Progress In Alpha Laser Characterization-1999*

Capt. Dean Fitzgerald, USAF, 2420 Vela Way, Los Angeles AFB, El Segundo, CA 90245
Sherwin Amimoto, David Johannsen, Munson Kwok, Aerospace Corporation, 2350 E. El Segundo Blvd., El Segundo, CA 90245
Bernie Bendow, R. S. Bradford, Jr, Paul Dickinson, Steven Fawver, Derek Fluegge, Robert Geopfarth, Pete Lohn, John Nella, Daniel E. Novoseller, C. C. Shih, TRW, One Space Park, Redondo Beach, CA 90278
(daniel.novoseller@trw.com)

Abstract-The Alpha laser is a hydrogen fluoride laser (2.7 μm) that is a ground based testbed for a space based laser (SBL). Performance of two recent high power tests has been quantified in terms of power, spectra, near field intensity and phase, far field intensity, and laser jitter. The following items were concluded

- Misalignments suggested in earlier analyses were found and corrected with improved precision instrumentation.
- Alpha power performance improved in recent tests because of improvements in alignment and internal clipper positioning.
- Alpha intensity profile characteristics were improved by the alignment correction.
- Alpha spectral characteristics show sensitivity to flow conditions.
- Alpha phase was relatively unaffected by the alignment and flow modifications.

Continued investigation of Alpha includes additional testing to explore a predicted improvement in power performance expected from optimization of the flows.

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1.0 INTRODUCTION

The Alpha laser was designed in the early 1980s and first tested in 1989 to demonstrate the scalability of hydrogen fluoride lasers to near operational class [1]. Recent investigations have focused on maximizing the amount of useful information extracted from the data collected during recent high power tests. The ultimate goal of recent efforts has been to advance toward a successful demonstration of the technology in space. The near-term goal is to improve the quality of HF laser models to support the design of a flight laser, and to extract lessons learned from the Alpha program that will enhance risk reduction, ground test, and data collection planning for the flight laser effort. This paper covers Alpha requirements, an overview of Alpha test objectives, key Alpha test results, interpretation of the data, discussion of the gain generator hardware and optics hardware, and Alpha resonator optical modeling.

2.0 ALPHA OBJECTIVES

The overall goal for the Alpha investigation is to provide data to advance SBL technology. The purpose of the recent investigations was to quantify our understanding of Alpha performance in terms of power (P) and power variations (temporal and test-to-test), spectra (P_λ), beam quality from near field phase and far field intensity measurements as well as a function of time, laser jitter, polarization, and internal power drains (parasitics, reverse wave and compound wave). In addition, the effort included improving modeling fidelity so that future SBLs can be designed with confidence to minimize the required design margin.

The accomplishments of the overall Alpha effort include:

- First near-full-scale space-configured megawatt-class HF laser functional demonstration of many crucial SBL attributes.
- Validation of design, fabrication and integration of lightweight bench structures, extruded aluminum cylindrical gain generators, annular optics and diagnostic technologies.
- Implementation of uncooled optics technology for low weight and low cost.
- Development and anchoring of laser design tools.

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- 21 high power tests to date to help provide understanding of SBL operation.

3.0 ALO BACKGROUND

The Alpha Laser Optimization (ALO) effort began in 1992 to provide necessary support and enhancements for the Alpha laser after the initial design, build and optimization efforts. ALO was begun largely to support the Alpha-Lamp Integration (ALI) program, which addressed the integration of the laser with the beam expansion and control system. The Alpha laser grew out of the 1970s TRIAD program, which was developing Space Based Laser (SBL) capability for military missions. The three elements of the TRIAD were the laser (Alpha), the Large Optics Demonstration Experiment (LODE)/Large Advanced Mirror Program (LAMP), and the advanced beam pointing (Talon Gold) programs. The purpose of these programs was risk reduction to support the ultimate use of an SBL. This implicit purpose was made explicit in 1980s studies in which the operational system was related to a more powerful laser (Alpha II), and the ground demonstrator was developed with reduced capability (Alpha I). The performance of the postulated Alpha II system was anchored to test data as well, based on subscale testing with the Alpha Verification Module (VM) testbed. The extraction efficiency from the VM tests, the gain generator length from Alpha I, and the predicted extraction efficiency for Alpha II, together provide scaling from the lab, to the ground test setup (Alpha I, or Alpha) to a typical operational size system (Alpha II). In recent years, there has been a plethora of system studies, including the Space Based Laser Concept and Development Definition (SBL CDD) Program, SBL Concept Formulation and Technology Development Planning (SBL CF&TDP), the High Energy Lasers for Global Protection Against Limited Strikes (HELs for GPALS), Zenith Star, and the SBL Readiness Demonstrator (RD). All these systems used Hydrogen Fluoride (HF)-based chemical lasers that can be scaled from the Alpha I device, though the precise operational characteristics differed in each case from the original operational scale system design, the Alpha II.

4.0 REQUIREMENTS BASIS & SCALING

The Alpha laser was a large step in advancing the technology of SBLs towards a future operational system. The major technology efforts in Figure 1 related to the laser include Alpha, the ALO effort, the HYLTE (HYpersonic Low TEmperature) nozzle development within the overtone laser program, the uncooled resonator (UcR) optics effort, and the advanced phase conjugation experiment (APEX). These are all key aspects of the development of high power lasers for space applications. The ALO program provides an integrating test facility for testing performance of the laser and validating scaling of performance to high power.

