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# Alignment of Targets and Flyers for Plate Impact Experiments

by David R. Ayers, Steven T. Davis, and Scott A. Turnage

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# Alignment of Targets and Flyers for Plate Impact Experiments

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## REPORT DOCUMENTATION PAGE

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| <b>14. ABSTRACT</b><br>Plate impact experiments require that the two interacting surfaces, target and flyer, must be held parallel to very tight tolerances. Using a low-power (<5 mW) laser, flat mirrors, and some simple geometry, the following alignment method is a fast, simple, and reliable means of achieving alignments within the tolerance of less than 5 mrad. The adoption of these techniques has led to a sharp decrease in time needed for alignment and an improvement of the measured tilt compared with previous methods. |                                    |                                             |                                   |                                                                    |                                 |
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## **1. Problem Statement**

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The goal of impact shock experiments is to simplify loading conditions to isolate material response to a single dimension. For the assumption of one-dimensional shock to hold, the experiment must be prepared very carefully. Targets and flyers must hold to certain tight dimensional tolerances in flatness and parallelism at time of impact to ensure the shock remains one-dimensional and steady throughout the entire thickness. Misalignment of the surfaces can introduce transverse loading conditions that may interfere with the desired one-dimensional loading, particularly upon release. The more complex loading state created by transverse loading means the effects of the intended shock are not adequately isolated to a singular dimension, violating the critical uniaxial strain assumption in the analysis. Poor tilt may also lead to inaccurate wave speed and particle velocity measurements, creating significant error in the results.

The typical goal for the alignment of a normal plate impact is to achieve a deviation of less than 5 mrad for measurements to be considered valid. The ideal alignment for oblique impact experiments is a much tighter window at less than 0.5 mrad of misalignment along the direction of imparted transverse motion. This more stringent requirement stems from additional transverse velocity from any misalignment in the direction of the measured shear wave that results from release of the normal shock.<sup>1,2</sup>

## **2. Normal Plate Impact Alignment**

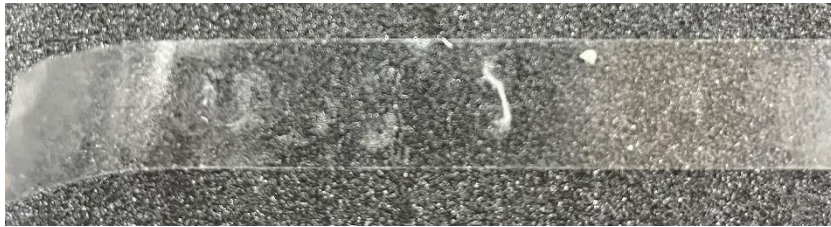
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Following the preparation of the target and flyer, the sabot-mounted flyer is loaded into the keyed barrel of the light gas gun. As the flyer is often not polished to a mirrored finish, the first step of the alignment process is to attach a flat mirror to the flyer surface using a double-sided adhesive tape (Figure 1).



**Figure 1. Loaded sabot with alignment mirror taped to front face.**

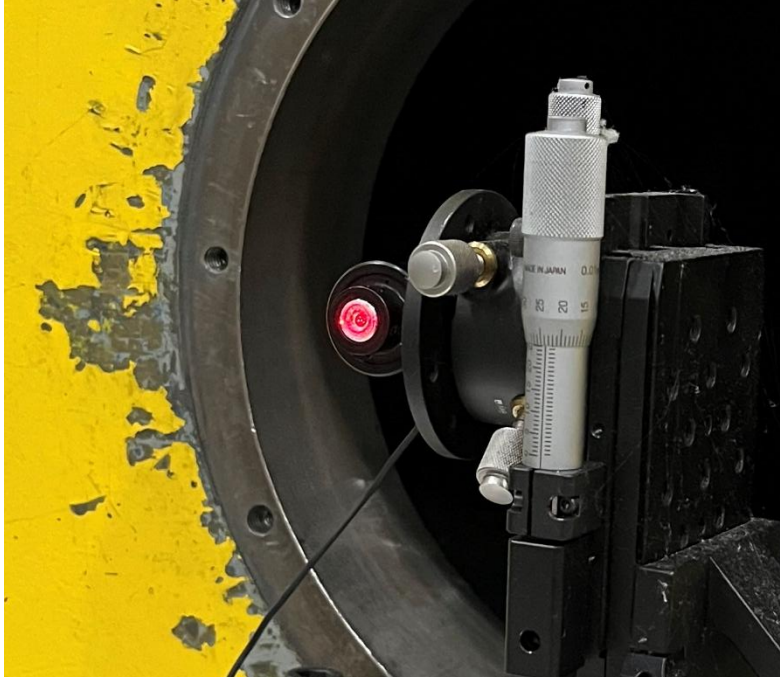
It is important to ensure that the surface of the flyer and mirror as well as the adhesive tape itself are free of debris and the tape is properly applied. The tape thickness is approximately  $75 \pm 5 \mu\text{m}$  and consistent across the span of the mirror barring contamination. Even small debris such as lint, hair, or dirt (Figure 2) can cause significant errors during alignment.



