hail resistance of modules we planned to sell and provide some assurance to our customers.

INTRODUCTION

The Jet Propulsion Laboratory conducted several durability tests of solar panels, including simulated hail impact, in 1978 and issued a report[1]. The National Bureau of Standards (NIST) issued a procedure[2] for hail impact testing of "solar covers" in 1982. The *Standard Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls*, ASTM E1038, was first issued in 1985. Despite this long history of attention to determination of solar module hail resistance, there is still no required test for solar modules sold in the United States. Underwriters Laboratories Standard 1703 includes an impact test but it does not simulate the impact of hail and visible damage does not necessarily mean failure of the test. IEC 61215 contains a hail test that is very similar to the ASTM test and solar modules sold in Europe must pass this hail test.

We wanted to be able to tell our customers that we had investigated the hail resistance of the solar modules and found them suitable for conditions in the United States. (Note: Hail stones are associated with thunderstorms. We can estimate the falling terminal velocity for a certain sized hail stone, but the coincident wind conditions around the thunderstorm can have an unpredictable effect on velocity at impact.)

Rather than having candidate solar modules tested at a third-party laboratory, we designed and built our own hail gun and developed the skills to do this testing at our product development center in Carrollton, Texas.

<u>General Outline of IEC 61215 Hail Impact Test Protocol</u>

Sub clause 10.17 of IEC 61215 describes the Hail Impact Test protocol. The solar module is impacted with ice balls in eleven different locations. There must be no major defect caused by the impacts and the maximum power output of the module is measured before and after this test to check for problems that might not be visually detectable. Likewise, the dielectric strength is checked to look for a change.

The following table shows the range of ice ball sizes that can be used during this test. The manufacturer decides which size ice ball they wish to certify to. The velocity goes up with the size of the ice ball. (This is to match what have been found to be typical terminal velocities for hail stones of a given size.)

Diameter (mm)	Mass (g)	Velocity (m/s)	Kinetic Energy Joules
12.5	0.94	16.0	0.116
15	1.63	17.8	0.24
25	7.53	23.0	1.85
35	20.7	27.2	7.18
45	43.9	30.7	19.5
55	80.2	33.9	43.4
65	132	36.7	84.7
75	203	39.5	150

According to TUV, a leading solar PV testing laboratory, they see very few solar modules fail the Hail Impact test. They also indicate that most modules are only tested with 25mm ice balls… at the request of the PV module manufacturer.

<u>THE NEED TO CONDUCT OUR OWN TESTING</u>

For the WOW-factor, we calculated the ice ball kinetic energy for each ice ball size (and corresponding velocity) and included it in the above table. The energy rises rapidly with ice ball size! Here is why:

Kinetic Energy = ½ * mass * $(\text{velocity})^2$

But: terminal velocity $\propto$ $(\text{diameter})^{1/2}$

(Resulting from balance of gravitational and aerodynamic forces)

And: mass $\propto$ $(\text{diameter})^3$ (for a spherical object)

So: Kinetic Energy $\propto$ $(\text{diameter})^4$

The upshot of this is that the impact energy of a 35 mm (1⅜") hail stone is almost four times as great as one 25 mm (1") in diameter.

This image, from the National Severe Storms Laboratory (NSSL), shows the climatological probability of 2" (or larger) hail occurring within 25 miles of any point for that day. This image is for the first few days of May. For North Central Texas, this probability is 2.5%. The highest frequency zone moves northward during the summer, and then back down. The hail concern we have is well-founded.

