Implosion Dynamics of Al/W Double Planar Wire Array Z-pinches on University-Scale Generators

A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in Physics and the Honors Program

by

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Abstract

Sandia National Labs is currently planning the development of large-scale Linear Transformer Driver (LTD) generators capable of delivering up to 65-MA current for inertial confinement fusion research. Recently, the first Double Planar Wire Array (DPWA) Z-pinch experiments on an LTD generator were done in a collaborative effort between the University of Nevada, Reno and the University of Michigan. By studying PWAs at the university scale, PWA experiments can be more efficiently designed for large scale LTD generators. Using multi-frame shadowgraphy and the Wire Ablation Dynamics Model, uniform Al and mixed Al/W DPWAs on the 0.5-1 MA MAIZE LTD at UM are analyzed and used to understand how various loads influence implosion characteristics. Analysis of experiments of similar aspect ratio (defined as array width divided by interplanar gap) showed significant differences in the implosion dynamics when compared with previous research.
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**Abbreviations**

AI: Aluminum

D: Diameter

DOE: Department of Energy

DPWA: Double Planar Wire Array

ICF: Inertial Confinement Fusion

IPG: Inter-Planar Gap

IWG: Inter-Wire Gap

LTD: Linear Transformer Driver

MAIZE: Michigan Accelerator for Inductive Z-pinch Experiments

MHD: Magnetohydrodynamics

MRT: Magneto Rayleigh-Taylor

NNSA: National Nuclear Security Administration

PCD: Photoconducting Diode

PWA: Planar Wire Array

SNL: Sandia National Laboratories

UM: University of Michigan

UNR: University of Nevada, Reno

W: Tungsten

WADM: Wire Ablation Dynamics Model

XRD: X-Ray Diode

Φ: Aspect Ratio
1. Introduction

Modern energy sources have a variety of economic and environmental drawbacks. Ideally, energy sources should be safe, clean, and cheap. Fusion power has the potential to be an ideal energy source, but it faces many challenges in its development because it is very difficult to sustain a fusion reaction in a controlled manner. For the better part of the past century, researchers have been attempting to overcome challenges in achieving successful nuclear fusion. Currently, inertial confinement fusion (ICF) is one of the leading methods for achieving fusion power (Chen, 1984). With ICF the goal is to heat and compress fuel to overcome the Coulomb repulsion between protons and fuse atoms together. Lighter elements release energy when fused and the excess energy could be used to run steam turbines that supply power to the population. It takes large amounts of energy to fuse atoms initially but atoms with fewer protons are the easiest to fuse. For these reasons, deuterium and tritium (isotopes of hydrogen) are the most desirable fuels for ICF. Due to the difficulty of achieving ICF, several routes are being explored.

Figure 1.1: The 26 MA Z-machine in operation. The device is very large and the blue area we see is dedicated entirely to pulse shaping.
Z-pinches are one of the primary methods for achieving ICF (Haines et al., 2000). Sandia National Laboratories (SNL) has the most powerful Z-pinch generator, the 26-MA Z Machine (Figure 1.1). The Z-machine is a Marx-driven generator that requires a large pulse forming line to reduce the time of the current pulse. SNL is currently developing two large scale Linear Transformer Driver (LTD) devices, the Z 300 and Z 800 generators (Stygar et al., 2015). The LTDs use a new architecture that is more space-efficient than traditional Marx-driven generators and allows for easier current pulse shaping which translates to more experimental flexibility. Unfortunately, experiments on large scale devices used for ICF are expensive and so exploratory research is generally performed on smaller devices, such as those at universities (Giuliani et al., 2012). The University of Michigan at Ann Arbor has the 1-MA 100-ns Michigan Accelerator for
Inductive Z-pinch Experiments (MAIZE) LTD generator which is ideal for novel experiments due to its space efficient design (Figure 1.3) (Gilgenbach et al., 2008).

**Figure 1.3:** The MAIZE LTD at UM. The 1 MA generator has a diameter of 3 meters. A higher current LTD can be created by stacking these units. The MAIZE LTD is very space efficient compared to the Zebra generator.

