

Environmental Modeling and Athermalization in CODE V

Use Multi-Environment Coupling for Super-
Athermalized Lens Designs

Introduction

Today's challenging optical designs need to perform over large temperature and pressure ranges. A robust and streamlined Multi-Environment Coupling (MECo) capability provides a simplified process for modeling and optimizing optical designs over significant environmental demands. It allows you to easily model the effects of changes in operational environment temperature and pressure for optical system with both spacer- and seat-based mounting schemes.

Why are Environmental Modeling and Athermalization Important?

The screenshot displays the CODE V software interface. On the left, three tables show environmental data for different positions, all coupled with POSITION 1. The tables include columns for SURF, LABEL, GLA, RMD, TEMPERATURE (deg C), PRESSURE (mm Hg), and INST CTE (ppm/C). The data for POSITION 1, 2, and 3 is as follows:

POSITION	SURF	LABEL	GLA	RMD	TEMPERATURE (deg C)	PRESSURE (mm Hg)	INST CTE (ppm/C)
POSITION 1	OBJ		AIRATP		22.000	760.000	
	1	e1s1	NLAK12_SCHOTT		22.000		7.624
	2	e1s2	AIRATP		22.000	760.000	
	3	e2s1	SFS7HTULTRA_SCHOTT		22.000		8.313
	4	e2s2	AIRATP		22.000	760.000	
	STO	stop	AIRATP		22.000	760.000	
	6	e3s1	NLAK33B_SCHOTT		22.000		5.948
POSITION 2 (coupled with POSITION 1)	OBJ		AIRATP		-80.000	760.000	
	1	e1s1	NLAK12_SCHOTT		-80.000		7.005
	2	e1s2	AIRATP		-80.000	760.000	
	3	e2s1	SFS7HTULTRA_SCHOTT		-80.000		7.985
	4	e2s2	AIRATP		-80.000	760.000	
	STO	stop	AIRATP		-80.000	760.000	
	6	e3s1	NLAK33B_SCHOTT		-80.000		5.399
POSITION 3 (coupled with POSITION 1)	OBJ		AIRATP		120.000	760.000	
	1	e1s1	NLAK12_SCHOTT		120.000		8.219
	2	e1s2	AIRATP		120.000	760.000	
	3	e2s1	SFS7HTULTRA_SCHOTT		120.000		8.628
	4	e2s2	AIRATP		120.000	760.000	
	STO	stop	AIRATP		120.000	760.000	
	6	e3s1	NLAK33B_SCHOTT		120.000		6.278

On the right, a 'List Environmental Data' dialog box is open, showing a list of environmental data options with checkboxes:

- ☒ All Environmental Data
- ☒ Environmental Couplings
- ☒ CTE Formula Coefficients
- ☒ Surface Environmental Data
- ☒ Housing Link Definitions
- ☒ Surface Environmental Contacts
- ☒ Housing Link Lengths
- ☒ dn/dT Formula Coefficients

With the increasing demand for image quality and the diversification of lens applications, it is more important than ever to consider environmental factors in the design process. Many optical systems operate across different environments, such as aerospace and defense, consumer electronics, automotives, and industrial applications.

A change in operating temperature shifts the focal plane and introduces aberrations, as the lens system deforms and the indices of the optical materials vary. Therefore, the performance of an imaging lens can be greatly affected by ambient temperature and pressure. This creates an athermalization task to design an imaging system that works well across a changing environment. To help optical engineers conquer this challenge, CODE V offers a unique and streamlined Multi-Environment Coupling (MECo) capability.

MECo provides a simple process for modeling and optimizing optical designs over significant environmental demands. MECo is built to use your nominal lens design data in the CODE V interface and create coupled positions of your lens that operate at different temperatures and pressures. CODE V automatically computes the changes in the lens system in multiple environments. Since these coupled positions exist in the model simultaneously, you can then optimize the design using CODE V's Automatic Design feature, and select materials using Glass Expert as you would in any design with CODE V. It is also possible to optimize the housing materials. This process can lead to solutions that have low environmental sensitivity. Creating super-athermalized optical designs is easier than ever with MECo and Glass Expert.



