**AOCM Program 1992 to 1993 Status Report:
Basilisk Subscale Laser Experiments**

M. Hermann, M. Norton,
J. Honig, and L. Hackel

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AOCM Program 1992 to 1993 Status Report: Basilisk Subscale Laser Experiments

Mark Hermann, Mary Norton,
John Honig, and Lloyd Hackel

Lawrence Livermore National Laboratory
P.O. Box 808, 7000 East Ave., L-495
Livermore, CA 94550

A. Executive Summary

This report summarizes the work performed by the Advanced Optical Counter Measures (AOCM) program from January 1992 to February 1993, funded by the Department of Defense and administered by the U.S. Army's Night Vision and Electro-optics Directorate (NVEOD). The AOCM program objective was the development of an advanced anti-sensor weapon system, the Basilisk laser. Basilisk is a high power, white light laser. Its compact size permits deployment on a variety of platforms, including the Bradley Fighting vehicle, where Basilisk would augment the Bradley's conventional weapon systems. The effectiveness of Basilisk was recently demonstrated in a series of battlefield simulations, CTAS 2.5, where its Mission Defeat Score was eight times higher than lower energy anti-sensor laser systems.

In November 1991 a program was proposed to NVEOD to develop the Basilisk white light laser system. The proposed strategy for developing the Basilisk field test unit (FTU) consisted of five phases.

- (1) A baseline design for the FTU was developed by updating and improving the work performed by the previous DARPA funded AOCM effort between 1987-1989. A much improved baseline design was developed and presented to NVEOD in May 1992. This baseline design and operating specifications were summarized in a previous classified report (AOCM Review University of California LLNL CLYA-92-045).
- (2) A comprehensive suite of modeling codes was developed to theoretically analyze all key laser physics technologies, perform trade-off studies and design the FTU baseline. A summary of this work was also presented to NVEOD in May 1992.
- (3) An experimental campaign was initiated to demonstrate key laser physics, and engineering technologies embodied in the FTU design. A series of subscale experiments employing existing laser hardware were performed. This is the focus of this report.
- (4) Once all key technologies have been fully demonstrated, a full scale, compact, FTU laser would be built and tested under laboratory conditions.
- (5) The FTU components tested in phase 4 would then be packaged for mil-spec testing and evaluation.

A two year program was proposed to NVEOD to accomplish the first three phases, to fully demonstrate the technological feasibility of the Basilisk concept and to produce a detailed design of a full-scale FTU. To date the AOCM program has completed all milestones associated with the first year of funding.

In particular the design of the Basilisk FTU and a detailed modeling analysis of all major components of laser system were completed. This work has been fully summarized in AOCM Review University of California LLNL CLYA-92-045 and presented to NVEOD in May 1992. Experimental demonstration of several key Basilisk laser technologies was also completed on schedule. Subsequently, after one year of funding, the program was canceled.

This report documents the experimental activities performed by the AOCM program and describes several major experimental milestones we achieved during this funding period. These accomplishments have significantly enhanced the technical feasibility of the Basilisk laser concept and the validity of our baseline design. The following milestones, which will be discussed in detail below, have been achieved during the first year of funding.

- (1) We have fully demonstrated the white light convertor subsystem scalable to Basilisk full-scale energies. These white light experiments, for the first time, successfully demonstrated 10 J white light production at 1 Hz with $< 4 \times$ diffraction limited beam quality from 15 J of 527 nm input. This important milestone fully demonstrates one of the major Basilisk laser technologies.
- (2) We demonstrated operation of the Basilisk baseline doubler design by producing $> 80\%$ conversion efficiency from 25 J at 1053 nm at 1-3 Hz repetition rate.
- (3) We built and fully tested the Basilisk master oscillator laboratory prototype.
- (4) We performed heat capacity power amplifier demonstration experiments on a "true" subscale slab, having the same gain, thermal loading, and parasitic losses as the full scale Basilisk amplifier.
- (5) We designed, procured and assembled the optics and hardware for the 1053 nm, 1 Hz, 150 J/pulse, laser system, utilizing the subscale heat capacity slab amplifier.

B. Basilisk Laser Effectiveness

The Basilisk laser is a compact, high power, white light, anti-sensor laser weapon system. The compact volume and low mass specifications of the Basilisk FTU permit deployment on a variety of platforms, including dedicated vehicles such as the HMMWV. More importantly, this compact system can augment conventional systems on multi-weapon platforms such as the Bradley Fighting vehicle. The experimental milestones we have recently achieved in the first year of this program significantly advances the validity of our FTU design and the technical feasibility of the Basilisk concept. Based on this work, we believe that a Basilisk FTU is a realizable weapon system.

