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PERFORMANCE MODELING OF EXPLOSIVELY ACTUATED VALVES

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ABSTRACT

The use of explosively actuated devices is widespread, with applications in the aerospace, defense, and automotive industries. They are commonly used on satellites to pull/retract pins, on rockets to open/close flow paths, and as part of airbag deployment systems. These devices require rapid energy production from self contained sources such as explosive charges. Historically, the design of these devices has been largely experimental [1]. While experiments are needed to characterize actual device performance, it would be beneficial to have predictive models to quickly assess the influence of design modifications on performance. Previous modeling work has only partially described device operation. Jones, et al., [2] analyzes the work requirements for explosive valves, but does not consider the effect combustion has on valve performance. The model of Gonthier and Powers [3] describes the combustion process and pin motion within a pyrotechnically actuated pin-puller device, but does not include the effect deformation within the device may have on performance. The present model will couple and extend the features of previous models to account for full device performance, including: 1) time dependent, multiphase combustion of an explosive charge, 2) work done by high pressure combustion gases, 3) elastic and plastic deformation of key structural members, 4) frictional resistance due to relative motion between components, and 5) heat transfer occurring within the device, and between the device and the environment. In order to more easily describe actuation, the valve is broken up into several different subsystems, including the actuator, expansion chamber, bore, and surroundings. The model tracks the evolution of mass, momentum, and energy within each subsystem during operation. The model is demonstrated for the B-61 Nitrogen Cartridge Valve, but is kept sufficiently general to apply it to different explosively actuated devices.

Figure 1 shows the Nitrogen Cartridge Valve in its a) prefired and b) postfired position. The purpose of the valve is to create a flow path allowing the transfer of nitrogen gas from a reservoir. It uses a piston with a cutting edge to puncture a diaphragm which seals the nitrogen gas in the reservoir. The first step of actuation is the ignition of the explosive charge by a hot wire. To enhance combustion, the explosive is encased by a metal burst disc having a smaller port cross sectional area. The port enhances combustion by restricting the flow out of the combustion chamber allowing the pressure to build up within. The burning explosive produces high pressure gases which push the tapered piston into the valve bore; this process is referred to as "insertion." The piston is then driven down the valve bore until it hits the skirt stops.

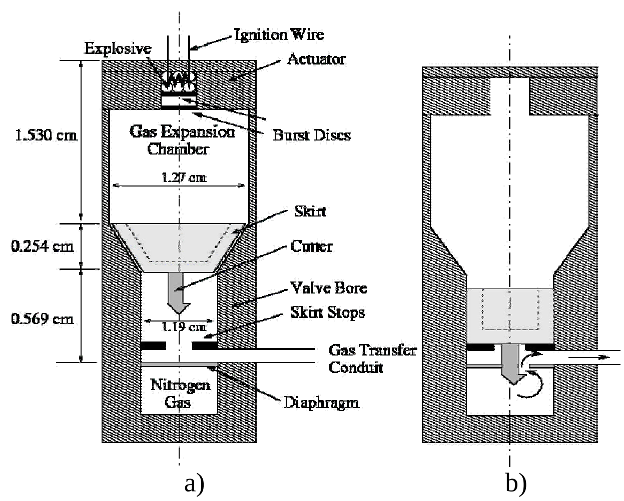

Figure 1: Nitrogen Valve Geometry a) Prefired and b) Postfired Position

Preliminary predictions for the nitrogen cartridge valve driven by 125 mg of the secondary high explosive HMX ($C_4H_8N_8O_8$) are given in Figures 2 and 3. As seen in Figure 2, the pressure within the combustion chamber rapidly builds up to 530 MPa approximately 25 μs after ignition. As a result of choked flow effects, the pressure within the expansion chamber more slowly increases to a peak pressure of 105 MPa (85 μs). The pressures then equilibrate and decrease due to the combined effect of heat transfer with the surroundings and work spent in pushing the piston down the bore. Actuation is complete around 140 µs following ignition as the piston hits the stops. Figure 3 shows the skirt position and velocity as a function of time. The peak velocity is around 80 m/s occurring just before the piston hits the stops. These predictions are consistent with the experimentally observed values for peak expansion chamber pressure (~110 MPa) and combustion time (~25 µs).

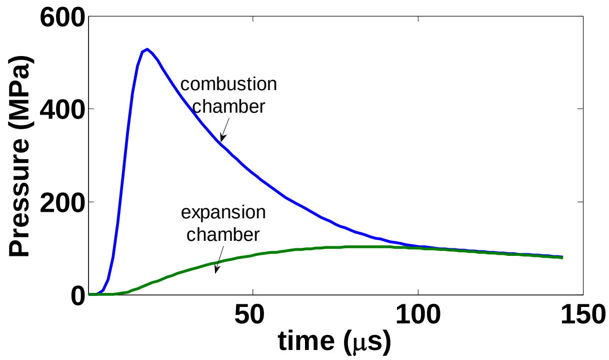

Figure 2: Preliminary prediction for HMX driven nitrogen cartridge valve: Pressure histories in combustion and expansion chambers.

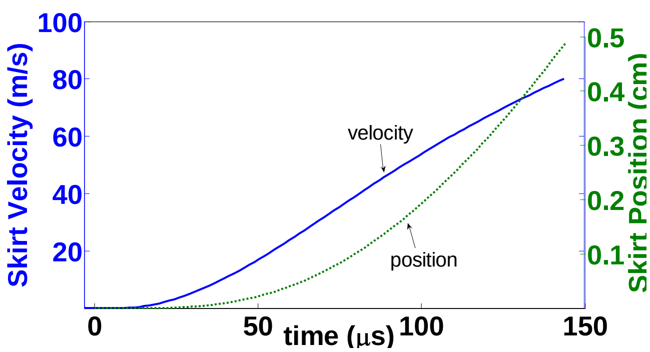

Figure 3: Preliminary prediction for HMX driven nitrogen cartridge valve: Skirt velocity and position.

The focus of the ongoing model has primarily been aimed at describing the piston deformation during insertion. This is believed to be critical in accurately describing valve operation. Recent quasi static, inert experiments were performed in order to characterize the energy requirements of the valve. The experimental and model prediction for the force displacement curve is plotted in Figure 4. As the skirt is being displaced into the bore, the force increases to a maximum experimental value of around 1000 lb (Prediction ~1100 lb). After the peak, the force continues to gradually decrease until the skirt is fully displaced in the bore.

Formulation of the model is ongoing. The near term effort will focus on accurately describing piston deformation. Subsequently, the combustion model will be coupled with the deformation model and a parametric analysis performed to identify optimum device configurations (i.e. materials, geometries, propellants, etc.)

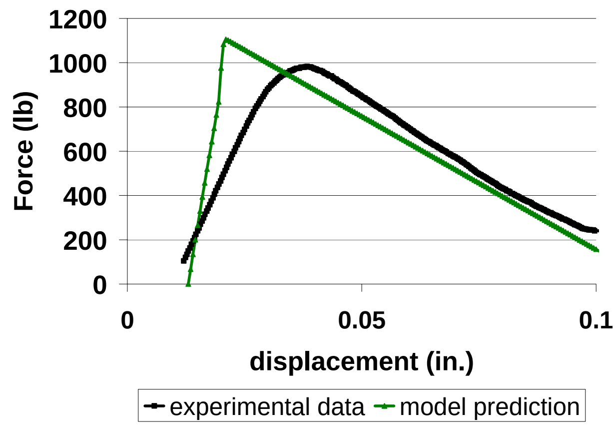

Figure 4: Comparison of force required to press the skirt into the bore.

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