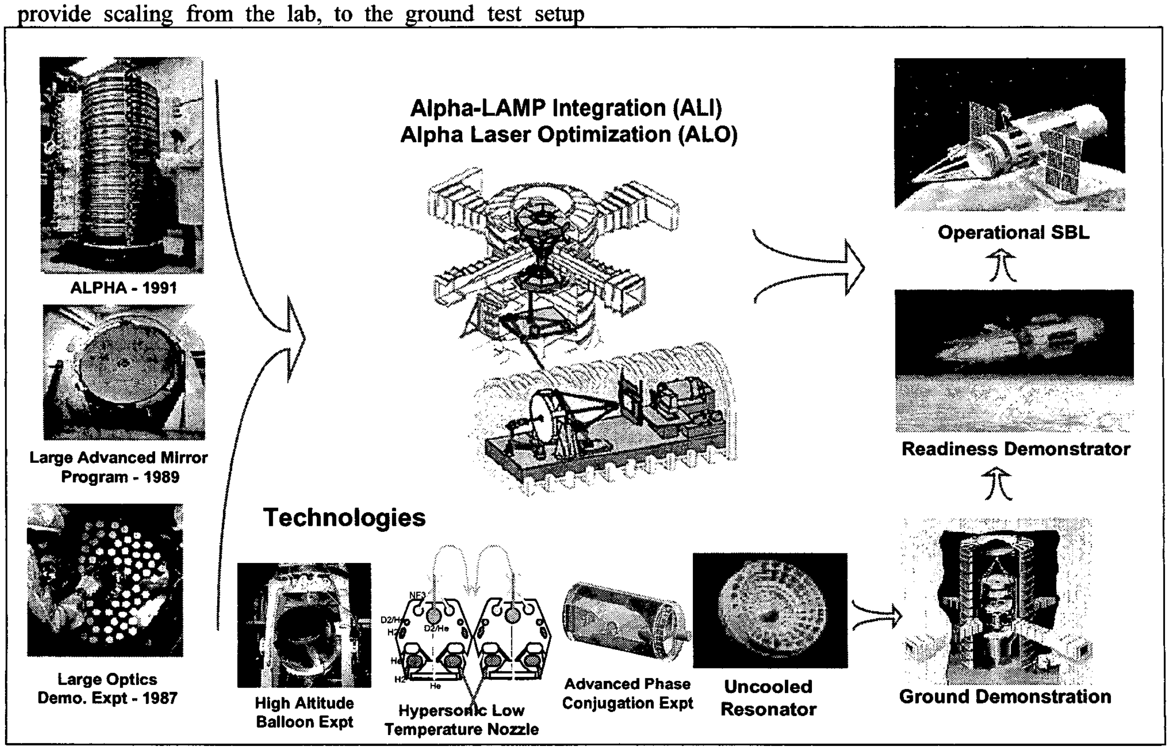

Figure 1. The ALO / Alpha Laser Is a Major Step Along the Path to an Operational SBL

The Alpha itself provides the basis for scaling from the current Alpha device to the operational-level power of the Alpha II device, as envisioned in the 1980s. The Alpha optical resonator assembly (ORA) and the gain generator assembly (GGA) were, in fact, designed so that Alpha I could grow to the level of the Alpha II performance by taking two steps. The first step in scaling is to fully populate the available 5 meter gain length with gain generation, rather than only filling 2 meters of the GGA (as in Alpha I) which would bring the power to over 100 reference units of power (called TUs). The second step in scaling is to improve the optical coatings from single layer to advanced multi-layer dielectric (MLD) designs to reduce absorption which would allow the resultant laser to produce 120 TUs of power. The use of single layer dielectric coatings and the underpopulated (2 meter long) GGA were cost economy approaches taken during the design period. This scaling is illustrated in Figure 2.

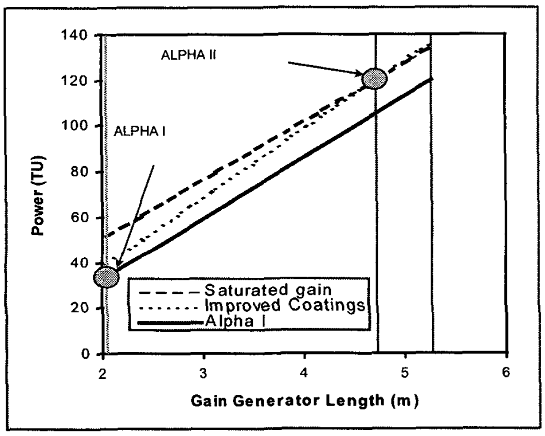

Figure 2. Alpha I Scaled to Alpha II by Improving Coatings and Fully Populating the GGA

An additional aspect of scaling is in the beam quality. Alpha I and Alpha II both had good beam quality designs. The scaling of the corrected beam quality from Alpha I to Alpha II included optical component effects (which dominated the corrected beam quality) which were identical in the two designs, including intrinsic optical quality, obscuration, figure and alignment contributions. The beam quality scaling also included dissimilar contributions – coating effects (which increase with power, and are worse in the Alpha I single layer coatings if they would have been used at Alpha II powers), medium inhomogeneity effects (which are worse in Alpha II, since there is a longer gain medium), and thermal effects (which are worse in Alpha I because of the inferior single layer coating design). The dissimilar factors are far smaller than the similar ones, so the scaling from Alpha I to Alpha II corrected beam quality is not a large step. Corrected beam quality scaling shows anticipated thermal performance improvement from advanced multi-layer dielectric coatings. However, scaling of the pre-correction beam quality is not that clear, and remains an issue for further evaluation on Alpha I.

In fact, a key issue for Alpha is how well can it be used to anchor the design accuracy for future SBL systems – can the outcoupled power, beam quality, and other key laser parameters be predicted adequately.