The effectiveness of a "Basilisk" type system was recently analyzed in a series of computer battlefield simulations - CTAS 2.5 (Virtual Prototyping of Countersensor Lasers in an Interactive Simulation Environment, John Meier and George Faulkner, Los Alamos National Laboratory, LACP-93-233). These simulations compared three laser systems, denoted as series 300, 400, and 600.

Series 300 is a single visible wavelength of moderate energy and low repetition rate. The magazine is unlimited and the duty cycle is continuous. Its effective range is 3.5 km.

Series 400 has one-third the energy of Series 300 and 40 times higher repetition rate. The output was distributed over six wavelengths in the visible spectrum. The magazine is unlimited and the duty cycle is continuous. Its effective range is 3.5 km.

Series 600 has 100 times the energy of Series 300 at 1/10 the repetition rate. The output is distributed over 26 wavelengths in the visible spectrum. The magazine depth was 200. Its effective range was 7 km. This system is similar to the proposed Basilisk FTU.

The CTAS 2.5 simulations employed a dedicated vehicle platform for the Series 600 laser. Simulations of Basilisk mounted on a Bradley platform, augmenting its conventional weapons, should also be considered in the next CTAS studies. One of the results of CTAS 2.5, which can be characterized by the Mission Defeat Score registered by each laser device under identical simulation, clearly demonstrates the potential effectiveness of the Basilisk laser weapon system.

Laser System	Total Mission Defeat Score
Series 300 (301)	10
Series 400 (401)	4
Series 600 (601) - Basilisk	83

Based the AOCM program's recent experimental accomplishments and the CTAS 2.5 simulations, we believe that the Basilisk laser system can be built and would make a very effective anti-sensor weapon system.

C. AOCM Experimental Program

The Basilisk laser system is a significantly advanced technology. The AOCM program's strategy initially focused on demonstrating key laser technologies embodied in the Basilisk concept. Prior to beginning this program, the required

level of operation of either the entire Basilisk laser system or the individual major components was well beyond the current state-of-the-art of both the solid-state laser community or the nonlinear frequency conversion community. For this reason LLNL embarked on an aggressive experimental campaign to fully demonstrate the key Basilisk laser technologies. Due to limited funding and an aggressive schedule, a strategy was initiated, utilizing previously procured DARPA funded AOCM program hardware and existing laser assets (i.e. 25 J, 1053 nm ARPA Advanced Lithography Laser) to demonstrate key Basilisk laser technologies. The following set of experiments were proposed.

Experiments	Goal	Completed
ARPA laser frequency doubler	80% 1 μ m to 527 nm conversion for baseline doubler design	✓
ARPA laser Raman white light convertor	Demonstrate white light generation at 10-15 J scalable to Basilisk FTU	✓
ARPA laser white light optics	Damage test white light optics	not funded
Subscale Basilisk master oscillator (MO)	Demonstrate operation of Basilisk MO	✓
Subscale Basilisk slab power amplifier (PO)	Demonstrate true subscale operation of heat capacity slab PO	✓(1)
Subscale Basilisk 1053 nm laser operation	Extract 150 J at 1 Hz for 100 shots in diffraction limited beam	not funded
Subscale Basilisk doubler	Demonstrate baseline doubler at 150 J 1053 nm	not funded
Subscale Basilisk white light	Demonstrate 75 J white light at 1 Hz	not funded

(1) Partially completed

1. Advanced Lithography ARPA Laser Experiments

The Raman white light convertor capable of operating at Basilisk full scale energies was initially considered a significant technological risk. Previously published white light experiments were limited to several hundred mJ at most. Consequently, demonstration of the high power Raman white light convertor subsystem scalable to Basilisk energies was the AOCM program's first major milestone. To accomplish this objective we initiated a set of experiments utilizing an existing laser asset, the ARPA laser system. This system utilizes a glass slab laser developed under ARPA Advanced Lithography funding, producing 25 J at 1053 nm at 5 Hz. Since this laser was an existing asset, critical white light experiments could be performed in a timely manner. These white light experiments were the first high power experiments to successfully demonstrated 10 J white light production at 1 Hz with < 3-4 x diffraction limited beam quality from 15 J of 527 nm input. Completing this milestone was a major accomplishment of this program. In addition to the white light experiments, this

laser was also used to demonstrate 80% frequency conversion utilizing a subscale doubler identical to the Basilisk baseline design. The specifics of these experiments will be discussed below.

An additional set of experiments, utilizing the ARPA laser and white light convertor, was planned for the second year of funding. These experiments, which were not carried out due to the programs cancellation, focused on measuring operating fluences of high power white light optics. Our direct experience with broad band coatings required for the Raman white light convertor and experience obtained by other LLNL programs, employing broad band coatings, indicate that the Basilisk operating fluences will pose no major problems.

