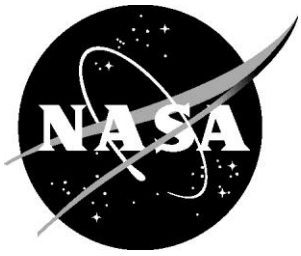
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Experimental Results for Temporally Overlapping Pulses from Quantel EverGreen 200 Laser

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November 2013

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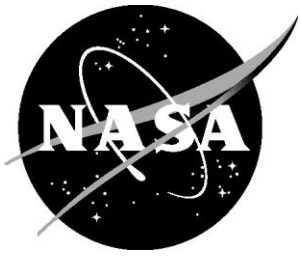
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Acknowledgments

The author would like to thank Mr. Luther Jenkins and Mr. Scott Bartram for many helpful discussions during this work. In addition, the author would like to thank Mr. Scott Bartram and Mr. Joseph Lee for the use of their equipment to acquire the waveforms and measure the laser beam profiles. This work was done in support of the Subsonic Rotary Wing Project under the Fundamental Aeronautics Program.

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Abstract

This report wiill detail the experimental results and observations obtained while investigating the feasibility of temporally overlapping the two laser pulses from a Quantel EverGreen 200 Laser. This laser was specifically designed for Particle Imaging Velocimetry (PIV) applications and operate by emitting two 532 nm laser pulses that are seperated by an adjustable finite time (typically on the order of ten to hundreds of microseconds). However, the use of this model laser has found recent application for Pressure Sensitive Paint (PSP) testing, especially for rotorcraft research. For this testing, it is desired to only use one laser pulse. While this is easily done by only firing one of the laser heads, more excitation energy could conceivably be had if both laser heads are fired with zero pulse separation. In addition, recently large field-of-view PIV measurements have become possible and need ever increasing laser power to illuminate the larger areas. For this work, two different methods of timing the laser are investigated using both a traditional power meter to monitor laser power as well as a fast photodiode to determine pulse separation. The results are presented here as well as some simple implications for PIV experiments using these methods.

Introduction

A tremendous effort to improve measurement capabilities in aerodynamic facilities has recently been undertaken by the NASA Aeronautics Research Mission Directorate (ARMD) and more specifically by the Subsonic Rotary Wing (SRW) project therein. This push has been to develop methods to make full field measurements of the flow (both off-body and on-body) under highly dynamic conditions typically experienced by rotorcraft. The goal of these technologies is to provide experimental results that can be used to develop as well as validate new prediction capabilities, especially for the next generation of rotorcraft vehicles. Two of the experimental techniques that have been under development for this project include large field-of-view Particle Imaging Velocimetry (PIV)[1] and high frequency Pressure Sensitive Paint (PSP).[2] Both techniques require the use of high powered lasers for illumination, whether it is to generate a light sheet for particle tracking (as in PIV) or to excite luminescent molecules to measure oxygen concentration (as in PSP).

One of the lasers that are used for both experiments is the EverGreen 200 laser manufactured by Quantel. The EverGreen 200 laser is a dual pulsed laser specifically designed for PIV applications. The system consists of a single laser head with a single power supply and designed to produce two precisely overlapped beams at 532 nm. Each laser beam is rated at a maximum energy of 200 mJ and using internal timing can produce two laser pulses with 10 μs separation at a rate up to 15 Hz. However, the real power of the system occurs when external timing of the flash lamps and/or Q-switch is used. In this case, the pulse separation can be user-defined to as short as 6 μs and as long as desired. While this is suitable for most PIV applications, its use in PSP as well as in PIV cases where more energy is required (either for greater signal return or larger light sheets), the ability to operate the laser so that the pulses temporally overlap is desired. This report will detail several experiments that were conducted to determine the minimum pulse separation that can be achieved with adequate results.

Experimental

The experimental setup for these measurements is shown in Figure 1. For this work, the EverGreen 200 laser was operated with both laser heads set to full power according to the front panel. A pair of beam splitters was used to pick off a very small portion of the beam that was further attenuated before impinging on a fast Si photodiode (Thorlabs DET210 High Speed Si photo Detector). The DET210 has a specified rise/fall time of 1 ns and the signal from the photodiode was collected using a Tektronix TDS3034 Digital Oscilloscope operating with 300 MHz bandwidth. This oscilloscope signal was digitized and recorded on a computer using the Tektronix WaveStar software program. The power of the laser beam was measured after the first beam splitter using a Coherent FieldMax II Laser Power Meter. To determine the beam profile, the silicon photodiode was replaced with a CCD sensor (Newport LBP-2-USB).