Table 1 illustrates the scaling status of key laser parameters. It illustrates that there is still a need to reduce the scaling uncertainty, to reduce uncertainty in the prediction of laser device performance. Though the power levels are adequate, the precision of predictability of the power is not adequate for scaling, and the variation during a test is not adequately understood. The robustness of the Alpha resonator design is shown in that power continues to be extracted from the laser at high efficiency in spite of problems that are causing significant phase variability.

The spectral distribution is consistent with expectations, but further understanding of the impact of flow changes on spectrum are needed before tying down the design of a beam control system. For example, the current approach for the Large Advanced Mirror Program (LAMP) is to beam sample using a single spectra line with holographic optical elements (HOEs). Recent tests showed variability during a test that depended on the flow rates and thermal variations to induce a spectral shift, a predicted peculiarity of the current hardware.

The output optical phase in the current device has low spatial and temporal frequencies and is thus correctable, but the existence of unpredicted phase structures needs to be more fully understood. These features increase the stress on the phase correction system, and inevitably lead to degraded performance. The next major laser improvement is expected to be the use of uncooled resonator optics, which will have an additional impact on beam quality. It is important to understand current beam quality so that future uncooled-optics-induced degradations can be quantified.

Finally, polarization and non-primary optical modes (reverse waves propagating in the resonator, compound waves coupling the resonator to the rest of the beam path, and parasitic gain paths which deplete the desired primary optical mode) need to be characterized better for more reliable scaling to higher power.

While the current Alpha testing activities have validated Alpha requirements and goals, there still remains the need to validate operability requirements. These include automatic alignment, power management for hardware protection (without throwing away the large amount of power eliminated with the current clipping configuration), as well as the accuracy of the ALI (beam control and beam expansion optics) interface performance parameters, such as residual wavefront error, jitter, polarization, and spectrum.

Table 1. Scaling of Alpha Parameters – Development Needs

Feature	Requirements Status	Need
Power level	HL902 test (1992) and HL909 (1999) met requirements. More power is predicted extractable	Re-optimize NF_3 and D_2 flow. Improve prediction precision. D_2 flow and flow split precision.
Irradiance Uniformity (spatial)	Imbalance since HL902 test reduced by HL909 alignment correction	
Spectral power level	Adequate for HOEs, repeatable	Variability with flow conditions needs to be better understood
Spectral power uniformity (temporal)	Many HOEs illuminated, but those illuminated vary in time	Need further validation
Beam quality – dynamic (limited correctability)	Meets requirement but Better would increase brightness	Improve for better brightness
Beam quality – static (correctable)	Correctable, but size implies too much residual	Improve for better brightness
Jitter	Meets requirements; mirror cooling driven; high frequency reduced in HL909 with reduced flow in resonator components	Reduction will reduce bandwidth requirements
Polarization	No requirement but subaperture sample not as predicted	Need more characterization
Scalability (reverse wave, compound wave effects)	Not accurately modeled	Instrument for scaling assessment

The current accuracy in predicting performance is adequate for building a space system only by including expensive design margin. This is illustrated in Figure 3. With 12% reliability in predicting power (which is typical after the laser device was built and anchored), and 15% in beam quality, we would have to design a SBL with a 40% margin to be assured of the required system brightness.

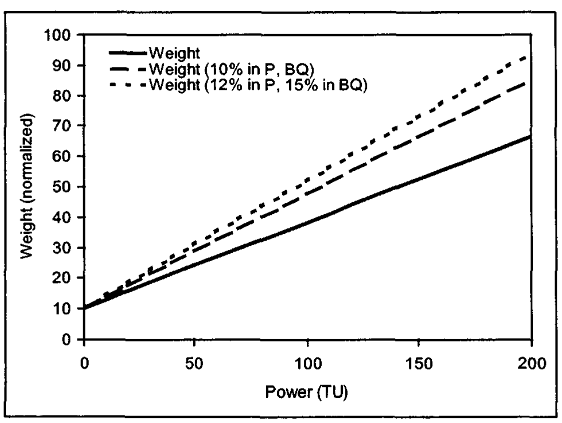

Figure 3. Impact of Lack of Confidence in Design on Platform Weight

Though much progress has been made in validating design concepts, there remains a strong need to further validate design models to increase the accuracy of scalability analyses and save money and platforms in future SBL design efforts. A 40% design margin on half the payload weight (i.e. the laser device, not including the beam control, beam director and rest of the spacecraft) implies extra platforms would be required to compensate for the inefficient payload design. It is important to measure and be able to predict the key performance parameters to better than this level to permit design with reduced performance risk. Progress in identifying sources of prediction uncertainty is being made. For example, limited small signal gain measurement accuracy is an important factor in limiting the precision of power predictions, as is the fact that current predictions don't model reverse wave modes in the resonator together with forward modes.

5.0 Alpha Hardware

Knowledge of Alpha hardware is required to interpret ALO data. Alpha is a combustion driven HF cylindrical laser designed for eventual use in an SBL (Figure 4). The system was first designed to Alpha II performance requirements then scaled back to that for Alpha I. The two key elements are the gain generator assembly (GGA) and the optical resonator assembly (ORA). In addition to the GGA and ORA, there is also an exhaust management system, thermal management system, optical bench and structure, optical diagnostics, reactant feed and storage, as well as the mounting and support assembly (MSA), which is the vacuum chamber which houses Alpha. The ORA is full Alpha II size (but uses single layer coatings) while the GGA consist of 2 meters out of the full 5 meter long cylindrical bank of nozzles designed for Alpha II.