During the course of these experiments the ARPA laser was upgraded to include an SBS phase conjugator. The phase conjugator removes aberrations produced by the thermally loaded slab amplifier. This upgrade produced significantly better output beam quality and increased pointing stability. These advances in turn lead to more efficient doubling and Raman white light frequency conversion. The primary reason for these improvements was the improved beam quality reduced the intensity fluctuations, permitting operation at higher fluences much closer to the damage limit of the optics. Since the phase conjugated laser output produced such dramatic improvements in the white light convertor subsystem, the Basilisk baseline design was modified to include a phase conjugator. The new design will be discussed in detail below.

2. Subscale Basilisk Laser Experiments

To fully demonstrate the Basilisk laser prior to fabrication of a costly full scale system, a subscale laser was designed and built. Since the laser was designed as a true subscale version of the full scale Basilisk laser, successful operation of this laser would fully demonstrate all key laser technologies required for the FTU. The design of the subscale laser will be reported in the next section. The subscale laser consists of (1) a master oscillator, identical to the FTU, (2) a slab amplifier, having the same gain, thermal loading, parasitic losses as the FTU, (3) an identical laser extraction scheme, (4) a subscale doubler, having the same thermal loading as the FTU, and (5) a white light convertor scalable to the FTU. The construction of an end-to-end subscale Basilisk laser system occurred in parallel with the ARPA laser Raman experiments. Once the Raman experiments were completed, the now tested white light convertor was to be integrated into the Basilisk subscale laser. This system can produce 75 J of white light at 1 Hz for 150 shots with $< 10 \times$ diffraction limited beam quality.

During the first year of funding AOCM fabricated a slab amplifier head, utilizing zig-zag slabs and flashlamps procured by the previous funded program. In addition all master oscillator and laser system optics were procured. The master oscillator was assembled and fully tested. The slab amplifier was assembled and tested. Results of these experiments are reported below. Activation of the laser, procurement of the doubler and integration of the white light convertor would have taken place during the second year of funding.

D. Basilisk Laser System Design

The Basilisk subscale laser system concept is shown in Fig. 1. The laser system employs a master-oscillator power-amplifier (MOPA) architecture, utilizing a single heat capacity segmented slab power amplifier shown in Fig. 2-3. The master oscillator generates a 5 mJ zero-order Gaussian output beam with a single longitudinal 70 nsec pulse. A phase conjugated system assures that the output beam quality will match the input, motivating the master oscillator's good beam quality requirement. A single longitudinal mode (i.e. single frequency) is required for efficient SBS phase conjugation. The beam is enlarged to a rectangular shape and is injected into the multi-pass slab amplifier. The beam is amplified with a single-pass unsaturated gain of 20-30 a total of three times and then inserted into the SBS phase conjugator. Each pass the beam width is reduced by the anamorphic telescope. The conjugated output beam then retraces its path. The whole system is fully relay imaged to insure that any aberrations are compensated for in the phase conjugator. After reflection from the phase conjugator mirror the beam has enough energy to saturate the first small slab segment. Its area is then increased via the anamorphic telescope and saturates the second slab segment and similarly the third. The scheme is similar to a conventional MOPA chain consisting of several increasing aperture amplifiers and enlarging telescopes. The advantage here is a single power amplifier and common optics produce a much more compact architecture. Fig. 4-5 are photographs of the subscale laser hardware.

Adding an SBS phase conjugator required modifying the laser operation from a burst mode to a single long 70 nsec pulse. In the original burst mode concept, 15 pulses were generated in 2 μ sec and amplified by the power amplifier pumped by a single 250 μ sec flashlamp pump pulse. Operation in this mode required a complicated and extremely reliable master oscillator. The primary concern is that a single pulse in the burst could extract too much energy, leading to damage of optics or the power amplifier. The burst mode master oscillator was required to generate 15 pulses with individually specified pulse energies to accommodate the change in gain in the power amplifier during depletion. In addition, the gain in the amplifier prior to extraction had to be monitored and the master oscillator was required to adjust the individual pulse energies on a shot by shot basis. Originally the burst mode operation was

chosen to reduce the fluence on the white light optics. Our recent experiences with broad band coatings and the dramatic improvement in beam quality obtained with an SBS phase conjugator indicates that the required 3-4 J/cm² operating fluence can easily be achieved with a 70 nsec pulse. This modification has lead to several improvements in the laser system: (1) The master oscillator is now a much simpler ring design, which has been fully tested. (2) The addition of the SBS phase conjugator produces better beam quality and pointing stability, permitting higher extraction efficiency and improved frequency conversion and white light generation. (3) The longer pulse improves white light conversion by operating in the long pulse, steady-state regime instead of the previous short pulse, low gain, transient regime.