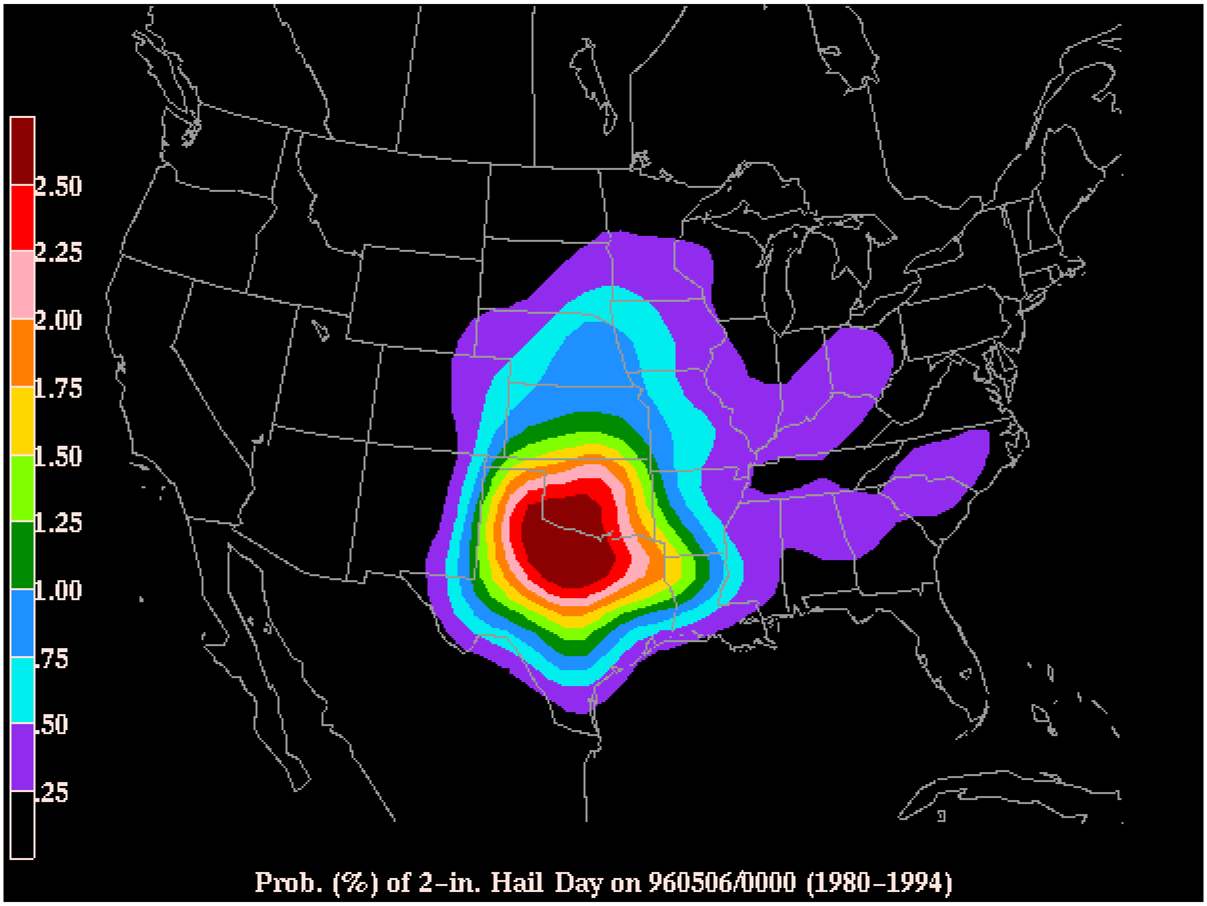

Figure 1. Hail Probability Map

Development of the Hail Gun

We found an old paper that mentioned a pneumatically operated hail gun developed at Sandia Laboratories. We also found several hobbyists "air cannon" descriptions on the internet. One of the better posts described an air cannon that ham radio operators fabricate as part of emergency preparedness. The cannon uses compressed air to launch a tennis ball high in the air. A temporary antenna wire is attached to the tennis ball. This gear is used to reestablish radio communications in a disaster area; the antenna wire is strung up to the highest object still standing in the area. We first built the hail gun along the lines of the ham radio air cannon. We made a video of the first test-firing, using a racquetball. Sure enough, it looked like we were going in a good direction: the hang-time of the racquetball was 5 seconds.