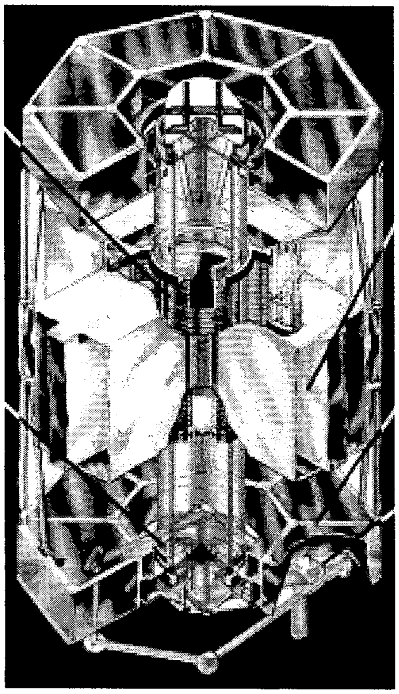

Figure 4. Alpha I Configuration

Figure 5 shows the overall Alpha facility. Most of the hardware is required to simulate space vacuum.

Gain Generator

The Alpha cylindrical gain generator is shown in Figure 6. Functionally, the device consists of a combustor, supersonic primary nozzles, secondary injection wedges, and a laser cavity. The combustor is used to generate a stream of free fluorine atoms that is expanded through the primary nozzles and mixed with hydrogen from the secondary injection wedges to form the vibrationally excited HF lasing species in the laser cavity at low pressure and temperature.

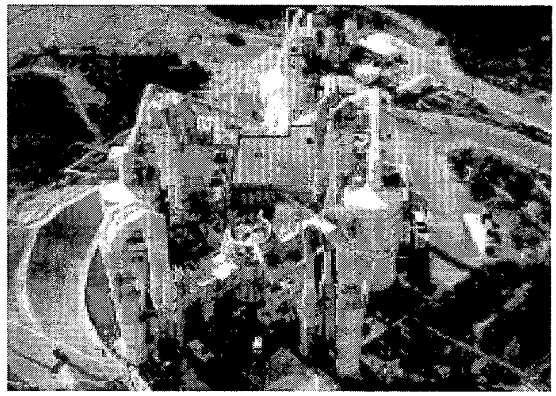

Figure 5. Alpha Facility

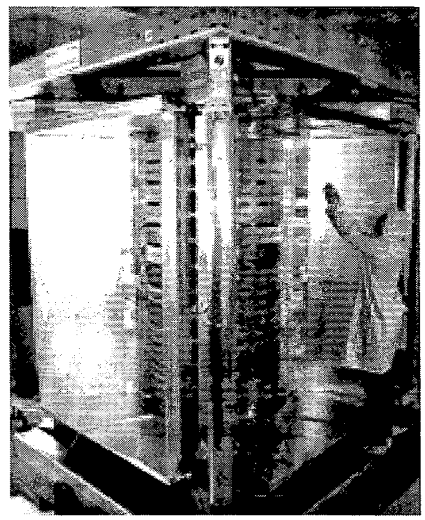

Figure 6. Alpha Gain Generator

The GGA hardware consists of stack of 27 aluminum rings (1.1 meters in diameter, 2 meters in height). The 27 rings, when stacked, provide 26 gaps between adjacent rings that form 26 cylindrical primary nozzles. Figure 7 shows a cross-section of two of these primary nozzles (one full ring and two half rings). The combustor is located on the inside of the rings (top of Figure 7) and the laser cavity is located on the outside of the rings (bottom of Figure 7). Also shown in Figure 7 are the secondary injection wedges that are used to inject the cavity hydrogen into the primary nozzle.

To generate the fluorine stream, the combustor burns excess oxidizer (NF_3) with a fuel/diluent (D_2/He). The combustor gases flow through the 26 gaps in the ring stack. The primary nozzles expand the combustor flow to

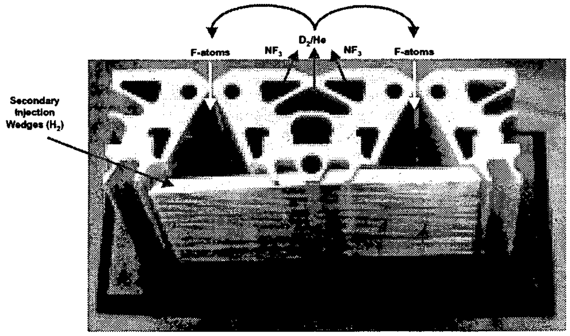

Figure 7. Alpha Gain Generator Details (Cross Section)

supersonic speeds to decrease laser cavity pressure and temperature, which minimizes cavity deactivation losses. The secondary nozzles, contained in the secondary injection wedges, inject hydrogen into the fluorine stream creating HF* for a gain region of around 3 cm downstream. The energy from the gain region is extracted by the resonator, and the spent effluents continue in their radial flow into the exhaust management assembly, and are pumped out of the Alpha through these ducts shown as cutaways in Figure 4. They are then pumped out by the Alpha pumping facility (Figure 5).

Optical Resonator

An isometric of the Alpha cylindrical resonator is shown in Figure 8. It extracts the optical energy from the 1.1 meter diameter gain generator. Since the ORA was designed to handle an entire 5 meter long Alpha II gain length, Alpha I has less than optimum extraction efficiency. The resonator for the Alpha laser is a High Extraction Decentered-feedback Annular Ring Resonator (HEXDARR). In Figure 9, the ORA is shown to consist of two regions; the Annular Leg, and the Compact Leg.

