Generation of Short Hypersonic Water Jet for Rain Erosion Testing of Materials

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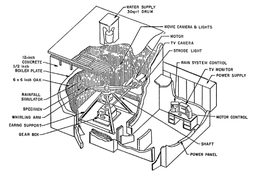
OBJECTIVES AND CONTENT

- Bodies moving at very high speeds through a rain-field can experience severe damage caused by the impingement of raindrops on their surfaces. This effect is usually referred to as “rain erosion”. Rain erosion has been a concern of the aviation and missile industries for many decades, and rain erosion resistance is an extremely important parameter of the materials interaction with the flight environment.
- We present a new, inexpensive rain erosion test method, which creates a millimeter-size short water jets, moving with the speeds in the range of 1000 m/sec and higher. The method is based on the use of an apparatus which can be considered as a highly modified Split Hopkinson Pressure Bar.
- Practical realization of the developed by us apparatus was made in collaboration with C. Morand, R. Lumpkins and J. Dignam, Mentis Sciences, Inc.

CURRENT RAIN ERROSION TEST METHODS-1.

Rotating arm



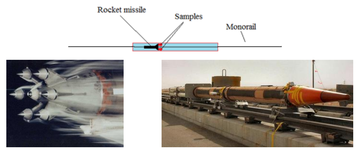
44.7-290 m/sec; 2 samples

The advantage of the methods like the “rotating hand” and “sled test”, is that they are good enough to model rain environments, including distribution of droplets over sizes.

Their disadvantage is that it is about impossible, or at least extremely difficult to understand the physics of the material’s destruction

Sled test

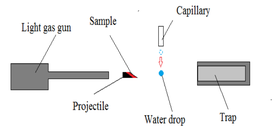
Holloman Air Force Base, New Mexico, 6000’ rain field.



7-Cone Test Fixture; 1280 m/sec

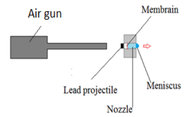
CURRENT RAIN ERROSION TEST METHODS-2. Modeling of the singular droplet impact

Light gas gun specimen launch



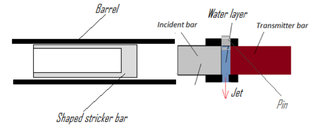
Speed 1000-1500 m/sec (?)
Exists only as a project

Single Impact Jet Apparatus (SIJA)



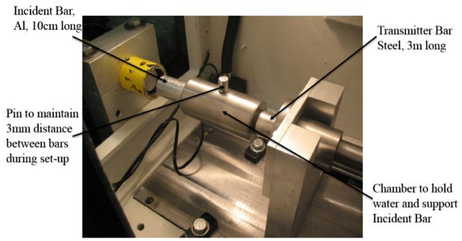
Bowden F.P. and Brunton J.H."Damage to solids by liquid impact at supersonic speeds" Nature 181 (1958) 873-875.

THE NEW METHOD - 1. Split Bar Water Jet Generator (SBWJG)



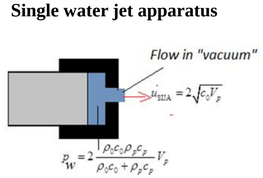
THE NEW METHOD - 2 . Split Bar Water Jet Generator (SBWJG)

The proposed apparatus for generating high speed water jets is a highly modified version of the Split Hopkinson Pressure Bar in which the water layer represents the “sample”.



SIMPLIFIED THEORY

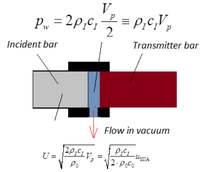
Single water jet apparatus



$$u_{SIJA} = 2\sqrt{c_0 V_p}$$

$$p_w = 2\frac{\rho_0 c_0 \rho_p c_p}{\rho_0 c_0 + \rho_p c_p} V_p$$

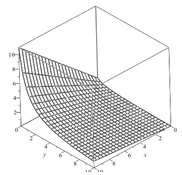
$$p_w = 2\rho_1 c_1 \frac{V_p}{2} \equiv \rho_1 c_1 V_p$$



$$U = \sqrt{\frac{2\rho_0 c_0}{\rho_0}} V_p = \sqrt{\frac{\rho_0 c_0}{2 \cdot \rho_1 c_1}} u_{SIJA}$$

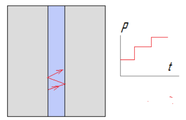
Theoretically, in case of over-compression of the water by sandwiching between materials with high impedance leads to the gain in jet speed in times in comparison with classic SJIA.

$$\eta_V = \frac{V_R}{V_{R0}} = \sqrt{\frac{1+\dfrac{\rho_1 c_{b1}}{\rho_w c_0}}{1+\dfrac{\rho_1 c_{b1}}{\rho_2 c_{b2}}}}$$



The best combination: transmitter bar has impedance significantly higher than incident bar. In turn, incident bar has impedance significantly higher than water.

ESTABLISHING OF THE EQUILIBRIUM PRESSURE

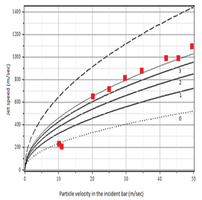


In reality, equilibrium within water layer is establishing not immediately. Multiple reflections are needed

$$p_n = 2\left(1+\frac{\rho_{b2}c_2-\rho_w c_0}{\rho_{b2}c_2+\rho_w c_0}\left(1+\frac{\rho_{b1}c_1-\rho_w c_0}{\rho_{b1}c_1+\rho_w c_0}(...)\right)\right)\frac{\rho_w c_0 \cdot \rho_1 c_{b1}}{\rho_w c_0+\rho_1 c_{b1}}\dot{\varepsilon}_1$$

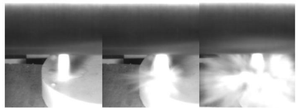
Experimental results show that 4-5 reflections needed to reach observed jet velocity.

For taken parameters of water layer, characteristic time of the jet forming is in the range of 8-10 microseconds. This time defines the jet length.

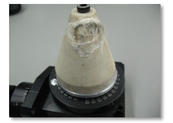


PRACTICAL APPICATIONS

High speed video captures of a sample number P309A-031411-002 being tested



Impact of the water jet moving with the velocity 1100 m/sec (particle velocity in striker bar 52.55 m/sec, maximal theoretical speed 1430 m/sec) onto a composite material.



Cumulative 6-drops impact on the cone under the attack angle 20 degrees. Special platform permits to regulate angle of attack.