This first design used a very simple “trigger”: a burst disc made of aluminum foil. We found that to be a limitation because we did not have good control of the ball’s velocity. A more repeatable trigger system would be needed.

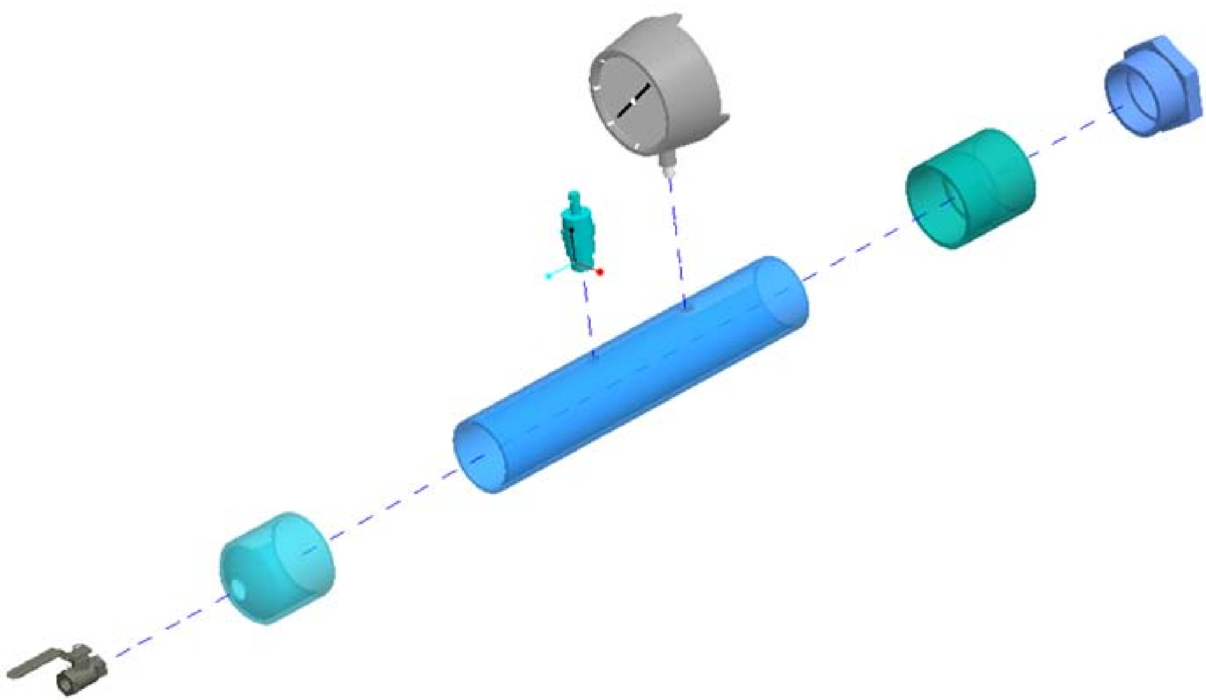

Figure 2. Components for Gun Air Chamber

The same website showed a scheme that used a poppet valve to release the large volume of air rapidly. The poppet is held closed by considerable force when the air tank is pressurized. A “pilot valve” system is used to provide the needed opening force. The pilot valve is a smaller air valve (a quarter-turn ball-type valve) that would connect to the left end of the tank shown in the figure below. A loose-fitting piston toward the left end of the tank is connected to the poppet valve by a rod. The air tank is pressured and the pressure is the same on each side of the piston. When the pilot valve is rapidly opened, the piston moves to the left because the air pressure has been reduced on that side. The poppet valve is rapidly drawn back, releasing the compressed air into the barrel.