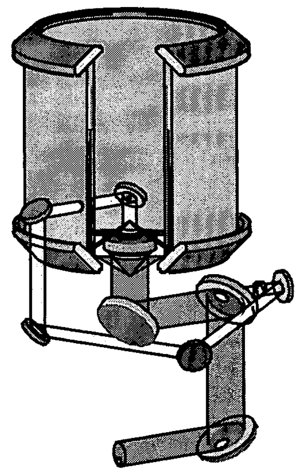

Figure 8. Optical Resonator Isometric

The Annular Leg contains the annular optics; the Waxicon Inner Cone (WIC) which is physically attached (back-to-back) to the Reflaxicon Inner Cone (RIC), the Waxicon Outer Cone (WOC) which is part of the same optic as the Reflaxicon Outer Cone (ROC), and the Rear Cone (RC). The rear cone and outer cone optics are

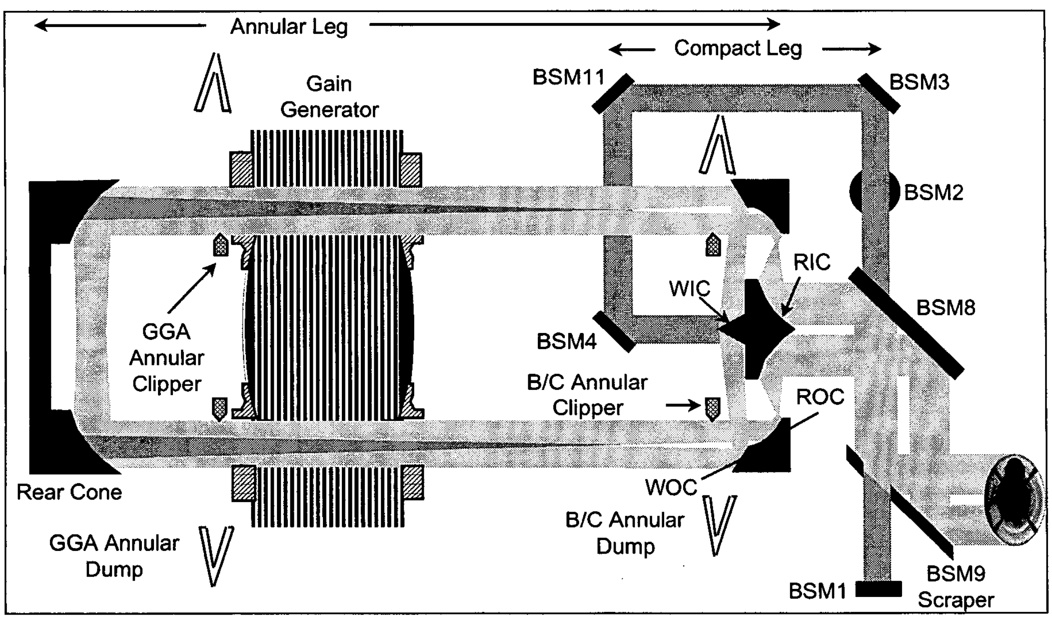

Figure 9. Alpha High Extraction Decentered-feedback Annular Ring Resonator (HEX-DARR)

slightly larger in diameter than the 1.1 meter diameter GGA.

The Compact Leg consists of the Large Turning Flat (BSM8), the Scraper (BSM9), and the small flats; BSM1, BSM2, BSM3, BSM11, and BSM4. The BSM4 optic is also called the small scraper because it has a hole in the center to allow stray energy to be dumped before it can strike the tip of the WIC.

The WIC/WOC/RIC/ROC optical surfaces form the Beam Compactor Module (Figure 10) which takes the collimated 8.3 cm beam from the Compact Leg (BSM4) and turns it into a 1.1 meter diameter annulus so that it can propagate twice through the cylindrical gain medium before it is turned back into a circular beam for outcoupling and feedback back into the resonator. The double passes through the gain medium can be visualized following one ray through the resonator. The ray first strikes the WOC part of the outer cone and propagates through the downstream part of the gain medium. The beam then strikes the RC and crosses over to the other side where it is turned back into the gain medium but travels through the upstream part of the gain. The ray then strikes the ROC and then the RIC part of the Beam Compactor and is outcoupled to the Compact Leg.

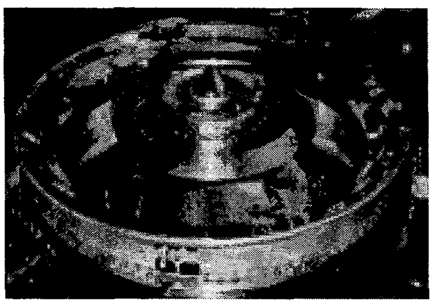

Figure 10. Beam Compactor

The annulus of light that propagates through the Annular Leg is magnified through the Beam Compactor so the 8.3 cm beam that entered the Annular Leg exits as a 25 cm beam. This beam is reflected from BSM8 to the scraper where ~90% is outcoupled to either the diagnostics and the Total Power Calorimeter (TPC) during an 'ALO' test (recently labelled as HL9xx), or to the Alpha Lamp Integration (ALI) beam control facility during an 'ALI' test (typically labelled HL4xx). The rest of the beam is fed back into the resonator through the small Compact Leg optics to continue the recirculating process of saturating the gain medium and extracting the energy. The resonator also contains clippers and dumps to maintain the safety of the hardware (especially the nozzles) from the recirculating high energy laser (HEL) beam. There are two sets of annular clippers in the resonator; one set is attached to the Beam Compactor and clips off the upstream part of the beam leaving the RC propagating to the ROC. The second set of clippers is attached to the Gain Generator and shadows the same portion of the beam that the Beam Compactor shadows. The role of the Beam Compactor clippers is very important, since they not only protect the hardware, but they also remove a significant fraction of the beam from the resonator, preventing it from being outcoupled. A major change made for the most recent tests has been repositioning the clippers in a safe, but less obstructive location.

