

Optical Engineering

SPIDigitalLibrary.org/oe

Aero-Optics and Adaptive Optics for Aero-Optics

Eric J. Jumper

Aero-Optics and Adaptive Optics for Aero-Optics

Eric J. Jumper

University of Notre Dame
Institute for Flow Physics and Control
Notre Dame, Indiana 46556
E-mail: ejumper@nd.edu

Since the early 1980s when the Airborne Laser Laboratory (ALL) first demonstrated that a high-energy laser flown in a military aircraft was capable of performing both offensive and defensive missions, the concept of a speed-of-light weapon system has been in the mind of future weapons planners. The ALL used a powerful CO₂ laser which lased at 10.6 μm. The maximum intensity at the target for a diffraction-limited beam of power P_o and aperture A is related to the inverse of wavelength λ times distance to the target R squared:

$$I_o = \frac{P_o A}{\lambda^2 R^2}.$$

Thus, the natural aspiration was to develop high-energy lasers that lase at shorter wavelengths to increase the lethal range of the laser for the same power and aperture size. On the other hand, the reduction in diffraction-limited intensity due to aberrations, measured in rms optical path difference OPD_{rms} imprinted on the beams wavefront by turbulent density fluctuations in the air flowing over the exit pupil, is governed by the large-aperture approximation

$$\frac{I}{I_o} \cong e^{-\left(\frac{2\pi \text{OPD}_{\text{rms}}}{\lambda}\right)^2}.$$

As will be explained in the papers in this special section of *Optical Engineering*, the aberration environment due to separated flows over the aperture and to a lesser extent attached turbulent boundary layers, referred to as aero-optics, stand as a system-performance limiter that must be understood and mitigated in order to appreciate the diffraction-limited promise of short-wavelength high-energy lasers that both exist now and have been integrated into demonstration airborne laser weapon systems. Experience gained from these demonstrators has underscored the important enabling technology of learning how to manage aero-optic effects. Although aero-optics has been studied since the 1970s, it is not an exaggeration to state that the Airborne Aero-Optics Laboratory (AAOL) program has contributed an order of magnitude more knowledge about aero-optics than the three decades of study that preceded it.

This special section, although broadened to include aero-optics in general, turns out to be primarily on the AAOL and analysis of the wavefront data collected during the AAOL program. While other papers making use of the AAOL data exist in other venues, this special section is by far the most extensive single collection of AAOL results. Included in the papers “Airborne Aero-Optics Laboratory” by E. Jumper et al. and the “Design, development, and in-flight testing of a pointer/tracker for in-flight experiments to measure the aero-optical effects

over a scaled turret” by M Krizo et al. are the only detailed description of the AAOL and laser-source aircraft used in the program.

Except for two historical papers, the remaining papers in this special section contain analysis of in-flight data, wind-tunnel data, or numerical data generated by the AAOL program. It should be noted that while many of the papers are authored by people involved in the AAOL program, others are written by researchers making use of the AAOL data; these data can be made available to others by contacting Notre Dame. The two historical papers are “The Airborne Laser Laboratory departure from Kirtland Air Force Base and a brief history of aero-optics,” by D. Kyrakis and “Challenges of high-brightness laser systems: a photon odyssey,” by K. Gilbert. These two papers have special significance to me, because although the AAOL is a much less-complicated program—at the university level with a much smaller team and a much-shortened time period—we felt a kinship to the ALL. I was present when Dr. Kyrakis delivered the ALL departure from Kirtland AFB to the Air Force Museum, and I was much inspired by it; parts of that address have often replayed in my mind as the AAOL approached its first successful data flight, and I felt Dr Kyrakis’ comments should have a wider audience. Keith Gilbert’s paper, in its original 1988 memo form, made me aware of the challenges that would be imposed by short-wavelength lasers as they propagated through the turbulent flow that surrounds an airborne laser platform. From a historical perspective, I felt it important to make these two papers more widely available in an archival format.

As discussed above and in the paper “Airborne Aero-Optics Laboratory,” the AAOL program, which has now ended, has greatly advanced the understanding of aero-optics and made available copious amounts of data that can and have been used to develop adaptive-optic approaches to mitigating aero-optical, system-degrading effects. The AAOL program has also provided a venue for examining flow-control mitigation strategies. As Keith Gilbert’s paper points out, the challenges to high brightness for short-wavelength lasers are higher-order wavefront aberrations in general; aero-optical flows around aircraft impose just these sorts of aberrations at frequencies that challenge traditional methods of adaptive-optic systems. As such, aero-optics forms one of the major challenges to airborne laser systems. The importance of the AAOL program cannot be understated and it is to the program’s credit that a follow-on AAOL-T program has now begun; the “T” stands for “transonic,” and the new program will migrate from Cessna Citations to Falcon 10’s that will allow testing at Mach numbers above Mach 0.8.



Eric J. Jumper is a professor in the Department of Aerospace and Mechanical Engineering at the University of Notre Dame. His PhD (1975) is in gas dynamics and laser physics from the Air Force Institute of Technology. Since the mid-1990s he has directed the Aero-Optics Group within Notre Dame's Institute for Flow Physics and Control (FlowPAC); the AAOL is one of the research programs in the Aero-Optics Group. He has published more than 50 papers in the area of aero-optics.