Wire arrays are arrangements of fine (micron-scale) metal wires and have been studied extensively on the 1-MA 100-ns Zebra generator at UNR (Figure 1.2) and on the Z Machine at Sandia in a variety of geometries (Haines et al., 2000). A wire array Z-pinch occurs when sufficiently large currents are driven through wire arrays so that the wires ionize into plasma (Figure 1.4). The ionized plasma is then “pinched” by the Lorentz $j \times B$ force, such that the particles are compressed towards the center of the array. The mass eventually coalesces into a central plasma column that stagnates and implodes, releasing high-intensity X-ray radiation (Chen, 1984). Double Planar Wire Arrays
(DPWAs), which consist of two parallel rows of fine wires have been shown to be very efficient radiators on the Zebra generator (Kantsyrev et al., 2008). In addition, the geometry of DPWAs allows for detailed shadowgraphy and makes DPWAs ideal for studying implosion dynamics. However, DPWA experiments have only recently been explored on the MAIZE LTD as a collaborative effort between UNR and UM (Safronova et al., 2016a). Here this work is extended at a higher current and with improved 12-frame shadowgraphy.

**Figure 1.4:** An example of a Z-pinch experiment. A large current is discharged from capacitors connected to the anode and cathode. The current creates a magnetic field and a resultant inward Lorentz Force attraction.

Shadowgraphy is a diagnostic tool that produces images by shining a laser through the plasma and recording images with a camera on the other side (Figure 1.5). The laser light is obstructed when the light passes through material, and a “shadow” is cast by the plasma. By taking pictures at different times throughout the experiment, we can better understand the implosion dynamics (Settles, 2001). For the experiments on
MAIZE, the shadowgraphy was done with a 532 nm, 2 ns pulse length, frequency-doubled Nd:YAG laser to provide 12 frames of shadowgraphy spaced 10 ns apart to observe the developing implosion (Yager-Elorriaga et al., 2016).

![Image of shadowgraphy](image)

**Figure 1.5:** An image created using shadowgraphy. The arrows indicate the location of the standing planes. We observe the x-z plane and the development of plasma between the two planes of standing wires.

One of the major challenges in achieving ICF is in maintaining plasma stability (Haines et al., 2000). Plasmas are subject to magnetohydrodynamic (MHD) instabilities that interfere with the ability to heat and compress fuel. By studying these instabilities, scientists can learn how to mitigate them. One of the most common instabilities is the magneto Rayleigh-Taylor (MRT) instability. The Rayleigh-Taylor instability describes the boundary interaction between fluids of different densities, much like interactions between oil and water (Figure 1.6). The MRT instability occurs when the magnetic field is considered a light fluid supporting the heavier plasma. Small perturbations result from random thermal fluctuations and the drift velocity of the plasma causes them to grow.
Using shadowgraphy, the MRT can be observed and studied in DPWA Z-pinches.

**Figure 1.6:** An example of the Rayleigh-Taylor instability resulting from a dense dyed fluid placed on top of less dense water. The dye penetrates through in a plume that is characteristic of the Rayleigh-Taylor instability.

The Wire Ablation Dynamics Model (WADM) is used to simulate wire array Z-pinches (Esaulov et al., 2012). One of the more important features is its ability to generate a contour map of mass density which works well with shadowgraphy to describe implosion dynamics. The WADM will be discussed in further detail in the next chapter.

Now that the framework has been described, the focus of this thesis can be fully understood. Using multi-frame shadowgraphy and the WADM, uniform Al and mixed Al/W DPWAs on the MAIZE LTD and Zebra generators can be analyzed and used to understand implosion differences of PWAs between the two architectures.
2. The Wire Ablation Dynamics Model

MHD codes offer the most exact modeling of dense wire array plasmas, but typical wire arrays use small units (micrometer diameter wires) and relatively large regions (centimeter scale loads) and require a lot of time and computing power to simulate (Yu et al., 2008). The Wire Ablation Dynamics Model (WADM) is used to simulate ablation and implosion of wire array Z-pinches with varying geometries and materials, typically simulating an experiment in under a minute on the average personal computer. The speed of the WADM makes WADM ideal for designing optimized wire array Z-pinch experiments when considering a large range of parameters (Esaulov et al., 2012). This section will highlight the methods used by the WADM and the information that the model provides.