E. ARPA Laser Frequency Doubling Experiment

The goal of these experiments was measuring the frequency conversion efficiency and angular bandwidth of an alternating-z KD*P doubler similar to the Basilisk baseline design. The experiments were performed with 25 J at 1053 nm 15 nsec pulse and 1-3 Hz repetition rate. The peak irradiance was similar to the Basilisk operating point. Both the Basilisk baseline and this subscale doubler utilized the same two plate alternating-z KD*P type II design. One KD*P plate is an x-cut crystal and the other a y-cut crystal. The ARPA doubler deuteration was 94%, while the Basilisk baseline will be > 98% for lower absorption and corresponding heating. All surfaces are AR coated with a single sol gel layer: the first surface optimized for the fundamental, the next two surfaces tuned for 790 nm and the last surface optimized for the second harmonic. A high aspect slab design provided efficient heat removal across the narrow dimension. Since thermal gradients lie in the narrow insensitive tuning plane, the impact on conversion efficiency by crystal heating will be minimized. By choosing the long dimension to lie in the sensitive tuning plane of the crystal, the inherently smaller angular divergence associated with this dimension results in a minimized contribution to the dephasing from the diffraction-limited output beam divergence. A schematic of the doubler design is shown in Fig. 6.

This subscale doubler consists of two 2.5 cm thick bars of KD*P with input aperture dimensions of 14 x 1.4 cm. The Basilisk design will utilize different dimensioned crystals. The two doubler crystals are independently mounted so that the gap between them is a few millimeters. The sides are in thermal contact with water cooled copper plates and the temperature of the water is controlled to $\pm 0.1^\circ\text{C}$. The mechanical design allows for separate control of the angle of each crystal in the sensitive direction. In practice, each crystal is independently oriented for maximum conversion and then fine tuning is accomplished by tuning both crystals as a unit. A photograph of the doubler is shown in Fig. 7.

A numerical solution of the coupled nonlinear wave equations shows that phase matched propagation through approximately 5 cm of KD*P is required to achieve single pulse conversion efficiency >70% with a 100 to 300 MW/cm² input irradiance of the fundamental. The angular sensitivity of KD*P would result in an external FWHM of 530 μ rad for this length of material. Even assuming the very high beam quality and pointing stability achieved from a phase conjugated amplifier system, this still places somewhat stringent requirements on the mechanical alignment needed for high conversion efficiency. Consequently an alternating-z design was chosen to increase the angular bandwidth. This design consists of two doubler crystals with the optical axes arranged alternating to each other. This results in more than a 2X increase in the angular tuning width to 1.6 mrad FWHM measured external to the crystal.

The measured conversion efficiency of the two crystal alternating-z doubler is compared with corresponding numerical calculations as a function of input energy in Fig. 8. This efficiency is defined as the second harmonic energy out of the doubler assembly divided by the fundamental energy into the doubler assembly which includes a 45° quartz rotator used to provide the needed polarization state of the input. A maximum conversion efficiency of 82% is obtained at 21 J corresponding to a peak irradiance of 185 MW/cm². The numerical solution to the coupled harmonic equations assumes a spatially and temporally flat topped pulse and a detuning angle of 50 μ rad. The numerically calculated improvement in angular bandwidth for 2 2.5 cm alternating-z plates versus a single 5 cm plate is shown in Fig. 9 and compared with measured results. These same proven models were used to design the Basilisk baseline doubler.

F. ARPA Laser Raman White Light Generation

The Raman white light experiments performed with the ARPA laser represent a new milestone in broad band white light generation. The white light convertor employs a collimated design. A collimated design is scalable to Basilisk energies by simply increasing the aperture of the two collimated cells. Since the operating fluences of these experiments is similar to the Basilisk operating point, these experiments fully demonstrate this key technology. The overall program goal was to generate a broad band frequency spectrum that maintains a beam quality of better than 10 times the diffraction limit. The required spectrum should consist of ten equally populated lines between 450 and 650 nm. A spectrum of ~15 lines in the 422 nm to 730 nm range has been generated with relative strengths ranging from <1% to 25% depending on the conditions. The overall beam quality from a near diffraction limited 527 nm pump was < 3-4x the diffraction limit. These experiments have fully demonstrated this key Basilisk laser technology.

The design of the Raman white light convertor consisted of three H₂ cells at ~ 2 atm pressure. The key aspect of this scheme is to tune the polarization of the 527 nm pump light to optimize the efficiency and beam quality of first Stokes spontaneous generation, first Stokes stimulated amplification, and white light parametric generation. The gain for spontaneous generation and subsequent stimulated amplification is optimized for circularly polarized pump light and the gain for parametric generation of higher order Stokes and anti-Stokes lines is optimized for linearly and parallelly polarized pump and Stokes light. The design of this subsystem is shown in Fig. 10. The actual experimental hardware with diagnostics removed is Shown in Fig. 11.

