INTEGRATION OF A DUST ACCELERATOR INTO THE IPG6-B TEST FACILITY FOR MATERIAL IMPACT TESTS. C. Montag\textsuperscript{1,3}, R. Lauffer\textsuperscript{1,2}, R. Srama\textsuperscript{2,3}, G. Herdrich\textsuperscript{2,3}, O. Przybilski\textsuperscript{1}, T. W. Hyde\textsuperscript{3}, \textsuperscript{1}Institute of Aerospace Engineering, Technical University of Dresden, Marschner Strasse 32, 01062 Dresden, Germany, \textsuperscript{2}Institute of Space Systems (IRS), University of Stuttgart, Pfaffenwaldring 29, 70569 Stuttgart, Germany, \textsuperscript{3}Center for Astrophysics, Space Physics & Engineering Research (CASPER), Baylor University, One Bear Place 97310, Waco, TX-76798-7310, USA.

Introduction: One collaboration project between the Center for Astrophysics, Space Physics and Engineering Research (CASPER) at the Baylor University, Waco, Texas, USA and the Institute of Space Systems (IRS) at the University of Stuttgart, Germany is to design and develop a single stage gas driven dust particle accelerator - a so called Light Gas Gun (LGG) – at the CASPER Space Science Lab. This design is based on an early existing stand-alone LGG breadboard model. To test materials simultaneously subjected to a plasma environment and to high velocity impacts by particles, as it occurs e.g. to spacecraft when re-entering the atmosphere the LGG shall be connected to an existing version of an Inductively heated Plasma Generator (IPG6-B facility). Additionally, the LGG can be used to investigate the long term influence of degradation by impacting particles e.g. on solar panels mounted on spacecraft [1].

As a consequence of a high interest of impact tests a variety of light gas guns has been developed. This makes it possible to launch projectiles like spheres and cylinders sized in diameter of 0.1 mm to complex models with transverse dimensions up to 175 mm [2]. Furthermore, the Light Gas Guns can be divided into single- and multi stage Light Gas Guns which reach projectile velocities up to 11 km/s [2]. A single stage Light Gas Gun releases highly compressed driver gas by opening a fast-opening valve to accelerate the projectile. Also, a rapture disk can be used [2]. Reasoned by their small molecular weight hydrogen and helium increase the performance of the LGG when used as driver gas in comparison to other gases [2]. A multi stage Light Gas Gun consists of at least of two stages. Here, the first stage contains a propellant driven piston. As a result of the forward movement of the piston when accelerated by the propellant gas (i.e. helium) in front of the piston gets compressed [2]. Thus, the rapture disk which separates the first stage from the second stage raptures. Following, the driver gas releases and accelerates the projectile which is directly located behind the disk.

This paper will describe new CASPER Space Science Lab design criteria i.e. objectives and requirements, performance and design of the LGG.

Objectives and Requirements: Primary objective of the Light Gas Gun is to accelerate different types of projectiles by minor changes in design. Secondary objective is the analysis of the behavior, e.g. erosion of material probes by impacting projectiles or particles. System requirements are defined to clarify boundary conditions for designing the Light Gas Gun. Firstly, the LGG shall be a compact stand-alone system which can be mounted to the IPG6-B as well as to other facilities e.g. a regular vacuum chamber. To reach high projectile escape velocities it should be possible to use helium as driver gas which is pressurized up to $p = 3000 \text{ psi} = 20,684 \text{ MPa}$. Furthermore, the design should allow the use of teflon sabots ($\Omega_{\text{outside}} = 1/8 \text{ in} = 3.175 \text{ mm}$) as projectiles to accelerate micron sized particles in the magnitude of 25 $\mu$m to 103 $\mu$m. Here, an escape of driver gas has to be avoided when shot to prevent a pressure increase in the vacuum. In addition to that the LGG should allow to shoot sphere shaped projectiles with various diameters in the magnitude of a few millimeters by only minor changes in design. Moreover, it should be possible to shoot in different angles to the plasma stream at the target. The design should contain a mechanism which allows connecting or disconnecting the LGG quickly from the vacuum chamber. Here, it has to be guaranteed that the vacuum in the chamber is unaffected. Last but not least a fast process of loading and reloading has to be considered.