External control of the timing of the laser was accomplished using a Quantum Composer Model 9514 pulse generator. This pulse generator has 4 independent channels that can produce pulses from 10 ns to 1000 s in width at a rate from 0.0002 Hz to 5 MHz. The resolution of the internal rate generator is 10 ± 1.5 ns. For this work, external timing of the components include both flash lamps as well as both Q-switches to give maximum control of the laser timing. Nominal timing of the laser was set according to the specifications provided by Quantel. This includes setting the optimum delay between the flash lamp firing and the Q-switch operation at 138 µs. In practice, this delay can essentially be varied by up to ± 5 µs without significantly decreasing the power at 532 nm.

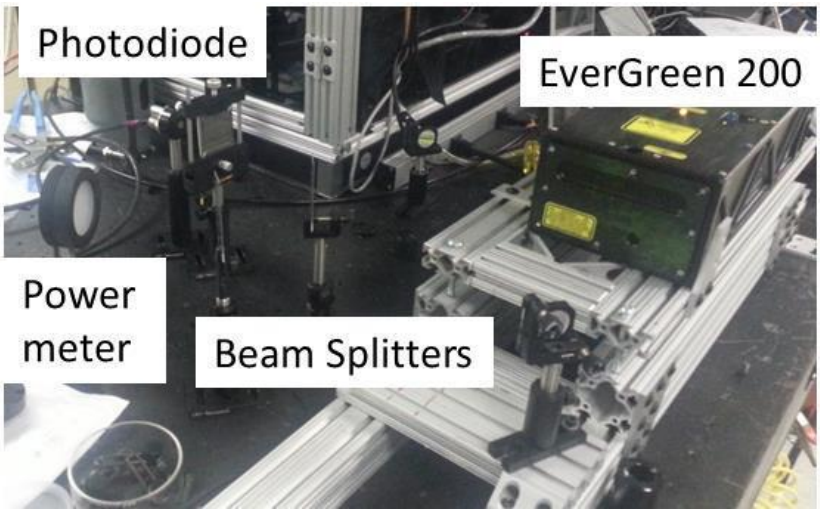


Figure 1. The experimental setup for investigating timing of the laser pulses.

Timing Methods

For this work, three different timing methods were explored:

1. A standard internal timing method was used as a control. In this method, all timing is handled internally by the laser itself. Nominally, the pulse separation is set at 10 µs, though it can be adjusted from 0 µs to 255 µs in 1 µs increments if the serial interface is used.

2. A method has been generated by Quantel for operating the laser with pulses separated by less than 6 µs.

This requires operation in full external mode (external control of both flash lamps and Q-switches). In normal external operation, the laser controller does not have adequate time to validate the external lamp trigger for Laser 1 and still detect the rising edge of the external lamp trigger for Laser 2. The result is that Laser 2 will stop functioning at these short delays. The method provided by Quantel for operating at less than 6 μs is as follows:

a. Set the external delay between Laser 1 lamp trigger (Channel A on the pulse generator) and Laser 2 lamp trigger (Channel C) to 10 μs. This fixed delay will ensure that the laser controller has time to adequately process both external lamp triggers.

b. Add 5 μs from the Q-Switch delay for Laser 1 (Channel B). This means Laser 1 will now be Q-Switched 143 μs after the rising edge of Lamp 1 trigger.

c. Subtract 5 μs from the Q-Switch delay for Laser 2 (Channel D). This means Laser 2 will now be Q-Switched 133 μs after the rising edge of Lamp 2 trigger.

d. Adjust the Q-Switch delays for each laser to achieve the desired delay.

3. A similar method was independently developed for PSP testing. It is similar to the above method except that no delay between the two lamps was used, and the delay between each lamp and its respective Q-Switch was set to 138 μs. The Q-Switch for Laser 2 was then varied to set the delay.

Results and Discussion

Comparison of Timing Methods: The initial timing was simply set to complete internal timing with the laser controller handling all timing events. In this mode, the power meter measured a total laser power of 430 mJ and the photodiode signal showing the two laser pulses separated by 10 μs is shown in Figure 2. An expansion of the photodiode signal for one of the laser pulses is shown in Figure 3. The slight elongation and tailing of the peak is most likely due to some photodiode effects as opposed to an actual feature of the laser beam. Employing the second beam splitter as well as the attenuation plates reduced the light input to the diode enough to minimize these effects. However, even with this present, it should still be possible to resolve the different laser peaks since the minimum resolution that is obtainable with the pulse generator is 10 ns.