Figure 1. A 360° panorama of the Jezero Crater on Mars taken by Mastcam-Z (Credit NASA/JPL-Caltech/ASU/MSSS). Mastcam-Z provides excellent imaging performance over temperature swings from -10°C (+14 °F) to a -80°C (-112 °F) over short to long focus.

Applications

Environmental modeling and athermalization are important for many applications.

- A crucial aspect of spaceborne optical design is thermal vacuum considerations due to the harsh environment.
- Infrared optical systems often use a cryogenic dewar to house an infrared sensor.
- Consumer camera modules are expected to perform during both skiing and safari trips.
- Lenses for outdoor surveillance and automotive must adapt to significant temperature variations.
- Underwater cameras function across a huge pressure range.
- Machine vision systems prioritize precision and stability under demanding conditions to ensure the reliability and repeatability of automated industrial tasks.
- Optical systems for agriculture and environmental monitoring are subjected to significant environmental extremes.

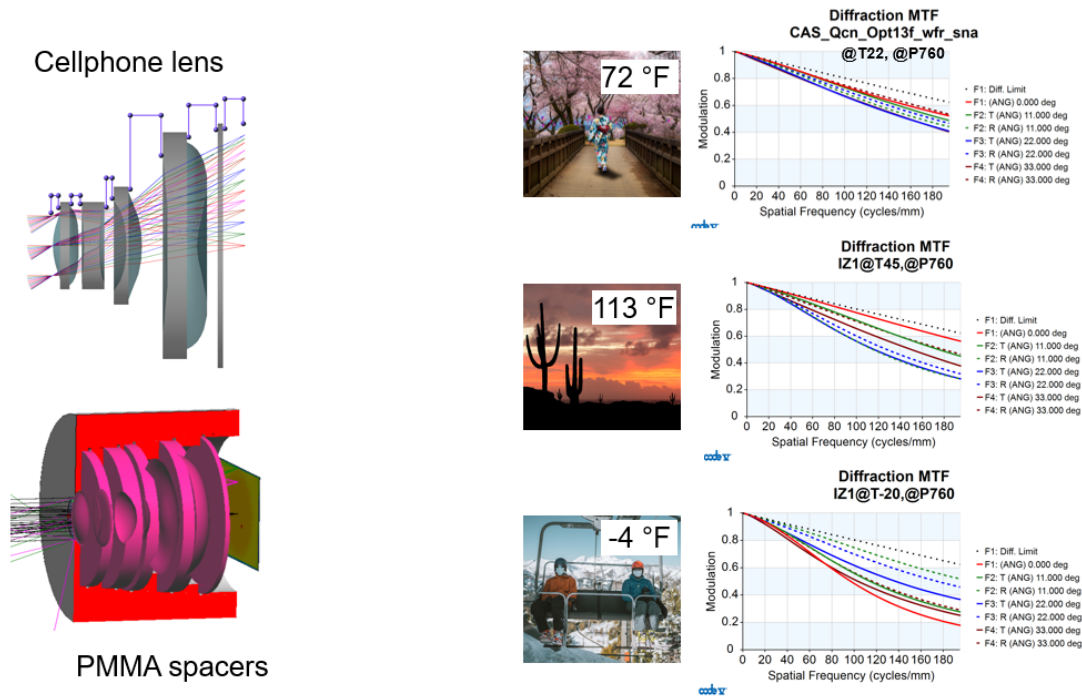


Figure 2. Consumer electronics require high performance over many weather conditions. In this cellphone lens, the performance at room temperature is good, while the performance at higher and lower temperatures can degrade unless the system is athermalized when designing.

MECo Key Capabilities

With MECo, designers can quickly set up configurations for different temperatures and pressures. It is easy and automatic to build environmentally coupled models to analyze lens performance under different environmental conditions. With MECo, you can:

1. Create **environmental zoomed positions** that are coupled together. When an independent zoom position (nominal design) changes, the dependent zoom positions (environmentally coupled design) update automatically. Thermal impacts on refractive indices, lens shape, lens spacing, and lens mount locations are automatically and accurately computed.
2. Model **multiple temperatures and pressures** in the same lens. Each element and space can be set to a different temperature and pressure. Each housing zone can be at a different temperature, which may be different from the optical materials. This flexibility allows designers to simulate real-world environmental conditions more accurately.
3. Support **arbitrary lens mounting schemes**, whether they are spacer based, seat based, edge mounted, surface contacts on a flange or notch, as well as combinations of these schemes. Lens mounting details are critical for thermal modeling schemes.
4. **Visualize** the opto-mechanical interfaces (housing links) without the need for detailed opto-mechanical mounts.
5. **List** all the environmental data for a detailed review of the model (ELI).

