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Stabilized Liner Implosions Driven by Axially-Moving Free-Pistons

P. J. Turchi, A. L. Cooper
R. D. Ford, D. J. Jenkins, and
W. L. Warnick

Plasma Physics Division

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NAVAL RESEARCH LABORATORY
Washington, D.C.

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The use of axially-moving free-pistons to drive rotating liquid liners is described. The advantages of this approach include simple synchronism of piston motion to avoid low frequency Rayleigh-Taylor instability, a great reduction in the number of moving parts, and excellent azimuthal symmetry. Initial experimental results are presented which demonstrate stable, repetitive implosion-reexpansion cycles using a hydrodynamic scale-model. Further developments are also indicated.

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STABILIZED LINER IMPLOSIONS DRIVEN BY AXIALLY-MOVING FREE-PISTONS

It has been demonstrated both theoretically[1,2] and experimentally[3,4] that rotating liquid liners can be used to compress low mass density payloads without suffering Rayleigh-Taylor instability at the decelerating inner surface of the liner. The outer surface of the liner will, however, experience such instability during its initial acceleration[3], but this problem can be greatly reduced by using free-pistons in continual contact with the outermost liner material as suggested in Ref. 5 and utilized in Ref. 4. The application of stiff free-pistons to the outer surface prohibits the growth of high frequency Rayleigh-Taylor instabilities, but does not restrict the growth of lower frequency modes[6]. Such growth results in variations in free-piston positions and in a nonuniform, asymmetric distribution of fluid mass and momentum. Indeed, variations in piston position and low mode number asymmetries of liner mass distribution have been observed in experiments with rotating liners driven by a plurality of radially-displaced pistons. The combination of a basic hydrodynamic instability with other factors, such as variations in reaction to the Coriolis forces on the radially-moving pistons in the rotating cylinder block, and reliability considerations of the statistically-large piston

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number, indicates the need for synchronizing mechanisms to insure the uniformity of the liner implosion.

With radially-moving pistons, a concatenation of individual mechanisms, such as gears, cams, tie-rods, valves, etc., would be needed to couple the piston motions. The number of moving parts in the system would increase as some multiple of the number of pistons. A different approach is to direct the pistons so that their motion can be rigidly linked, in effect creating a single moving part from a distributed series of piston surfaces. To avoid Coriolis forces, it is useful to displace these surfaces parallel to the axis of rotation. The concept of axially-driven implosion systems is thus derived, and is shown schematically in Fig. 1. High pressure gas from a peripheral plenum forces annular piston-plates to the right, thereby causing the free, cylindrical inner surface of the liquid liner to implode radially. The annular plates, while individually driven, are rigidly connected, allowing complete synchronism of their motion, with great simplicity.

In Fig. 2, an engineering layout is shown of a single-unit axial-piston implosion system for high energy density, rotating, liquid liner experiments (LINUS-O). This system is designed to utilize high pressure gas (~ 30 MPa) generated by high explosive combustion, and to implode Nak liners to peak pressures equivalent to that of a half-megagauss magnetic field. A one-third scale model of the piston and liner channel portion of this system has been constructed and operated using 0.7 MPa helium to drive liners of dyed-water, as in the earlier radial-piston experiments[4]. A schematic of the experimental arrangement is shown in Fig. 3 to indicate the photographic technique.

In Fig. 4, a sequence of high-speed movie photographs is shown of a liner implosion driven by axial-piston displacement. Note the excellent azimuthal symmetry and the repetitive implosion-reexpansion cycle, which continues for several more implosions. In this particular experiment, the internal ducting of the liner flow is symmetric with respect to the midplane of the implosion chamber. This ducting can be easily changed to study liner implosions that are shaped in the rz-plane. Such studies will be important both to establish the conditions for uniform implosion of the inner surface and to evaluate the feasibility of stabilized compression of a payload in three-dimensions. It should be noted that the normal turbulence and pressure-head loss that would afflict flows subjected to changes in area and direction are absent in the impulsive situations of interest here. This is because there is insufficient time for the diffusion of vorticity through the flow field to allow gross eddy formation[7,8].

The final figure (Fig. 5) shows an early conceptual view of an imploding liner fusion reactor based on axially-displaced pistons and shaped compression of a closed-field plasma configuration (for example, a reversed-field theta pinch or belt pinch of moderate aspect ratio). While it is clearly premature to be concerned with many details of such a system, it is useful to note some interesting features. For example, the use of shaped-liner motion, in addition to improving in some instances the relative plasma energy density, provides increased shielding of the system from axial neutron flux. The axial-drive is also shielded better than in the radial-drive case since the pistons do not move closer to the fusion plasma during liner implosion. An additional benefit of the axially-driven piston arrangement derives from its simple synchronism of the piston motion, namely, the pistons themselves can act as the main gas valve, with a "pilot-valve" (or cam, perhaps) providing the trigger motion which exposes the piston surfaces to the high pressure gas of the surrounding plenum. With high pressure, rotating "face" seals, the plenum pressure can be maintained without serious power loss. This arrangement would maximize the volumetric efficiency of the gas drive since there is negligible parasitic volume.