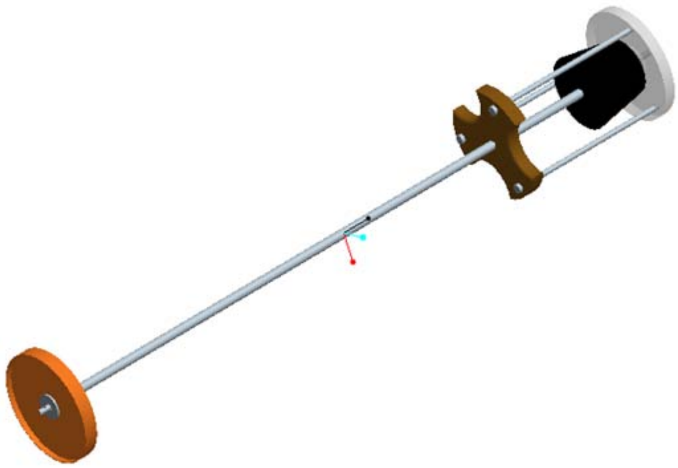

Figure 3. Poppet Valve and Piston Assembly

We fabricated the additional parts needed to make the pilot-operated air release system work. We also added a pressure gauge and a pressure relief valve. The device is made primarily of schedule 40 PVC pressure water pipe. The air tank portion is nominal 3" diameter with a 260 psi pressure rating. We have found we don't need to operate the hail gun with pressures higher than 20 psi.

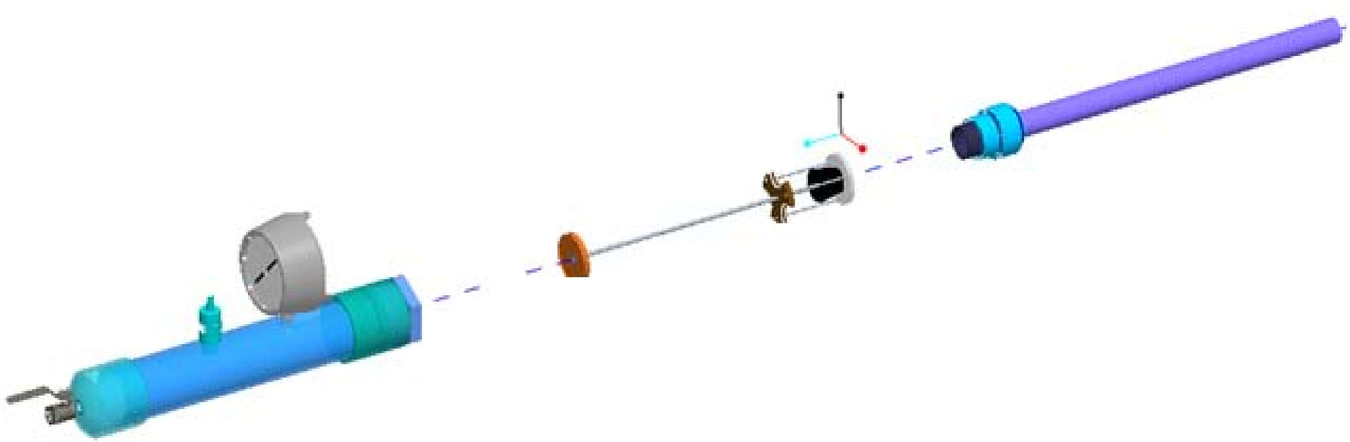

Figure 4. Gun, Valve Assembly and Barrel (Exploded View)

Figure 5. Photo of Assembled Gun with Various Interchangeable Barrels

Figure 6. Hail Gun Ready for Use in Test Chamber (1.375” Barrel Shown)

ICE BALLS

We have tried two different methods for making ice balls. We have had the best success using silicone molds made for casting balls of chocolate. A household refrigerator/freezer is used to freeze the ice balls in the mold. We use butter to help seal the mold parting line and use a graduated syringe to precisely fill the voids with water. There is always either a flat spot or a bump on the ice ball left as an impression from the fill port of the mold. With practice, we have learned to minimize the size of the imperfection. The picture below shows a silicone mold for casting 1” ice balls. Also shown is an individual mold we made out of PVC for casting 1.375” ice balls. The IEC standard calls for checking the weight of the ice ball and for discarding any that have cracks in them. We seem to have more cracks in the ice balls made in the harder mold.

