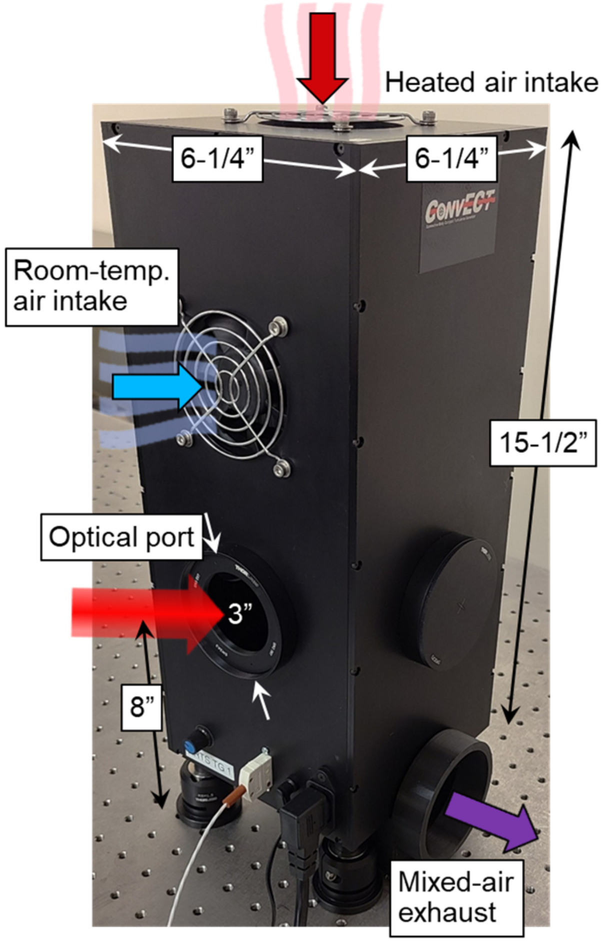
ConvECT Laboratory Turbulence Generator, TG-30-6614

Convective Eddy Compact Turbulence Generator



Description

MZA's Convective Eddy Compact Turbulence (ConvECT) generator units create real, dynamic turbulence for laboratory experiments. This allows researchers to test optical systems in a laboratory prior to use in outdoor, open-air experiments. The experimenter can adjust the turbulence setting to create known conditions for testing optical systems in parametric studies. This reduces technical risk and cost for outdoor optical experiments when distances at the test site are long enough that turbulence is a significant degrading factor. Optical turbulence degrades spatial coherence and imaging resolution. Accordingly, ConvECT units to add realism to laboratory measurements.

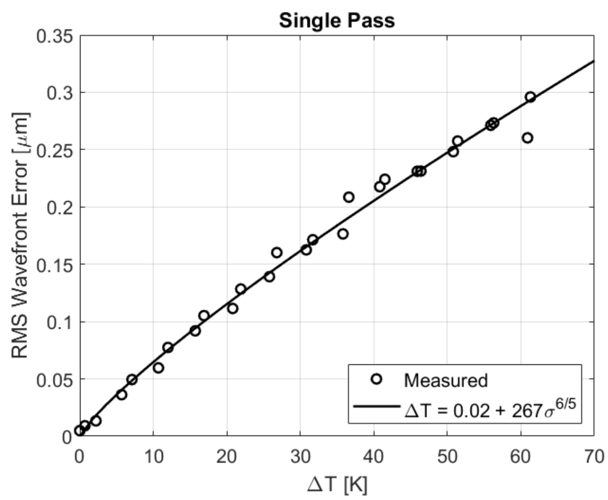
MZA can provide other equipment like a wavefront sensor to observe the turbulence conditions during the test. MZA's WavefrontTools and SlopeTools are ideal for analyzing data from such wavefront sensors. With this, the experimenter can correlate exact turbulence realizations with optical system performance.

Applications

- **Long-range passive and active imaging**
- **Ground-based astronomy and optical space surveillance**
- **Free-space optical communication**
- **Directed energy laser beam projection**
- **Wavefront sensing and adaptive optics**
- **Long-range direct-detect and coherent lidar**