To investigate the effects of the first external timing method (the one developed by Quantel), a series photodiode waveforms was collected at various Q-Switch delays. These results are shown in Figure 4. The waveforms are separated for clarity. From this data it is readily apparent that pulses can be generated at peak separations as small as 10 ns. However, an investigation of the photodiode at the shortest possible separation (10 ns) shows that there is some inefficiency in the doubling as evidenced by the lower amplitude of the peak. When the Q-Switch delay is increased above 10 ns, the second pulse is consistently about the same height and area as the first pulse. In addition, the pulse height does not appreciably change when the pulse separation is 0 ns. This implies that either only one laser head is actually firing at these separations, or there is some inefficiency with the doubling process due to an excessive amount of fundamental (1064 nm) energy present. These trends are also evident in the power meter readings. With the pulse separation set to 0 ns, the power meter reading was 200 mJ. When the separation is set to 10 ns, the power increases to 370 mJ and then to more than 400 mJ when the separation is 20 ns or greater.

Similar trends were also seen using the timing method developed for the PSP test. These results are

shown in Figure 5, and show essentially the same behavior. Additionally, the power meter readings are also similar, with essentially only 200 mJ produced with no separation and maximum energy with pulse separation 20 ns or greater. A comparison of the power meter readings for the different pulse separation values are shown in Figure 6 for both methods. According to the data, the maximum power occurs when the separation is ~ 40 ns, although the overall variance from 20 ns to 100 ns is approximately 3%.

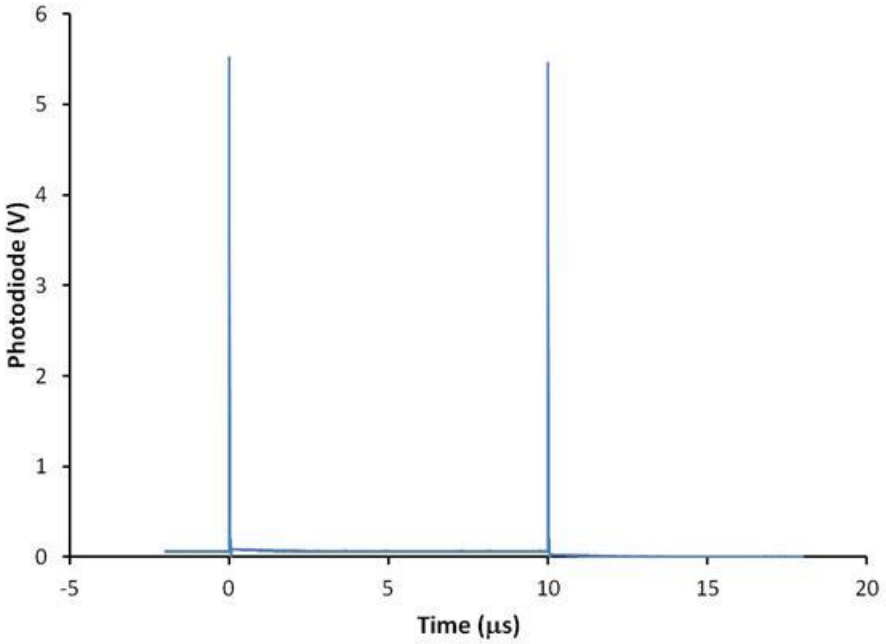


Figure 2. Photodiode response to the EverGreen 200 laser pulses using internal timing of both flash lamps and Q-Switches. A time of 0 μs indicates the trigger of the oscilloscope.

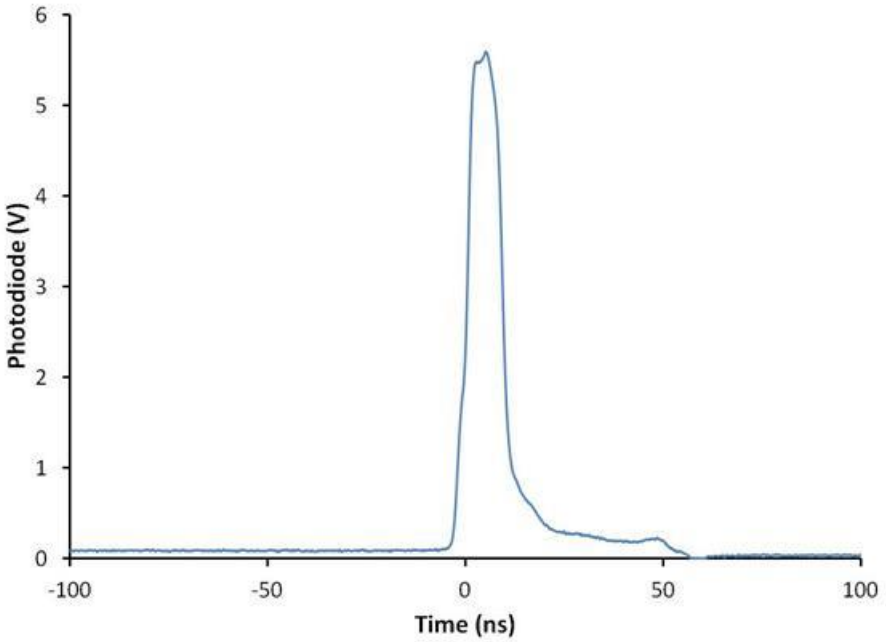


Figure 3. A single laser pulse as measured using the photodiode.