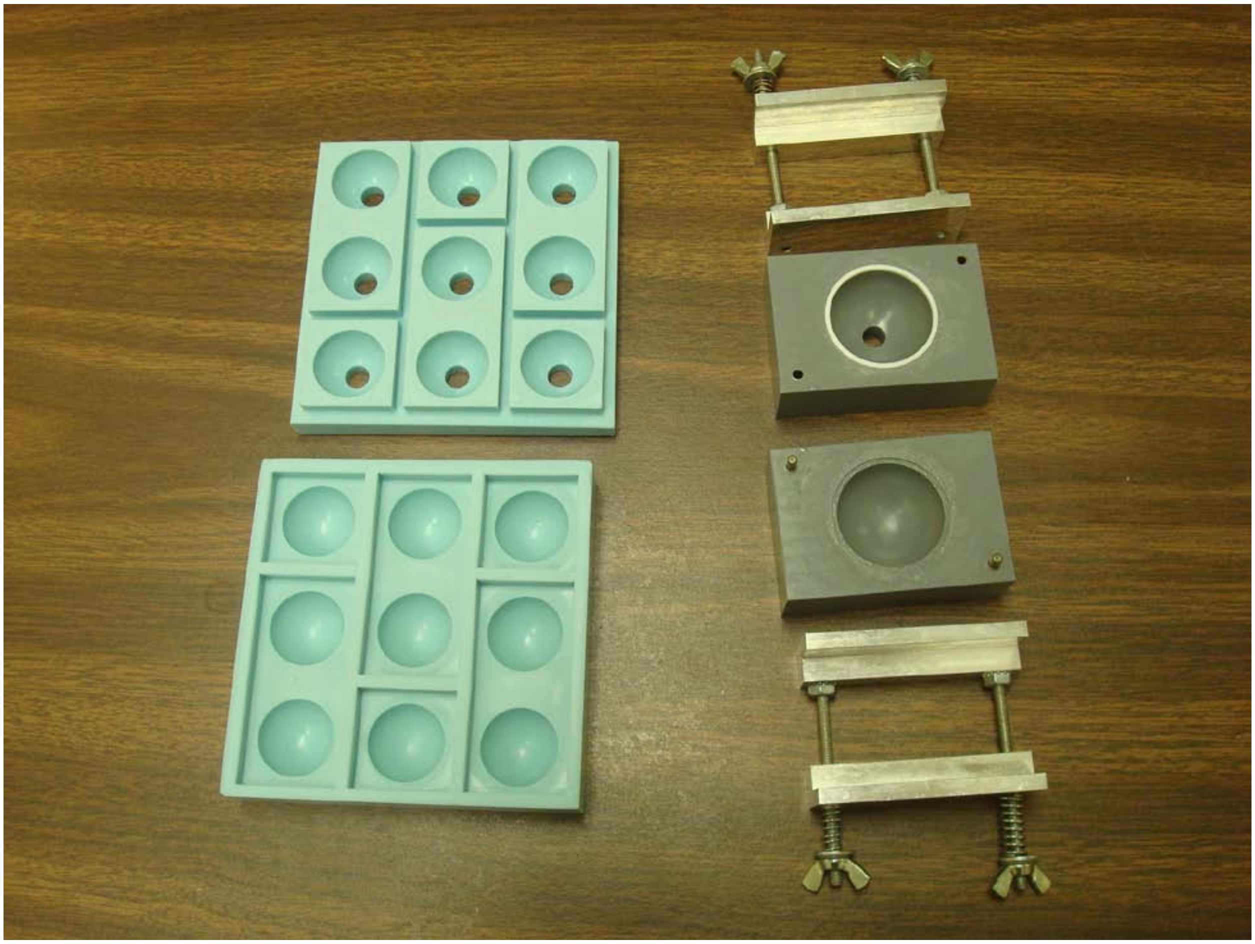

Figure 7. Ice Ball Molds

VELOCITY MEASUREMENT

Again, we tried a couple of different devices before settling on a radar speed gun available at sporting goods stores for about $100. These devices are used by coaches to measure the speed of baseball pitches and the like. The accuracy is advertised as “to +/- 1 mph” but we have not attempted to check calibration. The radar gun has been very reliable, giving us a velocity for each ice ball launched. We have fired ice balls in the range of speeds from 30 mph to 190 mph.