6.0 ALPHA TEST SUMMARY

The recent ALO effort extracted insights from two 1999 high power tests, comparing the results to the "highest power 1992 test". The test history of the Alpha laser is illustrated in Figure 11.

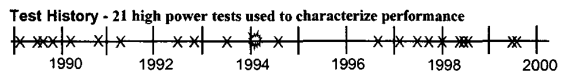

Figure 11. Alpha High Power Test History

The tests used in the current Alpha characterization are summarized below:

- HL909A – improved measurement of the alignment between the gain generator assembly and the optical resonator assembly, as well as repositioning of internal clippers after the realignment of the optical bench with the gain generator.
- HL909B – verification of HL909A performance repeatability

The key goals and results of the two tests are summarized in Table 2.

7.0 OBSERVATION SUMMARY

Most aspects of the Alpha data from these tests are well understood. In particular, our ability to predict and model the power and spectrum of the laser continues to improve.

Some of the highlights of the Alpha performance capability are discussed below.

The facility performance was exceptional. Recent repairs to the pumping system provided good diffuser performance and cavity isolation. The operating conditions, typically characterized in terms of scaled flow rate parameters and operating temperatures, were within 1-2 per cent of the target values. This is illustrated in Figure 12, in which the fluorine flow rate (MdotF/A), fluorine dissociation (alpha), temperature (Te), and diluent ratios (RL and Psi) are shown in the middle of the test, and compared to other tests with similar target

Table 2. Goals and accomplishments for HL909A & HL909B tests

Criterion	Results
Output power ≥ 10 TU	> 23 TU outcoupled in each test
Lasing Duration ≥ 2 seconds	Approximate 6 second run time
Sufficient power for model evaluation and reanchoring	Sufficient
GGA-ORA alignment tested and verified in low power tests, used in HL909A&B	GGA to ORA realigned; beam clipper position measured; clipper position reset for GGA-ORA alignment compatibility
ORA alignment tested and verified in low power tests, used in HL909A&B	ORA Alignment quantified using Power in the Bucket
Same laser operation settings used for HL909 as used as for HL908B	Operation conditions close to HL908B to permit comparisons. Changes in alignment and reduced cooling flow
Sufficient diagnostics to evaluate test results	Diagnostics – included facility improvements, new diagnostics, improved WFS
Repeatability: HL909B run after HL909A with limited changes	9 day turnaround; Filter cleaned; no changes to operating conditions
Lower coolant flow rates	Done – Lower residual jitter

values. The anomaly in HL909A is due to a low deuterium flow, which was fixed before HL909B.

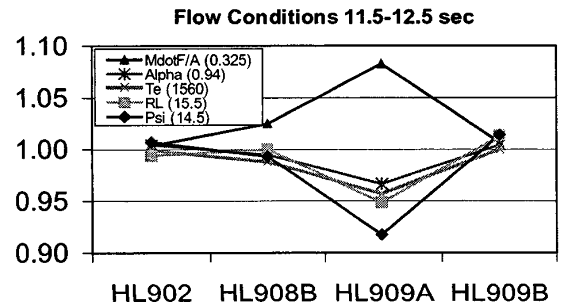

Figure 12. Operating condition comparison.

Important challenges in power observed in recent tests are that total power (in the gain medium) and power outcoupled (from the resonator) have been less than the maximum levels demonstrated in 1992 (test HL902). The HL909A and HL909B tests corrected this trend, by improving the performance of the resonator alignment, readjusting clipper positions (that had been overly conservatively placed, and whose position was changed in 1994), and improving the precision of measurement of dumped power. This improvement in power is illustrated in Figure 13. The laser power bar graph shows the comparison of wave optics resonator models with earlier tests, as well as the 1999 HL909A and HL909B tests. There is good agreement between the models and the HL909 experiments. There is still a large fraction of power in the shields, clippers and the dumps (where clipped power is redirected). Power may have degraded between HL902 and HL909, but that trend appears to have been corrected, presumably by the improved alignment, and HL902 and HL909 powers are comparable. Power is different from, and lower than, prediction, though HL909 demonstrates record power and agrees with models to within 20%. Power repeatability was verified between HL909A and HL909B. In addition, we have improved accuracy in outcoupled and dumped power, because of improvements in our instrumentation.

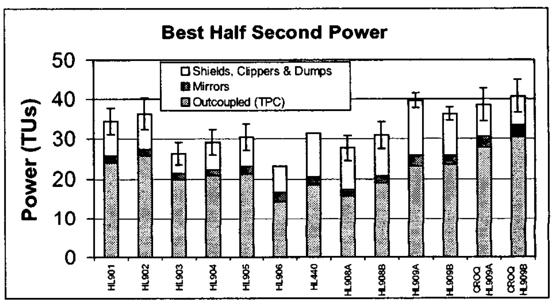

Figure 13. Power in HL909 tests is back to initial Alpha levels.

Another feature of the power produced by the Alpha is that it sometimes shows rapid fluctuations. This is not yet understood, and a low sample rate version of this data is shown in Figure 14. This figure also shows good repeatability in the power temporal trend, between HL909A and HL909B, and with earlier tests. The low power in the first second of HL909A is due to a combustor flow anomaly.