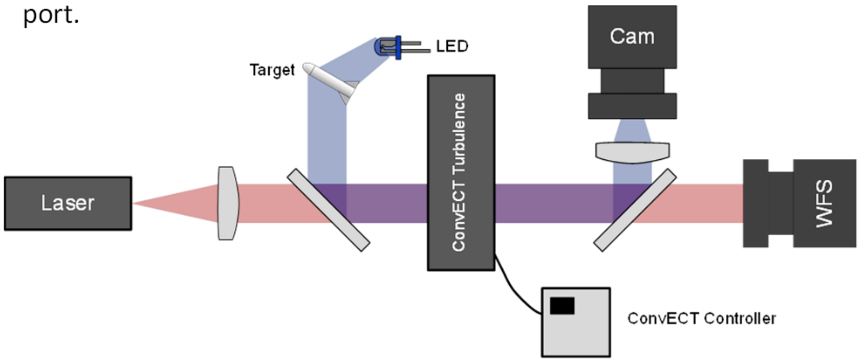
Unique Advantages

- **Inexpensive turnkey source of turbulence**
- **Engineered, compact, modular design**
- **Real-time, dynamic wavefront aberrations**
- **Broadband chromatic effects**
- **Calibrated, adjustable turbulence with r_0 > 4.2 mm**
- **Key building block for compact propagation range**
    - **Acts as surrogate for outdoor turbulence**
    - **Use multiple ConvECT units for distributed volume turbulence effects like anisioplanatism**
    - **Can vary turbulence along propagation path**



Operation

Heated air and room-temperature air are mixed inside the device to create convection and refractive-index fluctuations. The temperature difference controls the optical effect. The turbulence is blown downward into the beam path and then out the exhaust port.



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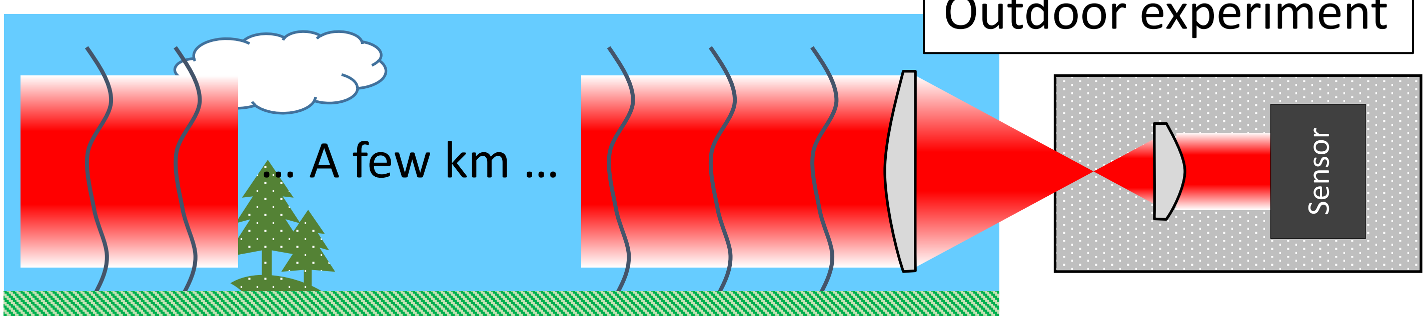
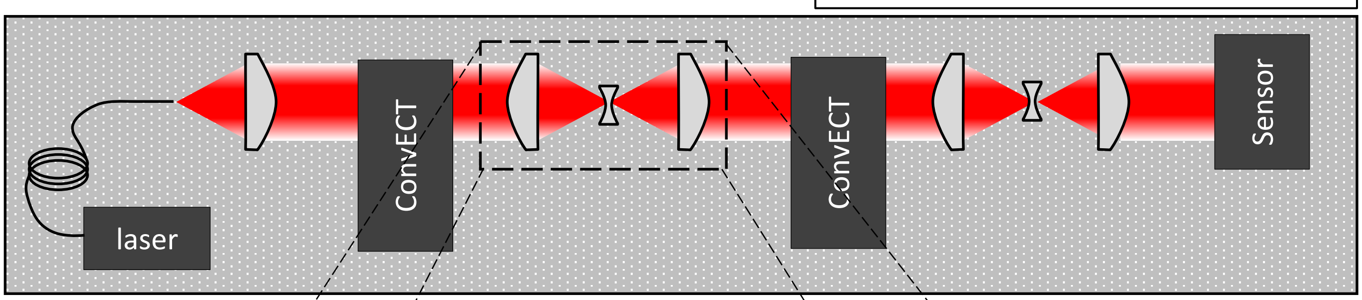
Compact, Turbulent Propagation Range in the Laboratory