POST-TEST EXAMINATION

The PV module is visually examined after each successive ice ball strike. Mainly we are looking for cracks in the glass. After all eleven ice balls have been shot we use Infra-Red Imaging (using a FLIR camera) to check for possible damage to cells or interconnects. Shown below are IR images of two different PV modules tested.

For IR imaging, the by-pass diodes are removed and a dc power supply is used to drive current through the module. At the start, the solar module has been soaked-out to a controlled ambient temperature of 60°F. The current flow is increased to a value perhaps 25% higher than the module's rated short-circuit current by carefully adjusting the voltage of the dc supply. Within 30 minutes, the module will have heated up enough to be near steady-state temperature (90°F to 95°F). The current flowing through the module shows up as heat on the IR image and cold areas would indicate abnormally low current flow, possibly due to impact related damage.

Figure 8. IR Image of 235 Watt Solar Module

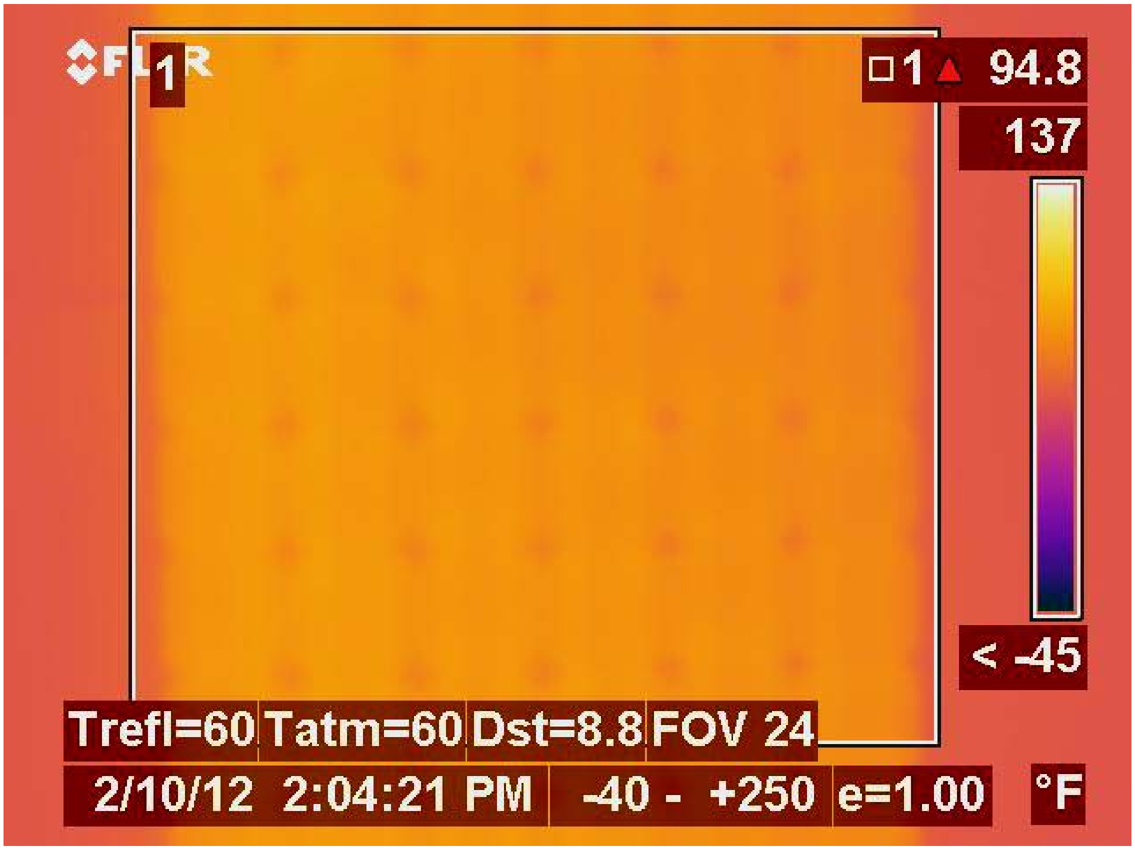

Figure 9. IR Image of 180 Watt Solar Module

We did not find any obvious damage to either of these solar modules. (We should have taken IR images before the test so that we could compare back. We plan to do this next time.)

CONCLUSION

The project to develop in-house hail test capability turned out to be relatively quick and inexpensive. Future work will include more and better module pre and post test evaluation. We also plan to switch to a solenoid operated pilot valve to improve consistency of ice ball velocity and targeting.

The ability to conduct hail tests on solar PV modules helped us address a concern our customers had about the likely longevity of solar modules in hail-prone climates. We have also incorporated video documentation from testing into our product marketing materials.