The laser spectrum has also been better understood as part of the current effort. In most recent tests, the laser spectrum has been dominated by four lines, two in each band. A fifth line appeared as a result of thermal growth of the gain generator during the HL909B test interacting with a slightly lower set of flow rates (that permitted longer gain profiles). This appearance of the P2(5) line, as in Figures 15a and 15b, was later shown to be

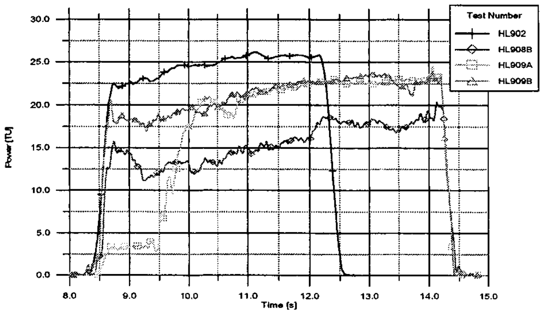

Figure 14. Time dependent power shows some fluctuations even at low rate sampling.

consistent with our standard models of the resonator. The P2(5) grows as the nozzle exit plane moves closer to the optical mode edge.

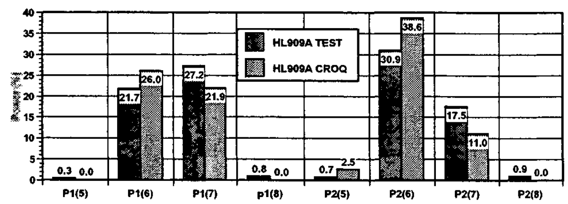

Figure 15a. HL909A Laser spectrum vs. model

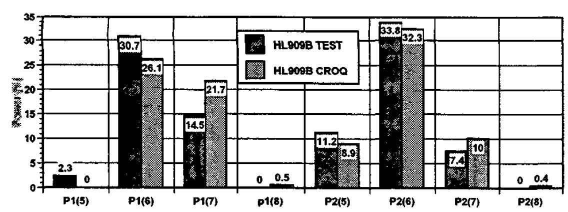

Figure 15b. HL909B Laser spectrum vs. model

The near field irradiance distribution in the past indicated non-optimal alignment (i.e. one quadrant, the D-quadrant, has more energy than other quadrants, and the central obscuration has been decentered). This is not seen in HL909A and HL909B, due to use of a more accurate alignment procedure developed in the past year. The resultant irradiance profile is shown in Figures 16a and 16b, in which the central hole (which is mapped from the outer edge of the gain region) is seen to be well centered, and the outer beam diameter is also seen to be nearly circular. The power in the four beam quadrants is integrated and compared to prediction in Figure 17, showing good agreement with prediction.

Uncorrected beam quality (BQ) is close to the budgeted amount but varies somewhat from test to test. The beam quality degradation is highly correctable with a wavefront correction system external to the resonator, though there is evidence that a significant portion can be and should be

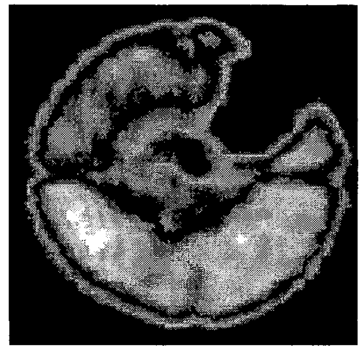

Figure 16a. HL909A Near field irradiance pattern

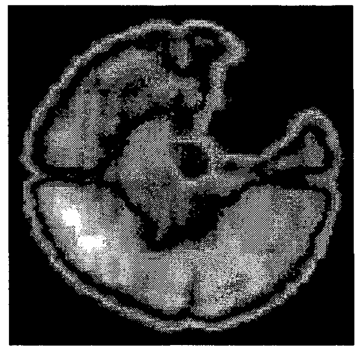

Figure 16b. HL909B Near field irradiance pattern

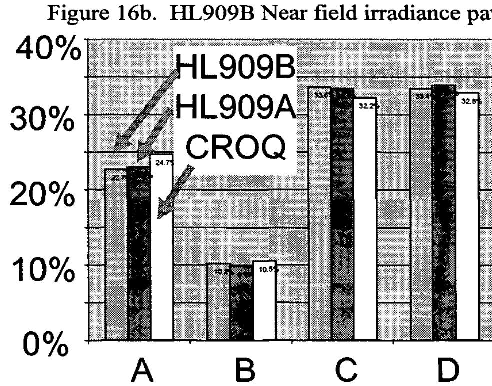

Figure 17. HL909 Quadrant power comparisons

prevented by improving resonator optical performance in order to reduce the stress on the wavefront correction system. In particular, the near field phase in the past has shown large cos(3ϕ) and cos(2ϕ) components, as well as a transient growth during first 1/2 second of lasing. The phase results from an earlier test are shown in Figure 18a.

The 3ϕ (coma-like) aberration derived from this phase profile was of concern, since it has no obvious source except for a component defect that is not believed to exist. In the HL909 tests, this component disappeared, as shown

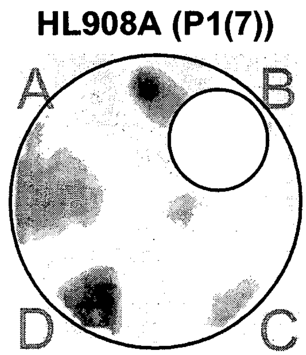

Figure 18a. Phase profile from a 1998 test

in Figure 18b. This has not yet been understood, and remains a major challenge for the Alpha program. Current postulates include concerns about the dependability of the phase reconstruction process.