A small fraction of the input pump is focused into the first Raman cell, the oscillator, to generate ~10-20 mJ of first Stokes. The use of circular polarized 527 nm pump and a focused geometry assure that the first Stokes will have good beam quality and competing parametric conversion to higher Stokes orders will be minimized. The Stokes output is subsequently amplified in the second collimated Raman cell, the amplifier, into which 10 to 50% of the pump beam has been directed. In both of these cells the pump is circularly polarized and the Stokes is oppositely circularly polarized. Again this is the optimal polarization choice for stimulated amplification and for reducing competing parametric processes. In the third collimated cell, the parametric mixer, the linearly polarized pump and identical polarized Stokes, both having similar energies, parametrically generate a comb of Stokes and anti-Stokes lines.

The results of these high power white light experiments are summarized in Fig. 12, showing the collimated white light beam, the spectral content, and the far field beam profiles in the two transverse directions. The collimated beams color is correlated with its transverse peak irradiance profile. It is white/yellow in the center due to higher conversion and becomes green at the lower irradiance beam edges. The beam divergence was measured at ~3-4 x the diffraction limit. A total of sixteen frequencies from 422 to 672 nm was observed. The corresponding spectrometer output is shown in Fig. 13, showing the power in each frequency component. Since the spectrometer could resolve the 7th Stokes and the close lying first vibrational Stokes, we are confident that undesirable vibrational scattering is not occurring. During the preliminary stages of this experiment we performed detailed experimental and modeling comparisons. These experiments were carried out at reduced energies, producing 6 J white light the measured spectrum is shown in Fig. 14 and compared with calculations in Fig. 15. The excellent level of agreement between theory and experiment further validates our Basilisk laser design.

G. ARPA Laser White Light Optics Damage Testing

Damage testing white light high reflectors was not performed due to a lack of second year funding. In the course of performing white light experiments we did observe much higher damage limits than originally thought possible for all optics, including complicated multi-layer dielectric coatings. Specifically these were multi-color broad band polarizers and beam combiners. The beam combiners required not only high efficiency but also high damage threshold as did all mirrors, polarizers, lenses and windows in either the pump, Stokes or white light optical paths. Past experience of LLNL optical damage experts and of numerous vendors indicated that our operating fluences were well beyond previously defined safe limits. Typical safe operating limits had previously been established at 2-5 J/cm² at 527 nm for a 10 nsec pulse. Damage threshold measurements on all our newly acquired optics varied from 5 J/cm² to better than 20 J/cm² for a 10 nsec pulse. Although, these coatings were not extremely broad band, the increase in level of performance indicates that significant advances in coatings occurred during the last five years. We are very confident that the required operating fluence for Basilisk of ~3-4 J/cm² for a 70 nsec pulse is attainable.

H. Basilisk Full-Scale Master Oscillator

The change in laser design from a burst mode to a single long pulse allowed us to build and test the full scale Basilisk master oscillator prototype. The master oscillator requirements are 10 mJ output in a lowest order Gaussian transverse mode and single longitudinal mode (TEM₀₀₀). The oscillator used a single flashlamp pumped Nd:YLF rod and was configured in a ring resonator configuration. The 1053 nm transition in Nd:YLF closely matches the fluorescence curve peak in the Nd doped phosphate glass used in this amplifier system. It is desirable to have a single frequency oscillator input pulse both for generating reproducible smooth temporal input profiles without modulation from multi-longitudinal modes and for achieving the best wavefront reversal fidelity in the SBS phase conjugator. Although single longitudinal mode output from a Nd:YLF Q-switched oscillator has been demonstrated by injection locking to a low power single frequency master oscillator, this technique requires careful mode matching between the master and slave oscillators and active cavity length stabilization of the Q-switched slave oscillator. This method would be difficult to implement in a fieldable system. A simpler method of achieving single frequency output was chosen for this application by using a variation of the electronic linewidth narrowing technique. In this method, very low power oscillation is allowed to build up in the Q-switched cavity over an extended period of time (1-2 μ s). By placing a frequency selective element such as an etalon in the cavity, this long build up time and the corresponding many passes through the etalon results in single

longitudinal mode oscillation. The intracavity power is monitored by the leakage through the high reflectivity (HR) mirror and when it peaks in a weak relaxation oscillation, the Q-switch is opened. The low power single frequency flux then serves to seed the build up of a high power Q-switched pulse.

The layout of the Nd:YLF self seeded ring oscillator is shown in Fig. 16 and the corresponding hardware prototype is displayed in Fig. 17. A thin film polarizing beam splitter in combination with a $\lambda/4$ waveplate is used to prevent laser oscillation during the flashlamp pumping pulse. By slightly rotating the $\lambda/4$ waveplate from the position of maximum extinction, the cavity is allowed to leak in order for the weak single frequency self seeding power to build up. A 30 mm solid fused silica etalon with 40% reflective coatings is used as a frequency selective optic. By varying the gain in the Nd:YLF rod at the time of Q-switching, pulse widths between 15 and 70 ns are achievable with 5-15 mJ output energy per pulse, respectively. The stability of the oscillator is displayed in Fig. 18, showing an overlay of 1000 consecutive temporal pulse shapes. In addition to the inherent stability of this design, additional safety can be achieved by incorporating an electronic multi-mode sensing filter.