Before such systems can be seriously contemplated, more fundamental studies must be completed of liner compression at high energy density. The system of Fig. 2 in this sense is both the initial prototype of future liner implosion systems and the primary apparatus for further development of the LINUS concept.

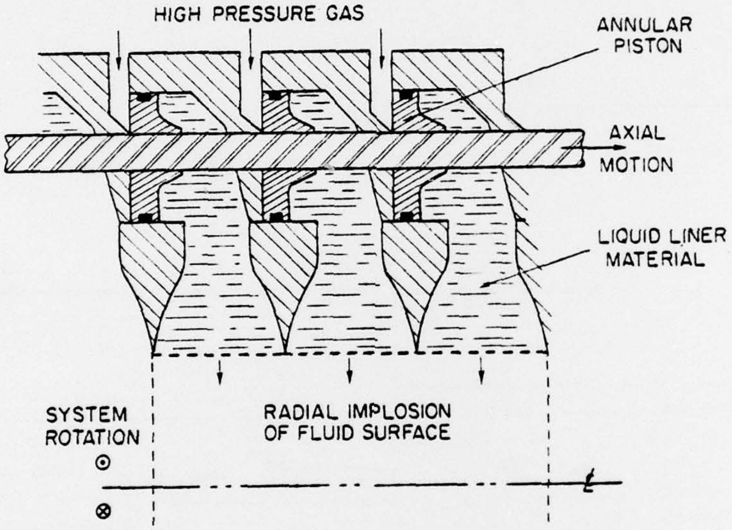

Fig. 1 - Schematic of axially-driven liner implosion concept

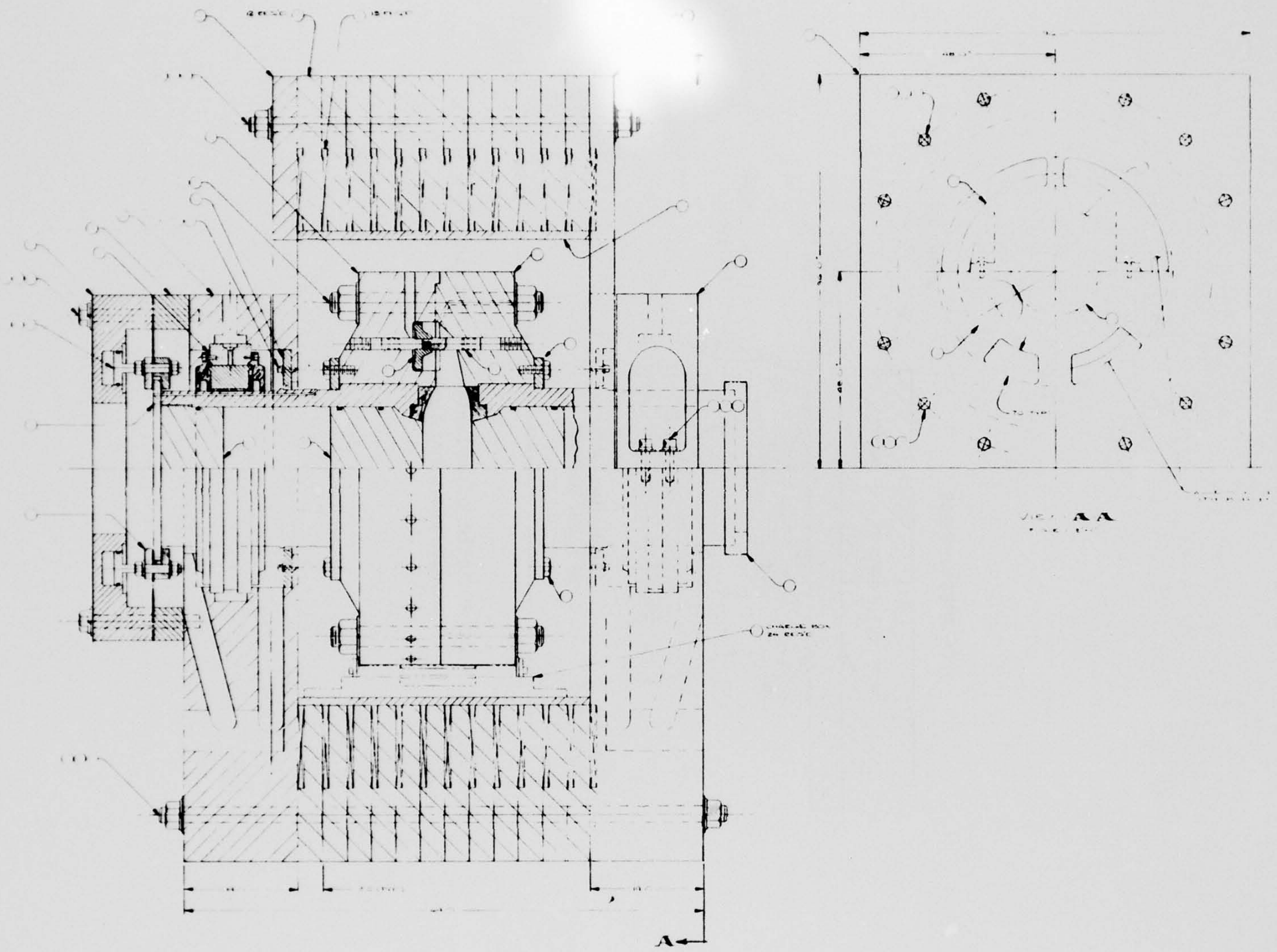