6. Have easy **material** handling: Properties for all common optical materials are included. User-defined materials are easily entered. If you have a special aluminum alloy or glass melt, just enter the CTE and dn/dT coefficients.
7. Perform thermal analysis with supplied macros to:
 - Analyze and plot performance vs. temperature for aberration terms, RMS wavefront error, best composite focus shift, MTF
 - Fit material data to dn/dT formula and Coefficient of Thermal Expansion (CTE) formula
 - Produce sensitivity analysis due to fabrication temperature
 - Convert a Meco zoomed system to an uncoupled system

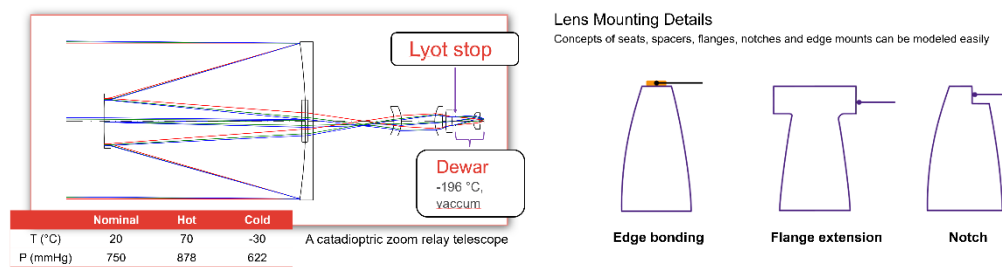


Figure 3. MECo supports the simulation of a dewar-based optical system and arbitrary lens mounting schemes. Lens mounting details are critical for thermal modeling

- Systems supported by MECo:
 - Axisymmetric
 - Folded systems
 - Zoom (multi-configuration) systems
- Surface types supported by MECo:
 - Spherical
 - Conic
 - Rotationally Symmetric Asphere
 - Qcon Asphere
 - Qbfs Asphere
 - Standard Zernike
 - Fringe Zernike Surface Types

Seamless and Intuitive Workflow

MECo's operation process is designed to be extremely seamless, allowing designers to easily set up and analyze multiple environments. Figure 4 shows how this feature works.

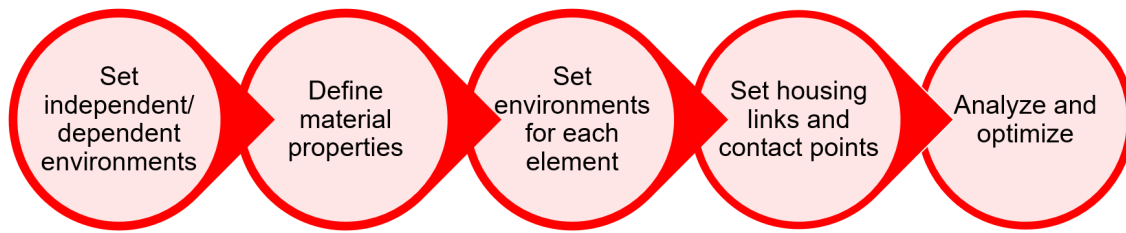


Figure 4. MECo operation process

- **Independent/dependent Environments:** First, set the nominal temperature and pressure of the lens. This is the environment that is typically used in manufacturing conditions. You can then add multiple dependent environments all at once.
- **Define Material Properties:** Enter CTE and dn/dT coefficients for custom optical materials or housing materials. CODE V automatically loads CTE and dn/dT information for catalog optical materials and provides reference data for commonly used housing materials. This data can be easily modified/entered for a specific glass melt, private material and aluminum alloy.
- **Environments for Each Surface:** Set temperatures and pressures for each element or space in the lens. You can model different environmental conditions for each individual optical element. This level of control allows you to model dewar-based optical systems that are common for infrared system design. You can also model a system where the temperature of the housing and the temperature of the lens elements are different. Modeling housing and lens temperature differences is often important, as the thermal contact between the housing and the lens is limited.
- **Set the housing link and contact point:** Set the contact point position of the mount or spacer on the lens surface. The contact point can be set to extend along a curved or flat surface from a transparent aperture. Extensions of notches or flanges can be defined to implement different optomechanical models. You should collaborate with the thermal engineer to make sure the thermal and optical models are in close agreement.
- **Analysis and Optimization:** After completing the above settings, you can evaluate the optical performance. If necessary, CODE V's proprietary Glass Expert can be used to athermalize your optical design.