Performance: Depending on the type of projectile different performances can be expected. To get a first overview of projectile escape velocities an analytical analysis has been accomplished. This analysis considers ideal circumstances which means losses by friction and heat transfer are not taken into account. Due to the fact that a barrel with a length of $L = 1 \text{ ft} = 304.8 \text{ mm}$ is an off the shelf component which also entails the requirement of a compact system the following calculations are done with this length. On one hand the correlation between the pressure of the compressed driver gas and the escape velocity of the projectile is illustrated by using Newton’s Laws:

$$v = \sqrt{\frac{p \times 2 \times L \times S}{m}}$$

(1)
Where \( v \) is the projectiles escape velocity, \( p \) is the pressure of the compressed driver gas, \( L \) is the barrel length, \( S \) is the cross sectional area of the projectile and \( m \) the mass of the projectile. Here, the type of driver gas is not being considered. On the other hand the correlation between pressure and escape velocity can be described by [2]:

\[
p = \frac{m \cdot 2 \cdot a_0^2}{(\gamma + 1) \cdot S \cdot L} \left( \frac{(\gamma + 1) \cdot \nu}{2 \cdot a_0} - 1 \right) \left( \frac{1 - (\gamma + 1) \cdot \nu}{\gamma \cdot \nu^{\gamma + 1} - 1} \right)
\]

(2)

There \( p \) is the pressure of the compressed driver gas, \( m \) is the mass of the projectile, \( a_0 \) is the local Mach number, \( \gamma \) is the heat capacity ratio, \( S \) is the cross sectional area of the projectile, \( L \) is the barrel length and \( \nu \) the projectile escape velocity. In equation (2) the characteristics of the driver gas are considered. The results of the analysis are illustrated in figure 1.

![Figure 1. Escape velocities of various projectiles using different types of driver gas which is compressed by a pressure up to \( p = 3000 \) psi = 20,6843 MPa are illustrated.](image)

Comparing the curves where an aluminum sphere with a diameter of 2.38 mm was used as a projectile it can be seen that the type of driver gas strongly influences the escape velocity. Due to smaller and lighter molecules the performance of the light gas gun increases by using helium. Furthermore, figure 1 illustrates a significant difference of the escape velocity when using different sized teflon sabots. This clarifies that the mass of the projectile also strongly influences the performance of the LGG. Since, those analyses do not consider friction the design of the sabot is an important factor to reach high particle impact velocities.

**Design:** In figure 2 an approved design of the Light Gas Gun can be seen which fulfills the requested requirements. In order to keep the system compact a solenoid valve is used to regulate the gas flow when shooting a projectile. To control the mass flow of the driver gas quick enough the solenoid valve operates in the low milli seconds range. Furthermore, the LGG is controlled by a computer aided control system which uses off the shelf components (Arduino board). A manual ball valve makes it possible to separate the vacuum chamber from the LGG. Also, a quick release mechanism is used to detach the LGG from the vacuum chamber. In order to do that a wing nut clamp at the front of the LGG needs to be removed.

![Figure 2. Approved design of the Light Gas Gun](image)

**Conclusion:** The designed, developed and built single stage Light Gas Gun is a compact system which can be mounted to the IPG6-B for testing the behavior of material probes which are subjected to the influence of plasma and impacting particles at the same time. Of particular importance was to avoid a pressure increase in the vacuum chamber, caused by the driver gas when shot. In addition to the possibility of using various projectiles the LGG is designed to be a stand-alone system which easily can be mounted to different facilities. Due to this it is possible to use the LGG in a wide field of application next to the use in connection to the IPG6-B.

**Prospect:** Additional experiments have to be accomplished in order to verify calculated escape velocities of the various projectiles. Further, particle velocities need to be measured and compared to simulated results. Also, the mechanism which avoids the entry of the driver gas into the vacuum chamber when shooting teflon sabots has to demonstrate its operational reliability. In order to improve the use of the LGG the source code of the control system needs to be enhanced.