I. Basilisk Subscale Power Amplifier

A series of experiments were performed on the subscale Basilisk heat capacity slab amplifier. This slab was designed as a "true" subscale prototype of the full scale system. The prototype has the same gain, thermal loading, and ASE and parasitic losses as the full scale system. The wedge-tip slab's dimensions are 24x20x2.05 cm³ (see Fig. 2). Successful completion of these experiments would have fully demonstrated heat capacity operation for the full scale system. During the course of these experiments several design problems were uncovered and corrected at a design level. Specifically, we found that larger bore flashlamps are required to produce the desired gain and higher average power handling ASE edge claddings are required to prevent parasitics at high repetition rate. Unfortunately, funding curtailment halted these upgrades.

1. Basilisk Subscale Laser Electrical Testing

Before any experiments were performed, the flashlamp circuitry was tested to guarantee reliable operation. The Basilisk subscale laser head is pumped by eight flashlamps organized as four pairs of two (see Fig. 19-20). Each flashlamp pair has its own storage capacitor (capacitance = 300 μ F, max. voltage = 5 kV) and trigger circuit. The storage capacitors are charged in parallel by six 10-kW power supplies. At a charging voltage of 4.47 kV, the flashlamps operate at an explosion fraction of 20%. This is the baseline operating point designed to produce a gain of 30. The flashlamps are not simmered, but are series injected. A 20-kV pulse is required to initiate flashlamp breakdown.

Initially, we had quite a bit of difficulty with lamps breaking. The original design adopted by the previous DARPA funded AOCM program used glass seal flashlamps and the flashlamps were free to move longitudinally. With the large forces involved and with questionable flashlamp design and quality, we incorporated tighter fitting solder-sealed flashlamps and this new design is significantly more robust and reliable.

2. Basilisk Subscale Laser Fluorescence and Parasitic Measurements

The first experiments we performed were measurements of parasitic threshold and fluorescence uniformity. The fluorescence is captured by a 30-cm diameter lens and directed onto a video camera by an uncoated flat. A field stop is present to give a more accurate measure of fluorescence uniformity by allowing only on-axis light into the detector. With the field stop removed, the flashlamps were taken to full operating energy (12 kJ stored electrical energy) and no parasitics were observed. With the field stop in place, we monitored the fluorescence uniformity. The fluorescence was reasonably flat across the majority of the slab, with only slight asymmetry.

Another check on the existence of parasitics was to replace the video camera with a photodiode and observe the shape of the fluorescence curve. If parasitics exist, the fluorescence curve would rise until the parasitic is initiated and then the curve would clamp. A fluorescence and current vs. time curve is shown in Fig. 21. The ordinate is scaled for the current waveform (A). The fluorescence ordinate is arbitrary. The lamps are operating at full energy and one sees that the fluorescence curve peaks at $\sim 250 \mu\text{s}$ without clamping.

3. Basilisk Subscale Laser Gain Measurements

The single-pass gain of the slab was measured along the slab's width and as a function of the delay time from the beginning of the current pump pulse. A Q-switched Nd:YLF laser collimated to $\sim 3 \text{ cm}$ was used as the probe beam to measure the gain over part of the $20 \times 2.05 \text{ cm}^2$ slab aperture. To remove any alignment errors, passive and flashlamp-pumped measurements of output-input ratios were taken at each position. With the probe beam centered in the slab, the probe pulse was time delayed from the beginning of the current pulse. Gain was measured as a function of delay time. The data, shown in Fig. 22, are for 12 kJ stored energy. The peak gain occurs at $\sim 225 \mu\text{s}$.

Fixing the delay at $225 \mu\text{s}$, the gain was measured as a function of position (results are shown in Fig. 23). For 12 kJ stored energy, the gain is approximately 10 across the majority of the slab, significantly less than the originally anticipated 30. If the gain is plotted as a function of either flashlamp energy or fluorescence, we do not observe exponential gain as would be expected. A plot of gain vs. flashlamp energy is shown in Fig. 24. To acquire