MECo Workflow Example

In this section, we will use a triplet lens to illustrate the MECo workflow. We set up the system to cover a temperature range from -80 °C to 120 °C. MECo can be used to set up spacer-based or seat-based mechanical links. We can visualize the links and contacts in the 3D viewer to review thermal expansion and contraction of mechanical parts due to temperature changes. Figures 5 and 6 show spacer-based and seat-based mechanical links, respectively. We show both the schematic diagram of the mechanical link (upper) and the corresponding 3D view in CODE V (lower).

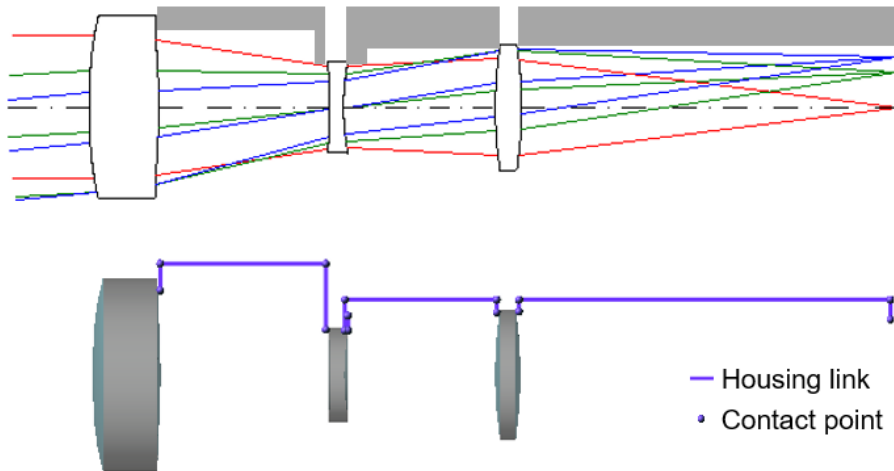


Figure 5. Spacer-based mechanical links

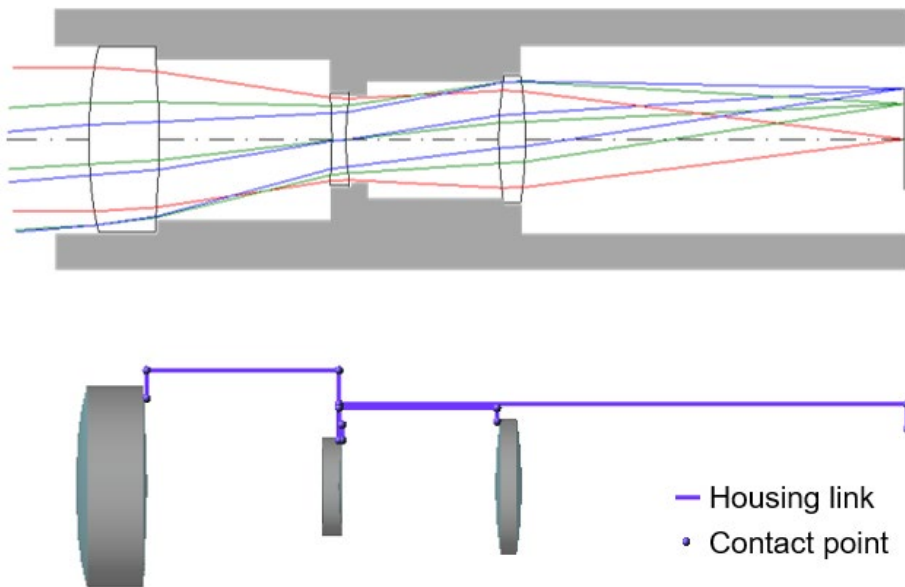


Figure 6. Seat-based mechanical links

With MECo, it is easy to enter CTE coefficients for both mechanical and optical materials (Figure 7). MECo uses exponential calculations to handle thermal expansion and contraction, which is more accurate than linear assumptions.