The WADM quantizes wires and their ablated mass as thin, current-carrying filaments. Given \( N \) current filaments \( (n = 1, 2, \ldots, N) \) in a complex plane with coordinates

\[
z_n = x_n + iy_n
\]

We have that the acceleration of the \( n \)th filament is defined by

\[
\frac{d^2 z_n}{dt^2} = \frac{F_n}{\mu_n}
\]

where \( \mu_n \) is the mass per unit length of the \( n \)th filament and the Lorentz Force on the \( n \)th filament, \( F_n \), is given by

\[
F_n = -\frac{\mu_0}{2\pi} \sum_{k=1, k\neq n}^{N} I_k \left[ \frac{z_n - z_k}{|z_n - z_k|^2} - \frac{a^2 z_k - |z_k|^2 z_n}{|a^2 - z_n \bar{z}_k|^2} \right]
\]

Where \( I_n \) is the current through the \( n \)th filament, \( a \) is the radius of an assumed cylindrical return current can, and the overbar represents a complex conjugate. This equation
accounts for the Lorentz Force contributions by all other wire filaments (first term in bracket) and the return currents (second term in bracket). It has been shown that a model of the inductive current partition provides the most accurate representation and agrees well with experimental data (Esaulov et al., 2008). Using this model, the current partition through the filaments can be found by solving $N$ linear equations

$$
I_n \ln \left( \frac{a^2 - |z_n|^2}{ar_f} \right) + \sum_{k=1 \atop k \neq n}^{N} I_k \ln \left( \frac{|a^2 - z_n z_k|}{a|z_n - z_k|} \right) = \frac{2\pi \Lambda}{\mu_0}, \tag{4}
$$

Note that $r_f$ is the effective filament radius and $\Lambda$ is the magnetic flux per unit length that comes from self and mutual inductance of the filaments. In the above equation, $\Lambda$ also represents the $(N + 1)$th unknown in the system of $N$ equations. Therefore, we must add the current normalization equation

$$
\sum_{n=1}^{N} I_n = I \tag{5}
$$

with $I$ being the total current through the array. From here the load inductance $L$ can be calculated from

$$
l_z \Lambda = LI \tag{6}
$$

where $l_z$ is the length of the wire array between the anode and cathode. It is also important to mention that in order to approximate thin wires, (Esaulov et al., 2006) the following must be true:

$$
r_f \ll \min\{|a - z_k|, |z_n - z_k|; k \neq n\} \tag{7}
$$

Now that the dynamics of the wire filaments have been described, the focus falls on mass and momentum redistribution. Initially, each standing wire is treated as its own
current filament. As plasma ablation occurs, the existing filaments will split into new, smaller filaments. One of the wires will be the continually ablating standing wire and the other represents ablated plasma that is free to move within the magnetic field of the array. To model this, consider M initial standing wires \((m = 1,2,\ldots,M)\) and introduce a new index \(j\) to represent the ablated filaments from each wire. These new filaments are created at the same time for each standing wire at time \(t_j\) with time intervals \(\Delta t\) such that

\[ t_j = j\Delta t. \quad j = 1,2,\ldots,J. \]  

To keep track of the filaments, each is assigned \(m\) and \(j\) indices so that \(mj\) represents the \(j\)th ablated filament from the \(m\)th standing wire and \(m0\) is the \(m\)th standing wire itself. Thus we can replace \(n\) with \(mj\) such that \(N = MJ\) in previous summations. We then assume that the mass ablation rate per unit wire length is

\[ \frac{d\mu_{m0}}{dt} = -G_m[I_{m0}]^\alpha, \]  

where \(I_{m0}\) is the current through the \(m\)th standing wire, \(G_m\) is the material ablation rate coefficient, \(\alpha\) is a configuration dependent ablation rate, and \(\mu_{m0}\) is the mass per unit length of the wire. For a low number of wires \((M \leq 24)\) in a planar wire array for 1-1.7 MA currents, it has been determined that \(\alpha = 2\) agrees well with experimental data (Esaulov et al., 2009; Williamson et al., 2009 & 2010; Kantsyrev et al., 2009). This suggests that the wire ablation rate is proportional to the power of Ohmic/Joule heating

\[ P = [I_{m0}]^2R \]  

where \(R\) represents resistance. It is also interesting to note that for larger arrays at higher currents, values between \(\alpha = 1.4 - 1.8\) are more accurate (Alexandrov et al., 2002; Sasorov et al., 2008).
Because the WADM is modeled as a discrete time dynamical system, it is assumed that mass ablates discretely from the standing wires in the following manner.

\[
\mu_m(t) = \begin{cases} 
  \mu_m(0), & 0 \leq t < t_1 \\
  \mu_m(0) - \sum_{n=1}^{j} \mu_{mn}, & t_j \leq t < t_{j+1}
\end{cases}
\]  