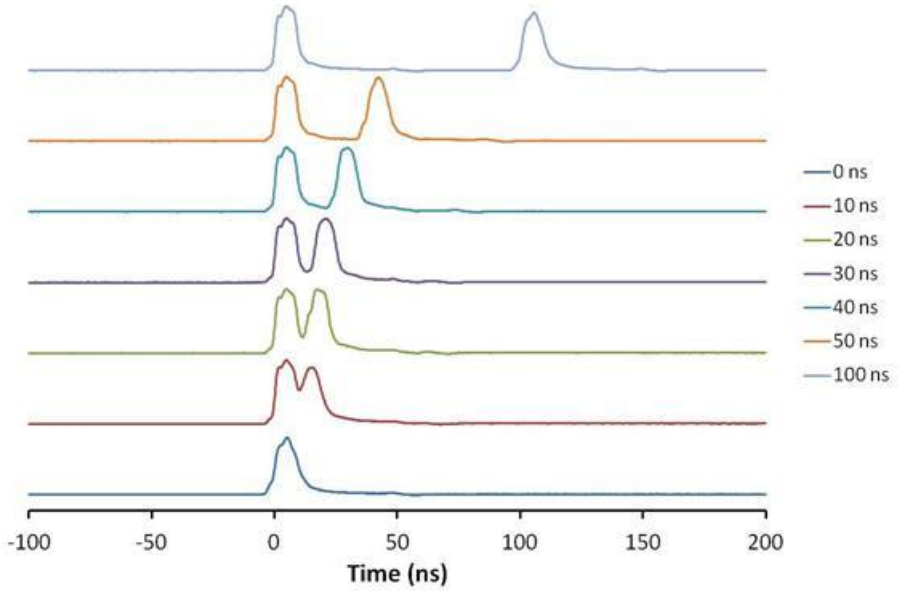


Figure 4. Photodiode waveforms generated by changing the pulse separation using the method developed by Quantel. The waveforms are separated for clarity.

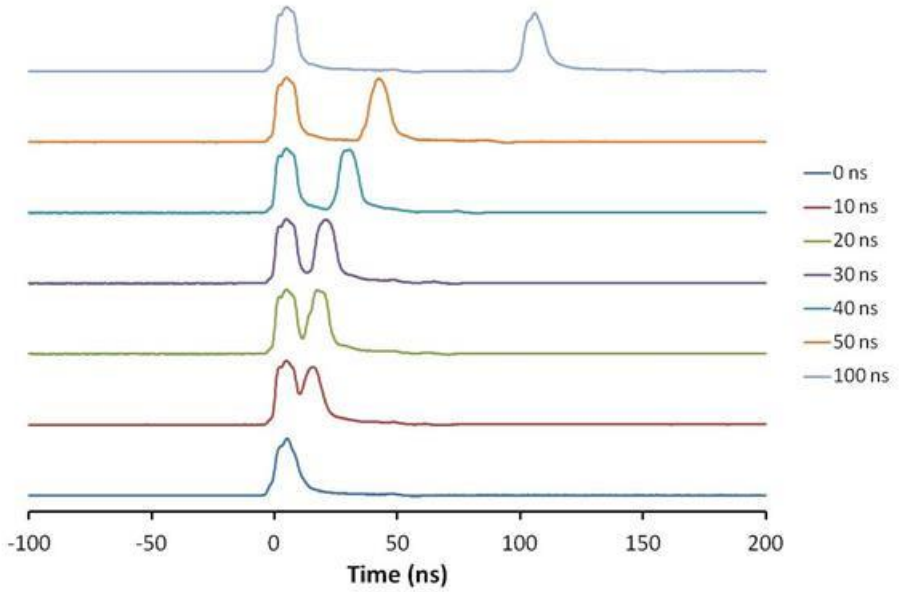


Figure 5. Photodiode waveforms generated by changing the pulse separation using the method developed for the PSP test. The waveforms are separated for clarity.