**Figure 2. A small piece of lint, a common contaminant on the range caught on double-sided tape.**

The tape should be placed as a continuous horizontal strip across the center of the back surface of the mirror to provide adequate support. The tape must support the center of the mirror, as placement of the tape across only the top edge of the mirror may allow it to sag until the bottom edge contacts the flyer, resulting in approximately 3 mrad of bias across the vertical axis using a 25-mm round mirror. Placement across the bottom edge places the tape in tension and may result in even greater errors due to tape debonding.

Once the mirror is properly in position on the flyer, a visible wavelength laser ( $<5 \text{ mW}$ ) is projected onto it to begin the second step of the alignment process (Figure 3). Notice the fine tuning available for positioning the spot relative to the flyer. The position and rotation of the laser are adjusted until the beam reflects back onto the laser emission source.



**Figure 3. Red alignment laser being reflected onto the source from the alignment mirror shown in Figure 1.**

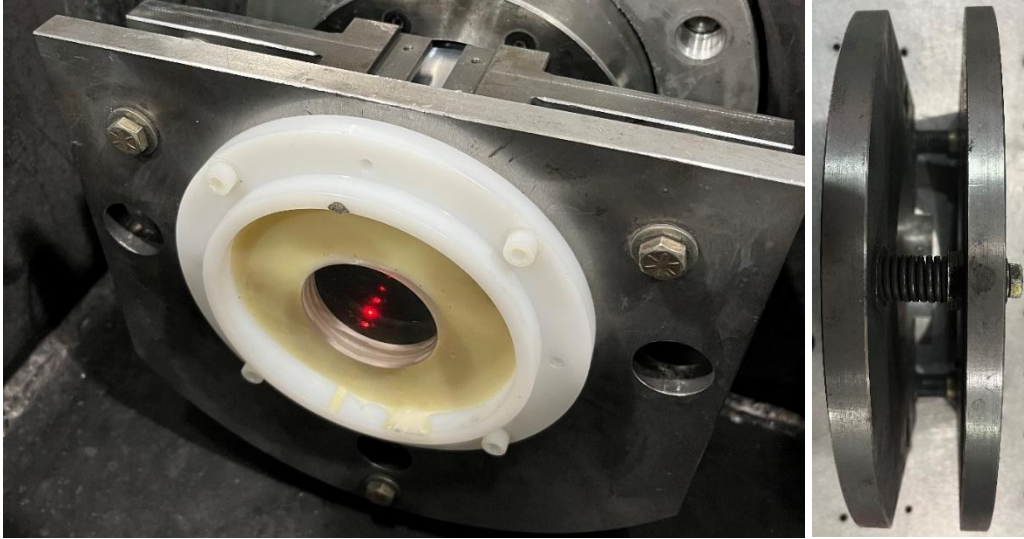
For a given laser displacement from the flyer ( $D$ ), the misalignment ( $\beta$ ) can be determined by the displacement of the reflected beam spot from the incident beam at the laser source ( $d$ ) using

$$\beta = \tan^{-1} \frac{d}{2D} \quad (1)$$

The angle of the reflected beam to the surface normal is equal to the angle of the incident beam to the normal, such that the angle of the surface normal is half that of the reflected beam requiring a correction factor of 2 in the denominator to determine the actual alignment of the surface from the displacement of the return beam spot. As the angles are sufficiently small, the small angle approximation can be used to further reduce this equation to simply

$$\beta = \frac{d}{2D} \quad (2)$$

With the laser aligned normal to the flyer mirror and left in a fixed position, the third step of the alignment process can begin. A flat mirror potted to a target ring is put in place of the target on the steel target mount structure (Figure 4).