(11)

\[
\mu_m(0)
\]
represents the initial mass per unit length of the \( m \)th wire and the specific mass, \( \mu_m \), of new current filaments is adapted from equation 9 to yield

\[
\mu_n = G_m \int_{t_{j-1}}^{t_j} [l_n(t)]^a dt
\]

(12)

Using equations 11 and 12, we can define the transfer of mass from the standing wires to the ablated plasma. From equation 12, it is seen that a larger current leads to a greater mass of ablated filaments with a dependence on the material ablation rate coefficient. It is also useful to note that the specific mass of new filaments cannot exceed the remaining mass of the standing wire. If this were to occur, then the ablation of the \( m \)th wire would be complete at that time step. This corresponds well with experiments performed in (Lebedev et al., 2001 & 2002) which show that standing wires do not move until ablation is complete on university scale generators. This was later confirmed on the 20 MA Z-machine at SNL (Cuneo et al., 2005 & 2006). To simulate this, the WADM requires that

\[
\frac{dz_m}{dt} = 0
\]

(13)

while the mass is still ablating. Afterwards, the remaining mass of the standing wire is treated as an ablated plasma filament. When two filaments collide, they are treated as an inelastic collision, combining into a single filament with a mass and momentum which results from the component filaments.
With the description of the WADM as above, simulations require only a few input parameters: geometry, number of wires, mass per unit length, the material ablation rate coefficient, and a current pulse. During operation of the WADM certain parameters are recorded at each time step so that the data can be analyzed afterwards. These parameters can be used to create contour maps of current density, magnetic field lines, or even implosion velocity (Safronova et al., 2016b). For the purposes of this thesis, useful data include maps of mass density for comparison with shadowgraphy (Figure 2.1).

**Figure 2.1:** A map of mass density created using WADM. We observe mass density filaments on the x-y plane where white/red represents a lower mass and blue represents a heavier mass. The arrows indicate the location of the standing wire planes, which are coming out of the board along the z-axis.
3. Analysis of DPWA Implosion Dynamics

This chapter will detail the relevant experiments performed and provide insight through analysis of the collected data. For the purposes of this thesis relevant experiments are DPWA Z-pinches composed either entirely of aluminum (Al) or Al mixed with tungsten (W) that were recently performed on the Zebra Generator at UNR and the MAIZE LTD Generator at UM. Implosion dynamics will be analyzed with the use of multi-frame shadowgraphy and WADM modeling. Using these methods, the MAIZE LTD Generator will be compared and contrasted with the Marx-driven Zebra Generator. Table 3.1 lists all relevant experiments and their important characteristics and figure 3.1 provides an image of the experimental setup.

<table>
<thead>
<tr>
<th>Shot #</th>
<th>Material</th>
<th>D (µm)</th>
<th># of wires</th>
<th>IWG (mm)</th>
<th>IPG (mm)</th>
<th>Φ</th>
<th>Mass (µg/cm)</th>
<th>Current (kA)</th>
<th>Risetime (ns)</th>
<th>Implosion time (ns)</th>
<th>Shadowgraphy time (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1256</td>
<td>Al/W</td>
<td>12.7/5</td>
<td>8/8</td>
<td>1</td>
<td>6</td>
<td>1.17</td>
<td>59</td>
<td>520</td>
<td>215</td>
<td>237</td>
<td>86-196</td>
</tr>
<tr>
<td>1257</td>
<td>Al</td>
<td>12.7</td>
<td>8/8</td>
<td>0.7</td>
<td>6</td>
<td>0.82</td>
<td>55</td>
<td>510</td>
<td>215</td>
<td>257</td>
<td>79-189</td>
</tr>
<tr>
<td>1258</td>
<td>Al</td>
<td>12.7</td>
<td>8/8</td>
<td>1</td>
<td>6</td>
<td>1.17</td>
<td>55</td>
<td>556</td>
<td>215</td>
<td>250</td>
<td>76-186</td>
</tr>
<tr>
<td>1789</td>
<td>Al</td>
<td>10</td>
<td>10/10</td>
<td>0.7</td>
<td>6</td>
<td>1.05</td>
<td>42</td>
<td>995</td>
<td>98</td>
<td>86</td>
<td>54</td>
</tr>
<tr>
<td>4601</td>
<td>Al/W</td>
<td>12.7/5</td>
<td>8/8</td>
<td>1</td>
<td>6</td>
<td>1.17</td>
<td>59</td>
<td>890</td>
<td>100</td>
<td>116</td>
<td>71,78</td>
</tr>
</tbody>
</table>

Table 3.1: Relevant Al DPWAs imploded on UNR’s Zebra Generator and UM’s MAIZE LTD.