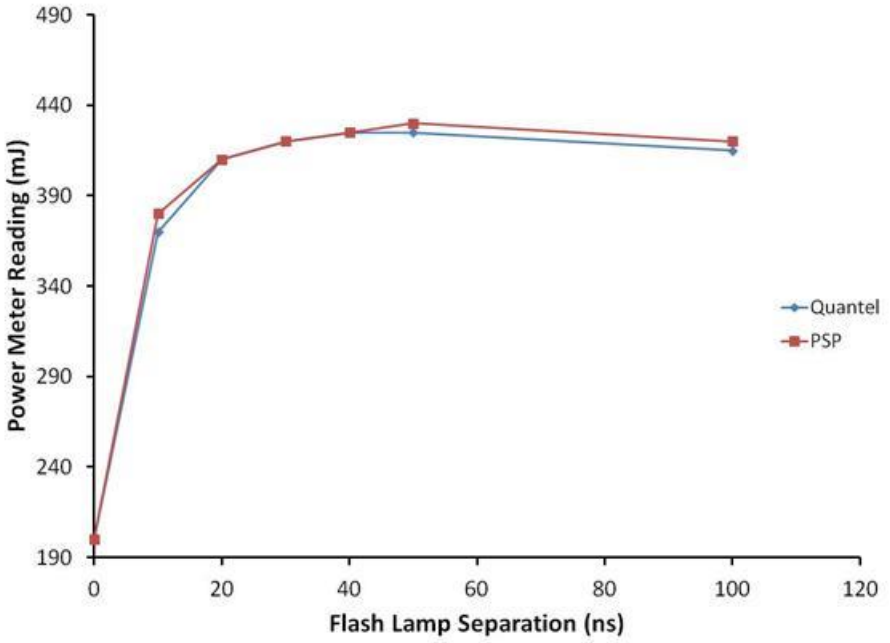


Figure 6. Laser power as measured by the FieldMax II as a function of pulse separation.

From these results it seems that if the pulses are timed to temporally overlap (i.e. both heads fire at the same time), then either only one head actually fires, or some other process is significantly degrading the doubling efficiency. In addition, the pulse separation must be greater than the nominal laser pulse width, and preferably twice the pulse width or greater. Optimal results were obtained using a separation of 40 ns, though this optimization is fairly minimal above 20 ns pulse separation. For PSP measurements, these separation values should have minimal effect as long as all of the data and external calibrations are accomplished using the same setup. This is especially true is multiple lasers are to be used. For PIV, however, this could cause some particle blurring, which would depend on the flow velocity, size of the field of view, and resolution of the camera.

Comparison of Laser Power: In the experiments described above, the power of both laser heads was set to 100%. For the EverGreen 200 laser, the power of each head can be set independently in 20 increments. An internsting phenomenon was observed when the power of one of the laser heads was reduced below 100% (or 20 on the front panel) while the timing was set so that both laser heads fired simultaneously. The total output power of the laser as measured by the power meter is shown in Figure 7. As the set power of one of the laser heads is decreased, the overall power seem to increase. This is actually due to a shift in the timing of the laser pulses as shown in Figure 8. For this laser, when the power of one head is reduced from 100%, a systematic separation of the pulses occurs that produces a similar effect as seen if the actual timing of the laser heads is altered as in Figures 4 and 5. This separation increase is fairly consistent as shown in Figure 9. For power settings below 8, the peak separation had to be estimated as the second pulse becomes very broad. This is indicated by the shaded box in Figure 9. This effect was seen regardless of which laser head was depowered, so only one set of data is shown.