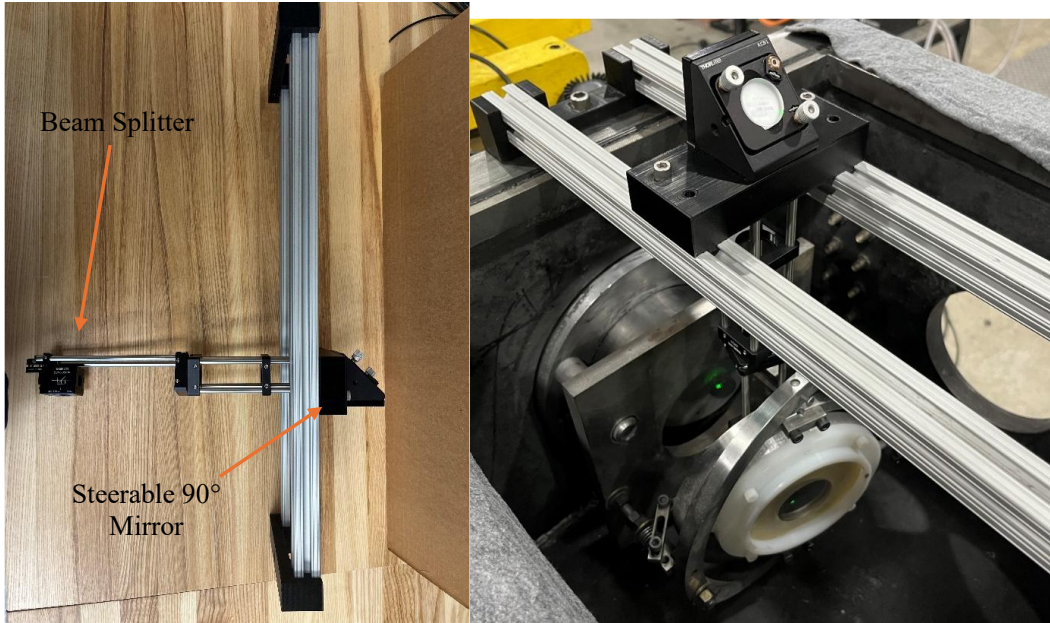
**Figure 4.** Potted alignment mirror in position on the target mount (left). Bolt and spring mechanism for adjusting target orientation (right).

The structure consists of two parallel steel plates separated by a set of three 0.5-inch bolts tensioned by compression springs. By adjusting the three hex bolts shown in Figure 4, the return beam from the potted mirror can be placed back on the emission source with the misalignment  $\beta$  calculated using Equations 1 and 2.

### **3. Oblique Plate Impact Alignment**

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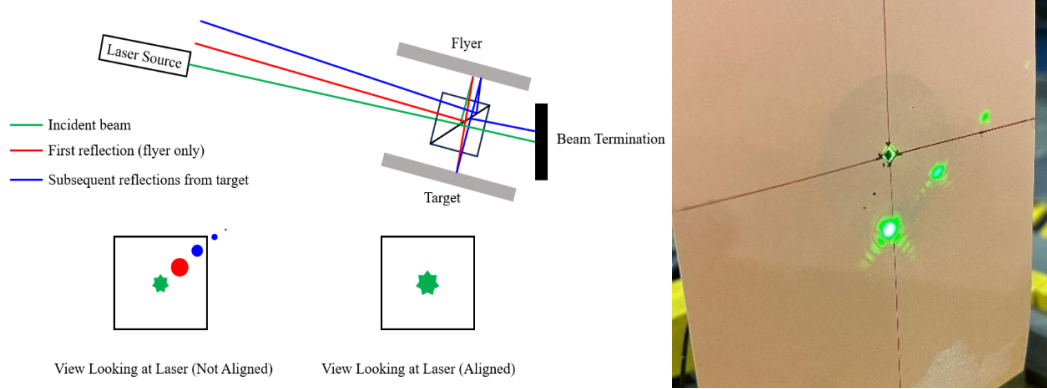
The classical method for aligning oblique plate impacts<sup>2</sup> is highly effective but time-consuming and nontrivial. The method described here is a modification of the classical method to simplify the procedure without sacrificing alignment results. The same basic principles of the normal plate impact setup can be used to align targets for the oblique plate impact setup but, due to the geometry of the target chamber, the beam must be directed in differently. A mirror is placed on the angled flyer in much the same way as a normal plate impact. A fixture is then placed over the target chamber, which holds a mirror, a beam splitter, and a series of positioning stages (Figure 5).



**Figure 5.** Alignment mechanism (left) for oblique impact alignment directing a green laser fired from above the target chamber onto the flyer and potted alignment mirrors (right).

The laser is then fired from near the breach of the gas gun and, using the positioning stages on the laser and mirror structure, the beam is redirected back onto the emission source. The potted mirror is then mounted to the oblique impact mount structure. This structure uses three bolts paired with strong compression springs similar to the normal impact structure for fine positioning of the target but also includes a 15° swivel that can be used for crude adjustment of the target angle. This method can also be used for normal plate impact, but looser tolerances on normal alignment usually do not merit the added complication.