FOOTNOTES

1. Moore, D., and Wilson, A., “Photovoltaic Solar Panel Resistance to Simulated Hail,” Low-Cost Solar Array Project Report 5101-62, Jet Propulsion Laboratory, Pasadena, CA, 1978. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161-0001

2. Jenkins, D. R., and Mathey, R. G., “Hail Impact Testing Procedure for Solar Covers,” NBSIR 82-2487, National Bureau of Standards, April 1982. Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161-0001

PARTS LIST

Hail Gun Parts List			23-Feb-12	
Item #	Qty	Description	Source	Mfg's Part Number
1	1	3" Sch. 40 PVC Cap	Spears Manufacturing	447-030
2	1	3" Sch. 40 PVC Coupling, Slip x Slip	Spears Manufacturing	429-030
3	1	3" x 2" Bushing, SPIG x FPT	Spears Manufacturing	438-338
4	1	2" x 2" Sch. 40 Adaptor PVC Slip x MPT	Spears Manufacturing	436-020
5	1	1.25" Sch. 40 PVC Coupling (modified)	Spears Manufacturing	429-012
6	1	2" x 1.5" Sch. 40 PVC Bushing	Spears Manufacturing	437-251
7	1	1.5" x 1.25" Sch. 40 PVC Bushing	Spears Manufacturing	437-211
8	1	Tube, Clear Polycarbonate 1.5" od x 1.375" id x 24"	McMaster Carr	8585K43
9	1	Pipe, 3" Nominal Sch. 40 PVC x 18"	Home Depot	
10	1	Rod, steel 0.250" diameter x 20", threaded nc both ends	Home Depot	
11	1	Disk, PVC 3.000" diameter x 0.375" thick (3.25" turned)	McMaster Carr	87025K74
12	1	Disk, PVC 3.040" diameter x 0.375" thick "scalloped" (3.	McMaster Carr	87025K74
13	1	Rubber Stopper, Tapered, #11.5, (1 and 31/32" diameter	McMaster Carr	9545K61
14	4	nut, 1/4" nc	Home Depot	
15	4	washer, steel for 1/4" diameter rod	Home Depot	
16	1	1/2" nominal 1/4 turn ball valve	RUB	S92D45
17	1	1/2" nominal close pipe nipple	Home Depot	
18	1	Pressure gauge, 0 - 30 PSI	Omega Engineering	PGH-45B-30
19	1	Pressure relief valve	Universal Pneumatic	ST25-30
20	1	Tire valve stem	Patchboy.com	17-500B
21	3	Screw, machine, #8 - 32 x 0.75"	Home Depot	