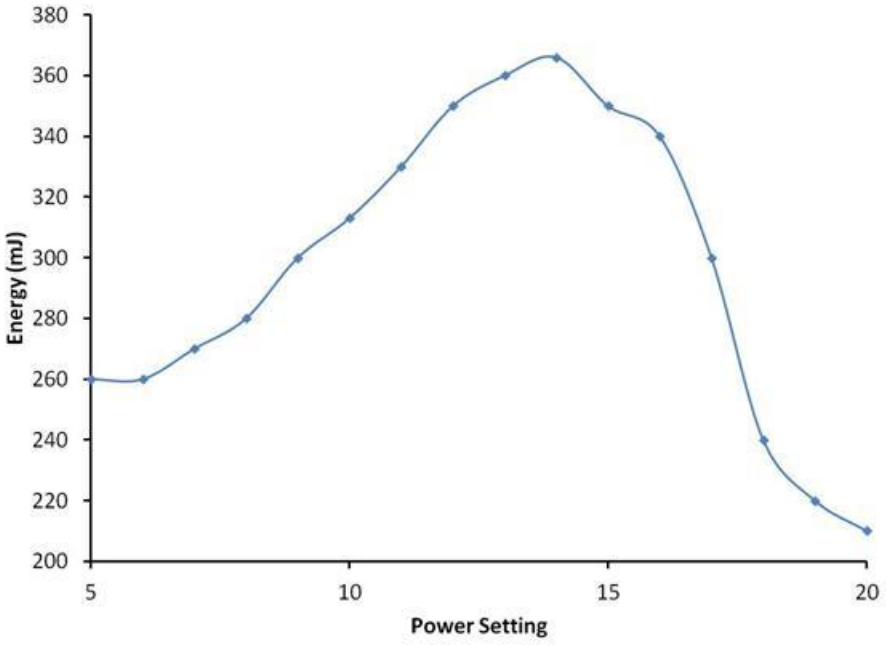


Figure 7. Laser power as measured by the FieldMax II as a function of power setting for one of the laser heads. The second laser head is maintained at full power.

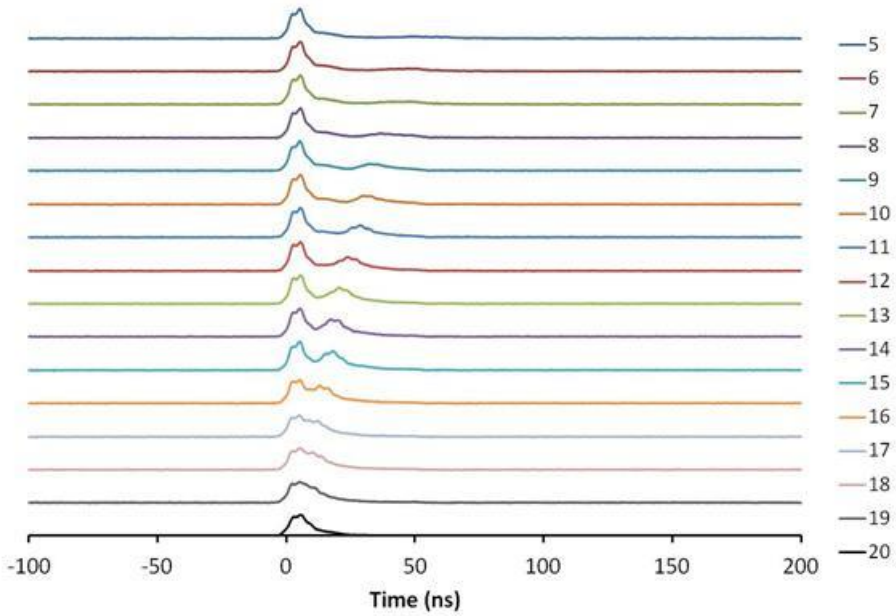


Figure 8. Photodiode waveforms generated by changing the power of one laser head. The second laser head is maintained at full power.

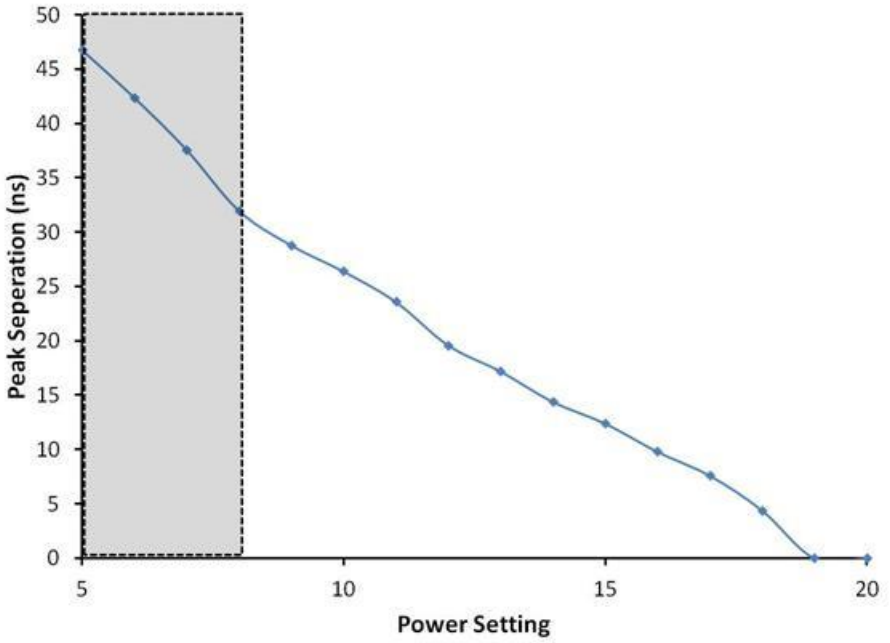


Figure 9. Peak separation as a function of power setting for depowering one laser head. The shaded region denotes estimated peak separation due to low signal from the second laser pulse.