Fig. 2 - Engineering layout of prototype, high energy density liner implosion system using the axially-driven piston concept (LINUS-0)

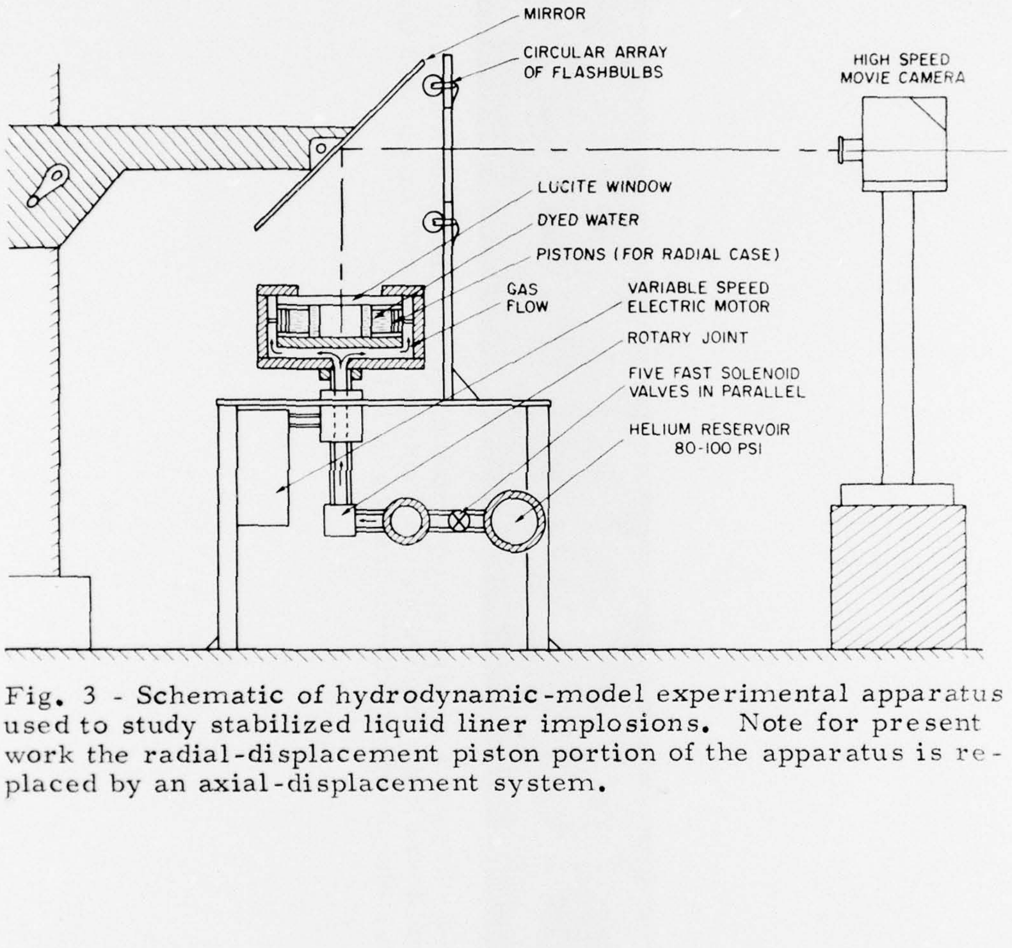

Fig. 3 - Schematic of hydrodynamic-model experimental apparatus used to study stabilized liquid liner implosions. Note for present work the radial-displacement piston portion of the apparatus is replaced by an axial-displacement system.