To observe the differences between machines it is best to focus on experiments with similar characteristics, specifically mass and aspect ratio, Φ, which is defined as the array width divided by the interplanar gap (Williamson et al., 2010).
Figure 3.1: A photograph taken of a DPWA load before an experiment. For both the MAIZE LTD generator and the Zebra generator, the anode is at the top and the cathode is at the bottom. The wires used in these experiments had a 5-12.7 μm diameter. For comparison, very thin human hair is about 40 μm in diameter.

3.1 Uniform Al DPWAs

Al has been shown to be an efficient ablator that is relatively easy to implode, making Al an ideal material for exploratory experiments (Esaulov et al., 2012). DPWAs have been shown to be efficient radiators (Kantsyrev et al., 2008) and provide a window for shadowgraphy. Al DPWAs make ideal candidates for studying the differences in implosion dynamics between the devices in question. In addition, the symmetry of uniform DPWAs allows for easier identification of instabilities and irregularities. Consider Zebra 1789 (Figures 3.2 & 3.3) and MAIZE 1257 (Figures 3.4 & 3.5) and 1258 (Figures 3.6 & 3.7). These experiments have intermediate aspect ratios near 1 and similar masses, so they should have similar implosion dynamics. The two machines respond
differently to the high inductance DPWA loads such that Zebra typically has 1-MA current at a 100 ns risetime and MAIZE has about half the peak current in twice the time (Safronova et al., 2016a). The difference in current is likely due to the low-impedance of the LTD (Steiner et al., 2016) which may introduce noticeably different implosion dynamics.

**Figure 3.2:** Experimental signals for Zebra shot 1789: current (thick red), XRD (thin red), and shadowgraphy timing (dot). The shadowgraphy occurs at 54 ns, about two-thirds of the way before the implosion shown by the XRD peak at 86 ns.
Figure 3.3: Shadowgraphy and WADM modeling of Zebra shot 1789 at 54 ns. Observe the structures shown by the arrows. There is an accumulation of mass that widens the appearance of the standing wires and two standing shocks (red) that have partially merged in the center (blue). WADM models this phenomenon well.

Shadowgraphy and WADM modeling in Figure 3.3 show that Zebra shot 1789 (Φ=1.05) is a prototypical intermediate aspect ratio shot where mass accumulates off axis before developing an axial precursor (Williamson et al., 2010). These dynamics occur because the global magnetic field is able to divide the planes. The shadowgraphy is also quite symmetric along the anode-cathode gap and seems free of any significant instabilities. We expect experiments on MAIZE to have similar implosion dynamics.
Figure 3.4: Experimental signals for MAIZE shot 1257: Current (blue), 1.4 keV PCD (red and yellow). The PCD estimates implosion time to be 257 ns.

Figure 3.5: Shadowgraphy and WADM modeling of MAIZE shot 1257 at 99 and 139 ns. The 139 ns frame occurs about two thirds into the current trace before the implosion. In
each frame there is a developing precursor that accumulates mass and grows more unstable as time progresses. WADM simulations agree well with the shadowgraphy.

Contrast Zebra 1789 with MAIZE shot 1257 ($\Phi=0.82$), which has an axial precursor in the implosion dynamics shown in Figure 3.5, but no off axis developments. According to Williamson’s 2010 paper, these dynamics are typical of high aspect ratio DPWAs because the global magnetic field is unable to separate the planes. Note too that the plasma column is asymmetric along the anode-cathode gap and there is significant MRT instability. To verify these dynamics, consider MAIZE shot 1258 ($\Phi=1.17$), which has very similar implosion dynamics to MAIZE shot 1257, except shadowgraphy in Figure 3.7 appears to be much more symmetric. Both of the MAIZE shots are modeled well by WADM, suggesting that the program could be used for future MAIZE experiments. The uniform Al DPWA experiments on the LTD are also more characteristic of high aspect ratio shots because the axial precursors form without any off axis accumulation, suggesting that the global magnetic field is unable to separate the planes (Williamson et al., 2010). The global magnetic field does not divide the array because the current is so much lower compared to the 1 MA Zebra generator and so the magnetic field is accordingly weaker (Chen, 1984; Safronova et al., 2016a).
Figure 3.6: Experimental signals for MAIZE shot 1258: Current (blue), 2.4 keV PCD (red and yellow). The PCD peak estimates implosion at 250 ns.