Laser Pulse Shape: The pulse shape of the laser beam was measured using a beam profiler to determine if the timing methods caused any spatial distortion of the beam. For these measurements, the beam had to be further attenuated using a neutral density filter (OD = 3) as well as attenuation plates placed in front of the beam profiler. The beam profile obtained using the internal timing of the laser (where there is a 10 µs separation between pulses) is shown in Figure 10. These results show that the beam is essentially Gaussian in shape in both the horizontal and vertical direction. There is some distrotion, but this is mostl likely due to aberations caused by the many beam reflections before reaching the profler. Figure 11 shows the profile fo the beam using the "optimal" Q-switch separation of 40 ns. This is virtually identical to the internal timing method. These results were seen regardless of the timing, so the other results are omitted for brevity.

Implications: Some simple expectation of the amount of blurring for PIV is presented in Table 1. These calculations were based on operating in 2 representative facilities: the 14- by 22-Foot Subsonic Tunnel at NASA Langley and the 20" Mach 6 facility at NASA Langley. The 14- x 22-Foot tunnel is the current facility where the PSP and PIV techniques are used with the EverGreen 200 laser and represents a more common environment for PIV use. The Mach 6 facility is simply used to represent the effects of minimal separation at much greater velocities. For these calculations, several assumptions are made: the tunnel velocity is 348 ft/sec for 14 x 22 or 6700 ft/sec for Mach 6, the particles are perfect particles that show no lag (i.e. travel at the tunnel velocity), the field of view for PIV is 15" high and 20" long for 14 x 22 (for the larger field of view PIV used recently) or 4" x 4" for Mach 6, and the camera has a CCD size of 2048 pixels (height) x 4096 pixels (length). In addition, it is assumed that the field of view is aligned with tunnel flow. From the calculations, some blurring will be evident even at the much lower speeds of the 14 x 22 facility. With an "optimal" separation of 40 ns, one could expect to see up to 0.5 pixel blurring at these speeds, while at the Mach 6 facility, almost 40 pixels of blurring can manifest. Again, it should be noted that these are very simplified calculations and are merely included to illustrate what could happen with these very small pulse delays.

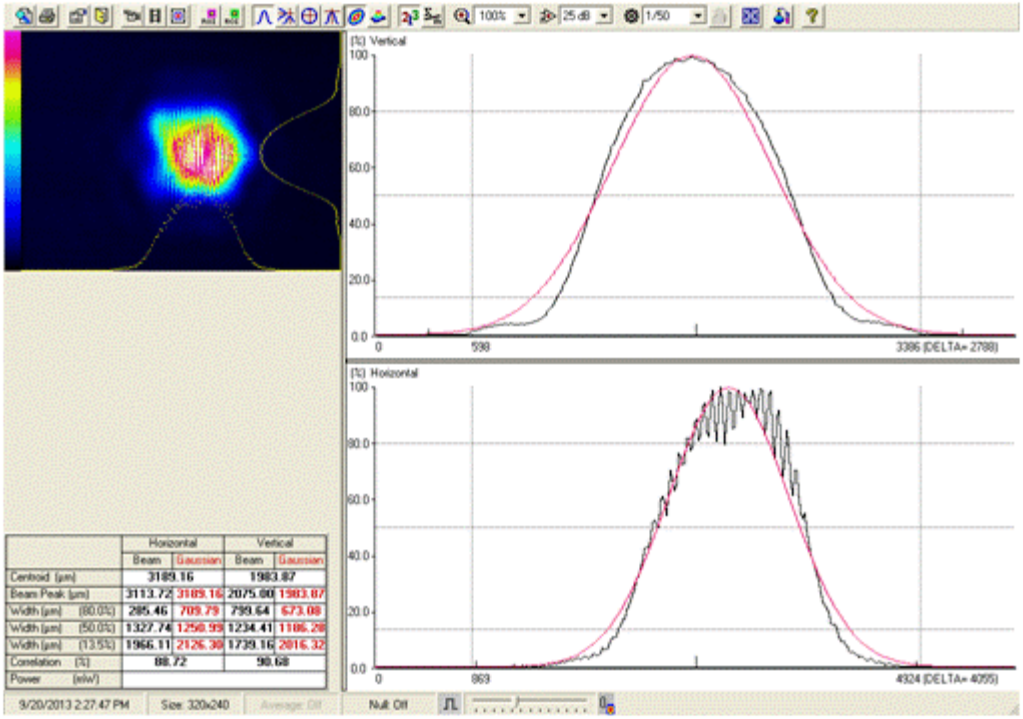


Figure 10. Laser beam profile obtained using the internal timing of the laser.