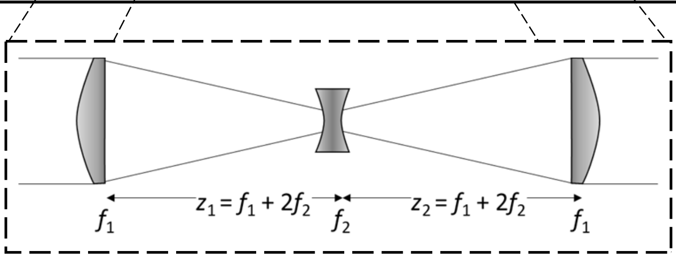
Thin phase screens can be used to emulate the effects of distributed volume turbulence in a laboratory. Fresnel scaling and appropriate relay optics can be used to scale multi-kilometer turbulence effects to fit onto a standard optical table. Diffraction effects for two beams are equivalent if they have the same Fresnel number. This way, the propagation distance scales with the square of the beam diameter. When a 30 cm beam outdoors is shrunken to 3 cm indoors, the propagation distance shortens by a factor of 1/100. 10 km outdoors becomes only 100 m indoors. Additionally, a three-lens system can achieve the effect of a much longer propagation distance in a compact space. We could use two ConvECT generators with 50 m of propagation each, which only takes a few meters of table space. To match the turbulence effect between long propagation outdoors and compact propagation in the laboratory, we adjust the settings on ConvECT so that D/r_0 and the Rytov number in the laboratory to match the outdoor path. While outdoor turbulence varies throughout the day, the laboratory setup matches one condition at a time, which works for parametric studies.

Outdoor experiment



Laboratory experiment





Key Equations:

Fresnel number

$$N_F = \frac{D^2}{4\lambda L}$$

Effective propagation distance for three-lens system

$$L_{eff} = -\frac{f_1^2}{f_2} - 2f_1$$

Fried parameter

$$r_0^{-5/3} = 0.432k^2 \int_0^L C_n^2(z)(1-\tfrac{z}{L})^{5/3}dz$$

Rytov number

$$\mathcal{R} = 0.563k^{7/6}L^{5/6} \int_0^L C_n^2(z)(\tfrac{z}{L})^{5/6}(1-\tfrac{z}{L})^{5/6}dz$$

Flexible configurations: The center lens's focal length adjusts location of phase screens.

Temperature settings can adjust turbulence strength of each ConvECT unit

	Real World Conditions	Lab Conditions	Three-Lens System	
wavelength [micron]	0.635	0.635	f1 [mm]	f2 [mm]
aperture diam [cm]	30	3		
range [m]	5,000	50.00	2,000.00	74.07
range [m]	3,500	35.00	2,000.00	102.56
range [m]	1,700	17.00	2,000.00	190.48
range [m]	500	5.00	2,000.00	444.44

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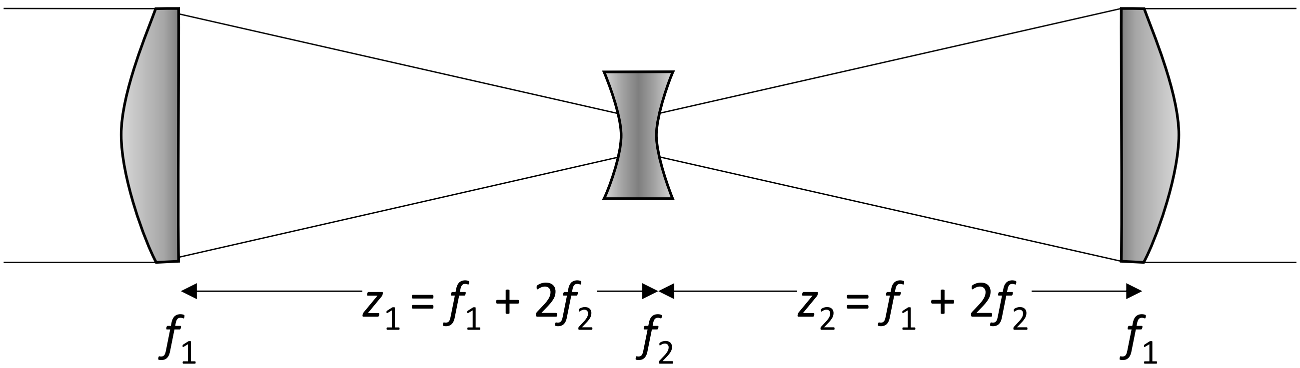
r_0< 50 mm



- $z_{eff} = -\frac{f_1^2}{f_2} - 2f_1$
- Beam does not focus
  - Minimum spot diameter is **2-3.5 mm**
  - Possible air breakdown less likely
  - Can use mirrors to alleviate limitations

Solve for Real World Range				
	Real World Conditions	**Lab Conditions**	**Three-Lens System**	
wavelength [micron]	1.064	0.532	f1 [mm]	f2 [mm]
aperture diam [cm]	30	2.54		
range [m]	10,881	156.00	2,000.00	-25.0
range [m]	5,301	76.00	2,000.00	-50.0
range [m]	3,441	49.33	2,000.00	-75.0
range [m]	2,511	36.00	2,000.00	-100.0