Figure 3.7: Shadowgraphy and WADM modeling of MAIZE shot 1258 at 76 and 96 ns. At 76 ns there is no visible precursor, but by 96 ns an obvious central column has formed. This development is clearly visible in the WADM mass density plot as well.
3.2 Al/W Mixed DPWAs

Mixed DPWAs introduce a material asymmetry that can be observed in the implosion dynamics because each array is comprised of a different material. Therefore, they allow for a more complete comparison of implosion dynamics between the two pulsed power generators. Zebra shot 4601 and MAIZE shot 1256 have identical initial parameters and should offer a reliable juxtaposition.

![Figure 3.8: Experimental signals for Zebra shot 4601: current (red), XRD (blue), shadowgraphy timing (dot). The XRD peak suggests an implosion time of 116 ns.](image)
Figure 3.9: WADM modeling (top) and shadowgraphy (bottom) of Zebra shot 4601. Left: 71 ns. Right: 78 ns. Between 71 and 78 ns, there is a developing W standing shock. WADM simulates this well as there is an accumulation of mass in the area indicated by the red arrow. WADM also shows another wave of Al mass moving from the wires towards the standing shock as indicated by the blue arrow.

Figure 3.9 shows the implosion dynamics of Zebra 4601, ablated W forms a standing shock that accumulates mass while ablated Al coalesces into a wave around the standing wires. MAIZE shot 1256 has similar characteristics around the same time relative to implosion (Figure 3.10) which suggest that the two machines are analogous. The few differences being that MAIZE 1256 seems less symmetric along the anode-
cathode gap and is vulnerable to large MRT instabilities. This may be a result of lower current and longer risetime on the LTD.

Figure 3.10: Experimental signals for MAIZE shot 1256: current (blue), 2.4 keV PCD (red and yellow). The PCD peak suggests an implosion time of 237 ns.
**Figure 3.11:** Shadowgraphy and WADM modeling of MAIZE shot 1256 at 106 and 126 ns. We see a W standing shock develop and a wave of accumulated Al mass building in the shadowgraphy and these results are verified by WADM modeling.
4. Conclusion

The focus of this thesis was to investigate the implosion dynamics of Al and W DPWA Z-pinches on the LTD generator and determine differences when compared to traditional Marx-driven generators. Through collaborative experiments performed on the MAIZE LTD at the University of Michigan and similar experiments done at UNR’s Zebra generator, the diagnostic tools of shadowgraphy, X-ray diode signals, and the WADM made this analysis possible.

It should be noted that the LTD had a typical current near 500-kA and 200-ns, about half the current and twice the risetime when compared to the 1-MA 100-ns Zebra generator. The implosion dynamics of intermediate aspect ratio Al DPWAs on MAIZE are characteristic of higher aspect ratio DPWAs as described previously on Zebra (Williamson et al. 2010). MAIZE also had greater axial asymmetry and was more vulnerable to MRT instabilities. The difference between the two devices is likely attributed to the differing current traces in that a lower current yields a lower magnetic field. A weaker magnetic field can amplify the effects of the MRT (Chen, 1984) and reduce magnetic influences on implosion dynamics.

In order to better determine any differences between PWA Z-pinches on LTD and Marx-driven generators, it would be valuable to have comparable current traces. During the experimental campaign on MAIZE, the capacitor voltage was 70 kV out of a possible 100 kV. Increasing the voltage allows for a greater current in accordance with Ohm’s Law (Griffiths, 1989). However, the decreased voltage was implemented to prevent possible damage to the LTD insulator, and it may take some time to safely adjust the voltage to ideal conditions. However, if differences persist once experiments are
performed at similar currents, then the differences could be attributed to some combination of the low impedance of the LTD and high inductance of PWA experiments.

Overall, the experiments performed and analyzed in this thesis represent a small step towards an increased understanding of PWA Z-pinches on LTD generators. Research done on MAIZE provides valuable insight towards understanding future experiments on the Z 300 and Z 800 LTD generators at SNL. If DPWAs are shown to perform well on the large scale LTDs, then hohlraum experiments can be pursued to achieve ICF (Jones et al., 2010; Kantsyrev et al., 2014). Regardless, LTD technology represents the new era of Z-pinch research and university scale experiments are leading the way.
References