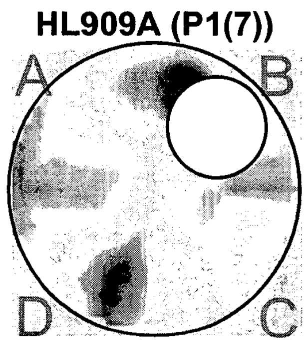

Figure 18b. Phase profile from HL909A

The jitter on the laser beam is within requirements, though determining this fact requires subtraction of the jitter contribution of some optical mounts in the input diagnostics assembly. These should be replaced to remove uncertainties associated with the extrapolation. Reducing the jitter further will permit reduction in stress on the jitter correction system. An important improvement in performance in the 1999 tests (HL909A and HL909B) was reducing the coolant flow in the beam clippers and dumps. These components are coupled to the resonator, so reducing the flow reduced the amount of high frequency resonator jitter. The fact that the high frequency jitter was reduced in the recent tests is shown in Figure 19. The jitter is decomposed into mirror (FTM) and sensor (FTS) components for the elevation (EL) and azimuthal (AZ) axes. The mirror carries most of the corrected jitter, and the sensor measures the high frequency jitter. The sensor jitter is reduced by a factor of two from earlier tests, showing the benefit of reducing the dump and clipper flow rates.

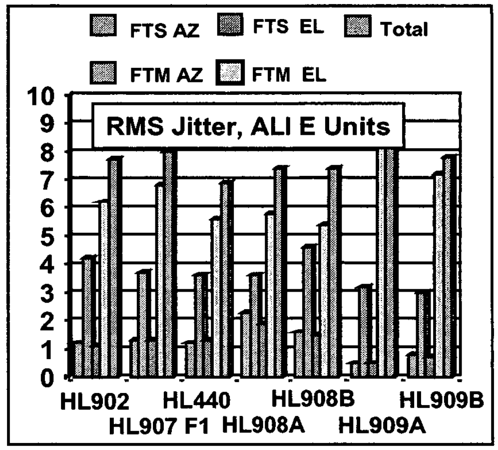

Figure 19. Jitter characteristics for recent tests

8.0 CONCLUSIONS

In summary, the performance requirements and goals for the two tests were met.

The total power observed in the HL909 tests are the highest yet on Alpha. The outcoupled powers are also among the highest seen to date. Power prediction is reasonable, and total power agreement with modeling is good, though not yet at the level needed for use in designing of a space system. Spectral content is also understood and consistent with model calculations.

Alignment improvements performed in 1999 are key to the improved performance, as predicted.

Power and beam quality repeatability were demonstrated, meeting a test goal.

The Alpha beam quality, when corrected for low temporal and low spatial frequency aberrations (as will be done for the operational system), is very good.

Open issues with the Alpha include the fact that though power was high, the amount of power in the clippers and dumps leaves some uncertainty as to the magnitude of the power produced. Moving to a configuration where more power is outcoupled could be of value in reducing this uncertainty.

Also, these tests have all been at one flow condition. If explored further, the multidimensional space could give greater insight into the impact of flow-optics interaction in the Alpha resonator, and help define optimization directions for design of future resonators.

Some features in the uncorrected phase still could be explored further to improve our understanding of the device. The amount of aberration, and whether it is 2ϕ or 3ϕ in azimuthal dependence, is important to understand, especially if this aberration is a property of alignment control (and not due to an optical component that will be replaced with the next SBL testbed). Also, the degradation of the beam quality over the beginning of the shot is a phenomenon that should be explored, and corrected in future designs if it is not just an Alpha-specific component effect.

Transient power effects (power rising in the beginning of the shot) remains a concern. Time dependent power effects are important to beam control operation, and require further characterization to be sure that the beam control interface requirements are properly specified.

Finally, the issues of beam polarization, reverse wave, compound wave and parasitics all have not been sufficiently explored for good characterization of the Alpha device.

The goal of the ALO effort is to improve modeling fidelity to the point where an SBL can be designed with confidence to minimize the required margin for future space based lasers. Alpha has helped to validate the design of lightweight bench structures, extruded aluminum cylindrical gain generators, annular optics and diagnostic technologies. It has been a robust testbed for furthering SBL technology development. Plans for continued use include better understanding of the maximum power that can be outcoupled, as well as the dependence of outcoupled power on flow conditions.

REFERENCES

[1] American Physical Society, 'Science and Technology of Directed Energy Weapons', Rev. Mod. Phys., 59, No. 3, Part II, July 1987

Sherwin Amimoto, Ph.D., Research Scientist at The Aerospace Corporation.

Bernard Bendow, Ph.D., Laser Analysis Senior Staff at TRW.

Robert S. Bradford, Jr., Ph.D., Senior Project Manager at TRW, rs.bradford@trw.com

Paul Dickinson, Optics Project Manager at TRW

Steven Fawver, Laser Device Engineering Staff at TRW, steve.fawver@trw.com

Dean Fitzgerald, Captain, US Air Force, Manager of Alpha Laser Optimization Program.

Derek Fluegge, Optics Engineering Staff at TRW, derek.fluegge@trw.com

Robert Geopfarth, Integration and Test Project Manager at TRW, bob.geopfarth@trw.com

David Johannsen, Ph.D., Senior Project Engineer at The Aerospace Corporation, david.c.johannsen@aero.org.

Munson Kwok, Ph.D. (aeronautics and astronautics with applied physics minor), Stanford University, Senior Scientist at The Aerospace Corporation. He has worked in chemical lasers for over 30 years, Munson.A.Kwok@aero.org

Pete Lohn, Ph.D., Gain Generator Senior Scientist, TRW, pete.lohn@trw.com

John Nella, Ph.D., Systems Engineer at TRW

Daniel E. Novoseller, Ph.D. (physics), Caltech, Project Manager at TRW, daniel.novoseller@trw.com

C. C. Shih, Ph.D (physics), Caltech, Laser and Resonator Senior Scientist at TRW, cc.shih@trw.com