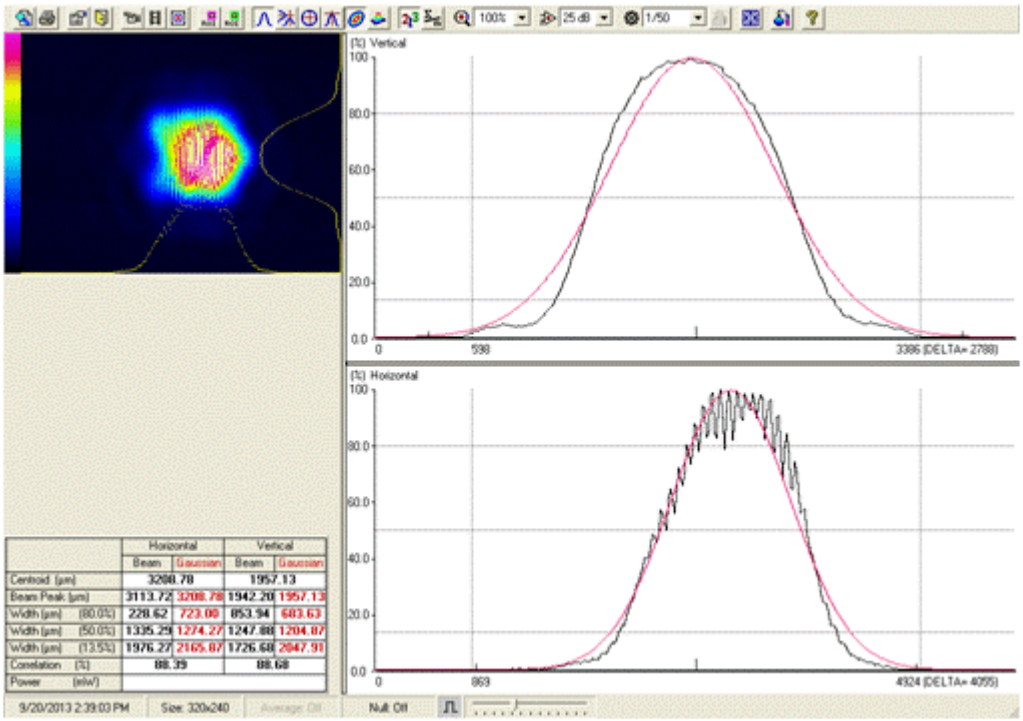


Figure 11. Laser beam profile obtained with the Q-switches delayed by 40 ns.

Pulse Separation (ns)	Low speed blur (in.)	Low speed blur (pixels)	High speed blur (in.)	High speed blur (pixels)
0	0	0	0	0
10	4.1×10^{-5}	0.10	8.0×10^{-4}	9.9
20	8.3×10^{-5}	0.21	16.1×10^{-4}	19.8
30	12.5×10^{-5}	0.31	24.1×10^{-4}	29.6
40	16.7×10^{-5}	0.41	32.2×10^{-4}	39.5
50	20.9×10^{-5}	0.51	40.2×10^{-4}	49.4
100	41.8×10^{-5}	1.03	80.4×10^{-4}	98.8

Table 1. Calculated blurring of particles in low speed flow (14 x 22) and high speed flow (Mach 6). Assumptions used for the calculations are detailed above.

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2. Watkins, A.N., et al., "Deployment of a Pressure Sensitive Paint System for Measuring Global Surface Pressures on Rotorcraft Blades in Simulated Forward Flight," presented at the AIAA 28th Aerodynamic Measurement Technology, Ground Testing, and Flight Testing Conference, New Orleans, LA, June 25-28, 2012, and published as AIAA-2012-2756.

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4. TITLE AND SUBTITLE

Experimental Results for Temporally Overlapping Pulses from Quantel EverGreen 200 Laser

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Watkins, A. Neal

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

380046.02.07.03.03.01

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

NASA Langley Research Center
Hampton, VA 23681-2199

8. PERFORMING ORGANIZATION REPORT NUMBER

L-20339

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSOR/MONITOR'S ACRONYM(S)

NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

NASA/TM-2013-218057

12. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified - Unlimited
Subject Category 35
Availability: NASA CASI (443) 757-5802

13. SUPPLEMENTARY NOTES

14. ABSTRACT

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15. SUBJECT TERMS

Lasers; Particle imaging velocimetry; Pressure sensitive paint

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