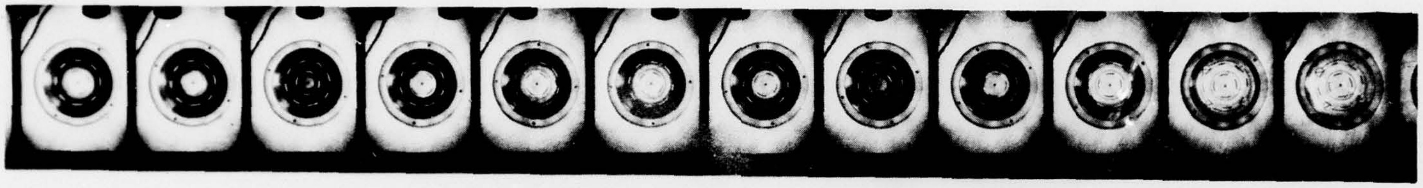

Fig. 4 - Sequence of high speed framing camera photos of a axially driven liquid liner implosion. The outermost fiducial circle is 3 in. diam., and the time between frames is 1.17 msec.

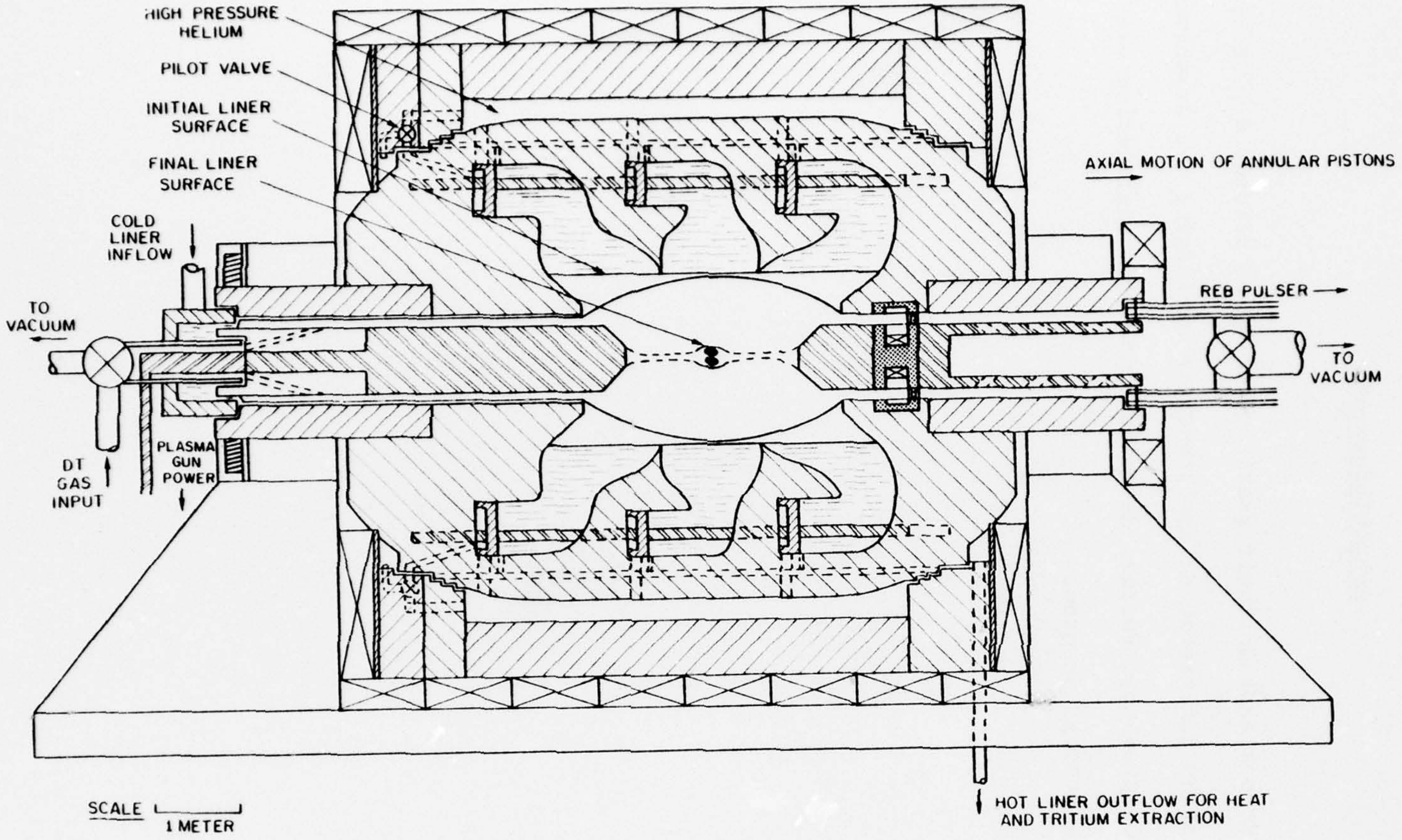

Fig. 5 - Schematic of conceptual stabilized imploding liner fusion reactor utilizing axially-driven piston concept to achieve three-dimensional compression of a moderate aspect ratio closed field-plasma

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