The beam that is aligned to the flyer passes from the flyer through the beam splitter onto the potted mirror. The mount is then adjusted until the return from the potted mirror passes back through the beam splitter onto the flyer then back to the laser source. Because the laser light is reflected multiple times between the flyer and target, multiple spots are expected to be visible in a case of misalignment (Figure 6). As perfect alignment is approached, those spots will fall on top of each other.



**Figure 6.** Schematic of oblique plate impact alignment system (left). Photographed return from misaligned target and flyer (right). Return was deliberately moved from the emission sources to better illustrate secondary reflections.

The same linear relationship between displacement of the spots  $d$  and the misalignment of the mirrors  $\beta$  exists as in the normal plate impact setup for the first (red) spot shown in Figure 6. For a total path length for the oblique impact setup (2D) of 25 m, the alignment can be calculated at 1 mrad per 25-mm  $d$ .

#### 4. Tilt Verification

During an experiment, target and flyer alignment are verified by ionization pins at the time of impact. The pins are coaxial conductors lapped flush with the target impact face. Pins are placed within a circle surrounding the target. A conductive flyer with diameter larger than the circle within which the pins are placed will short the pins upon impact. The short results in a voltage spike, the timing of which is measured on an oscilloscope. The difference between the timings of the pin closures ( $\Delta t$ ) combined with the spacing between the pins ( $h$ ) and the impact velocity ( $v_i$ ) gives a measure of the actual tilt  $\beta$  during an experiment, classically obtained by

$$\beta = \sin^{-1} \frac{v_i \Delta t}{h}. \quad (3)$$

Tilt is measured between each of the pins placed around the target, and true tilt is taken as the maximum measured tilt.

#### 5. Introduced Error and Future Improvements

In principle, the orientation method of superimposing a reflected beam onto the initial source as described above simplifies alignment to within less than 0.1 mrad. In practice, however, the measurements are more often in the range of 1 to 2 mrad when measuring tilt via ionization pins. Several factors, some of which have already been discussed in this work, contribute to this difference in measurement.

The largest contributor is thought to be in the tape used to attach the mirror to the flyer surface. As mentioned previously, even small contaminants such as lint (Figure 2) caught in the tape at the wrong spot can produce a 1- to 2-mrad misalignment of the mirror to the flyer surface. Likewise, the placement of the tape at an inappropriate spot can cause the mirror to sag more dramatically, causing potentially large misalignments—particularly in the vertical axis. Even variations in the film thickness of the tape can cause small errors to occur. The ideal solution to solve the issue of mirror sag resulting from the use of tape is to polish the flyer to a mirror finish such that the beam can be reflected directly from the surface. While this is an optimal solution, it may not always be possible due to either burdensome increases in sample preparation time or material properties that prevent such a finish.

Another major error source is the use of the potted mirror for the alignment of the target. While the mirror has been potted on a flat plate in the same manner as the target, there is some possibility of small differences being introduced to the target during the lapping of the tilt pins or debris being introduced between surfaces of the target mount and mirror or target. Polishing the target impact face and directly aligning the impact faces of the flyer and target using the oblique plate impact alignment method can mitigate this error if time and material allow.

The third possible contributor to difference in measurements may lie in error of the tilt pin measurement itself. Care is taken in placement of the tilt pins and, if possible, the pins are lapped flush to the target surface. However, due to the nature of some target materials, lapping the entire surface to perfect flatness may be infeasible. Pins that are glued in place may also shift slightly when cables are attached. A protrusion of a single pin by 30  $\mu\text{m}$  for typical center-to-center pin spacing of 30 mm for a 30-mm-diameter target sample can produce a measurement error of 1 mrad. Other possible contributions to differing alignment measurements may come in the form of distortion of the flyer during acceleration, rotation of the flyer from its position during initial alignment due to loose keyway tolerance, and gas blowby causing target shift, particularly at lower flyer velocities.

## **6. Conclusion**

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The procedures documented herein provide a fast, robust means for achieving alignment of target and flyer for plate impact experiments. These methods have been proven effective over hundreds of experiments, with speed and reliability improving incrementally as inefficiencies and sources of error have been discovered and corrected. Further improvements to the process continue with an emphasis on reducing error without significant increases to setup time.

## 7. References

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2. Kumar P, Clifton RJ. Optical alignment of impact faces for plate impact experiments. *J Appl Phys.* 1977;48:1366–1367.

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