data at the lower energies, half the flashlamps (alternating between the bottom half and the top half) were disconnected. To better understand this phenomena, we performed more detailed modeling of flashlamp/slab energy transfer dynamics. Our flashlamp/slab cavity transfer model was modified to include spectral shift of the flashlamps at high explosion fraction and the spectral reflectivity of the silver reflector. Since the Basilisk subscale slab is pumped at much higher energy densities (to achieve the same gain) than the full scale slab the flashlamps were operated at much higher explosion fractions. The loss in gain can be attributed to the blue-shifting of the flashlamp pump light as the energy to the lamp is increased and the roll off in reflectivity of the silver reflector. Consequently, the slab absorption efficiency, upper state population and gain decrease. In addition, during the initial assembly and testing of the head the silver reflectors were damaged, further reducing the cavity transfer efficiency. The use of larger bore flashlamps, operating at a much lower explosion fraction, will alleviate this problem. A simulation of our results indicated that our gain measurements do, in fact, match theory. These calculations are also presented in Fig. 25, showing the excellent agreement between theory and experiment and the anticipated improvement obtained in employing larger bore flashlamps. The correlation between explosion fraction, lamp bore and gain predicted from our models is shown in Fig. 26. These calculations have lead us to redesign the head for larger bore flashlamps. Unfortunately, funding curtailment has stopped this effort.

4. Basilisk Subscale Laser Free Lase Experiments

A Fabry-Perot laser cavity (with 50% output coupling) was placed around the laser head to further measure the total stored energy in the slab. The output light from the free-lasing head was captured by an f/5.6 lens and directed into a Scientech joule meter by an uncoated wedge. The free lasing output is compared with theory in Fig. 27. A total of 250 J was extracted at 1 Hz operation.

5. Basilisk Subscale Laser Interferometry Measurements

A Michelson interferometer was used to monitor the wavefront distortion across the slab aperture as a function of slab heating, or number of shots. An initial series of low pump power experiments were performed at different flashlamp energies (higher power experiments were planned after larger bore flashlamps were integrated). At a given energy, an interferogram was taken of the cold slab and then another interferogram was taken after 9 shots at 1 Hz. The phase map of the cold slab was subtracted from the phase map after 9 shots yielding the optical path difference due to the 9 shots. Plots of the optical path difference for different flashlamp energies are shown in Fig. 28. The optical path difference is plotted as a two-dimensional surface over the aperture and cross

sections along the aperture center (horizontal and vertical) are also shown. Fig. 29 shows the optical path difference after 21 shots at a flashlamp energy of 4 kJ. In all cases, wavefront distortion is less than 1 wave over 80% of the aperture and less than 1/2 wave over 50% of the aperture. The optical path difference at the sides of the aperture are largest, indicating that the current edge cladding is too absorptive. There were also significant optical path differences at the top and bottom of the aperture due to tip curling. These aberrations can easily be corrected with an SBS phase conjugator.

6. Basilisk Subscale Laser Heat Capacity Slab Measurements

Experiments designed to document the decrease in gain as a function of slab heating (number of shots) were performed. Beginning with a cold slab and a fixed flashlamp energy, the single-pass gain of the slab was measured after each of 96 shots (1 Hz). Data from this series of runs are shown in Fig. 30. The occasional negative-going spikes are due to flashlamp misfirings at these low pump powers. Although the decrease in gain as a function of shot number (or heating) is evident, an exact analysis of these results was unsuccessful due to the excessive heating of the edge claddings. As the slab and edge cladding temperatures increased, the edge cladding began to delaminate from the slab, initiating parasitic oscillations which invalidated the experiment. A new edge cladding has been designed which should follow the slab temperature more closely, yielding a larger distortion-free aperture and reducing the thermal load on the slab.

J. Summary

The AOCM program during this last funding period has accomplished several major experimental milestones, demonstrating key Basilisk laser technologies. Originally, the Raman white light convertor scalable to Basilisk was considered an extremely high risk component of the concept. Our recent 10 J experiments indicate that a compact, low pressure and passive system can produce a white light laser having a balanced output spectrum and having an output beam quality 25 times lower than required. This design is easily scalable to Basilisk FTU energies. This is a major advancement toward building a Basilisk FTU.

We have fully demonstrated the design of the Basilisk doubler at subscale energies. These experiments produced > 80% conversion using a 25 J laser. In addition we have built and tested the Basilisk master oscillator prototype. It produces a 70 nsec 10 mJ pulse with stable shot-to-shot operation. We have also completed the first phase of heat capacity slab amplifier measurements. These experiments documented several design flaws, which have been identified and can easily be corrected. All optical components for building the 150 J 1053 nm laser have been procured.

The AOCM program has made significant advances toward realizing a Basilisk FTU. Many of the major technological risks have been fully or partially resolved. Recently, the effectiveness of the Basilisk concept has also been demonstrated in computer battlefield simulations (CTAS 2.5). CTAS 2.5 results clearly show that a Basilisk scale laser produces significantly more mission defeats than current low power laser systems. We are very confident that a Basilisk laser FTU, although technically more advanced than lower power systems, could be built given appropriate funding. This renewed program would result in an extremely effective air defense weapon system.

K. Figure Captions

- Fig. 1 Schematic of Basilisk subscale laser system.
- Fig. 2 Diagram of segmented slab, indicating slab partitions for pass 1-6.
- Fig. 3 Photograph of subscale laser slab. Slab dimensions are 24x20x2.05 cm³.
- Fig. 4 Photograph of anamorphic ring portion of laser extraction system. In foreground is the heat capacity, zig-zag slab, power amplifier, on the right is the anamorphic relay telescope, and on the left is the 1:1 relay telescope.
- Fig. 5 Photograph of input of power amplifier. In background is anamorphic relay telescope.
- Fig. 6 Schematic of the Basilisk baseline alternating-z frequency doubler, used in 25 J ARPA laser demonstration experiments.
- Fig. 7 Photograph of ARPA KD*P laser doubler.
- Fig. 8 Measured conversion efficiency of doubler as a function of input energy for a 14 nsec FWHM pulse. Also shown are corresponding calculations for a temporally flattop and Gaussian pulse assuming a detuning of 50 μ rad.
- Fig. 9 Measured frequency conversion efficiency as a function of angular detuning of alternating-z, 2-plate (2x2.5 cm), KD*P crystals. Also shown are corresponding calculations for same 2-plate design and for single 5 cm plate design, showing improved bandwidth with alternating-z design.
- Fig. 10 Schematic of Raman white light convertor. Parentheses refer to the field polarization (s,p are linear, rc,lc are left- and-right circular)
- Fig. 11 Photograph of white light convertor hardware. Not shown are diagnostics and relay telescopes used in experiment. Long tube on far right is 2 m collimated parametric mixer H₂ cell, in middle is 1 m collimated Stokes amplifier H₂ cell, and left is focused oscillator H₂ cell (1 m).
- Fig. 12 Photograph of near field, collimated, white light, 10 J laser beam and corresponding spectra obtained from diffuser prism. Also shown are far field measurements for each transverse coordinate, related to diffraction limit spot size.
- Fig. 13 Spectrometer measurement of 10 J white light convertor output.

- Fig. 14 Spectrometer measurement of early 6 J white light convertor output.
- Fig. 15 Comparison of measured (Fig. 14) and corresponding calculated spectra.
- Fig. 16 Schematic of Basilisk ring master oscillator prototype.
- Fig. 17 Photograph of master oscillator hardware. Master oscillator is in foreground.
- Fig. 18 Photograph of overlay of 1000 pulses produced by Basilisk master oscillator prototype. (50 nsec divisions)
- Fig. 19 Photograph of Basilisk subscale power amplifier laser head.
- Fig. 20 Photograph of power amplifier with top-half of pump cavity removed, showing slab and bottom four flashlamps.
- Fig. 21 Measured fluorescence output and flashlamp current vs time.
- Fig. 22 Measured gain as a function of delay from beginning of current pulse.
- Fig. 23 Measured gain across 20 cm width of slab.
- Fig. 24 Measured gain vs. electrical flashlamp pump energy.
- Fig. 25 Comparison of measured and calculated gain as a function of flashlamp pump energy for current experimental parameters and for larger bore flashlamps.
- Fig. 26 Calculated gain and explosion fraction as a function of flashlamp pump energy for current and proposed larger bore flashlamps.
- Fig. 27 Measured and calculated 250 J free laser output.
- Fig. 28 Optical path difference in waves across slabs 20 cm width and 2.05 cm height. Data measured after 9 1 Hz shots at 10 kJ flashlamp pump power.
- Fig. 29 As in Fig. 28 but after 21 1 Hz shots at 4 kJ flashlamp pump power.
- Fig. 30 Gain of heat capacity slab as a function of number of shots at 1 Hz repetition rate operation for different flashlamp pump powers.

Figure 1

Figure 2

Figure 3

Good Shot
3.

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

10 J rotational white light laser output

Figure 13

Figure 14

*Time dependent plane wave cal.: $E_p=5$ J, $E_s=.5$ J, $\tau_p=14$ nsec, $\tau_s=12$ nsec, $z=200\text{cm}$, $A=3.8\text{cm}^2$

Figure 15

Figure 16

Figure 18

Figure 17

Figure 70

Figure 21

Figure 22

Figure 23

Figure 24

Figure 25

Larger bore lamps reduce: explosion fraction
unwanted blue lamp output
slab heating

Larger lamps increase: efficiency
heat capacity magazine depth
gain

Figure 26

Figure 27

Optical Path Difference
10 kJ/shot, 9 shots @ 1 Hz

Waves for 20-cm slab width

Waves for 2.05-cm slab height

Figure 28

Optical Path Difference 4 kJ/shot, 21 shots @ 1 Hz

Figure 29

Figure 30