	Material	Reference	T0 (deg C)	CO	C1	C2	C3	C4	C5
1	NLAK12_SCHOTT	Catalog	20.0000	7.6000 e-06	1.2143 e-08	0.0000	0.0000	0.0000	0.0000
2	'AI6061MH'	Default	0.0000	2.2217 e-05	2.2217 e-05	2.2217 e-05	2.2217 e-05	2.2217 e-05	2.2217 e-05
3	SF57HTULTRA_SC HOTT	Catalog	20.0000	8.3000 e-06	6.4286 e-09	0.0000	0.0000	0.0000	0.0000
4	Consumer	Catalog	20.0000	5.8300 e-06	8.7857 e-09	0.0000	0.0000	0.0000	0.0000

Figure 7. CTE coefficients for both mechanical and optical materials

MECo also provides a detailed listing of environmental data (Figure 8). This listing is convenient for designers to review the specific mechanical changes on each surface in each environmental setting.

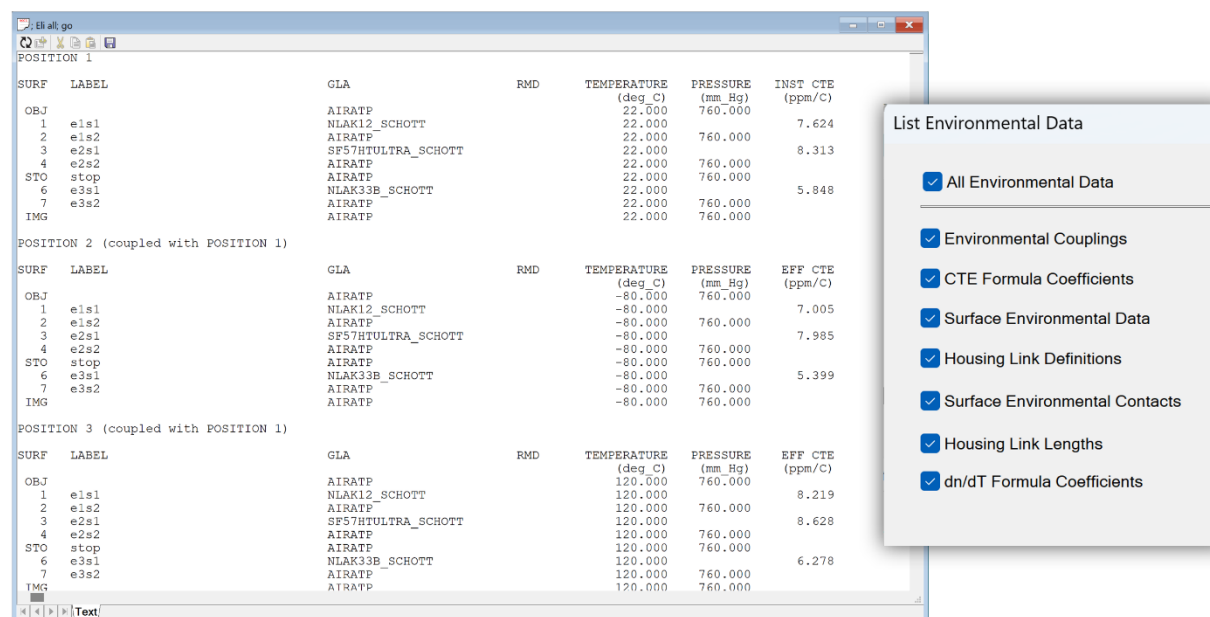


Figure 8. Listing of environmental data

Finally, CODE V's proprietary Glass Expert allows designers to create super-athermalized lens designs. The following figure shows the results before and after using Glass Expert to athermalize the triplet system with a seat-based housing. After athermalization, there is a significant improvement in performance.

Figure 9 shows the transverse aberration plot up to 0.02 mm. The defocus at the cold and hot environment is significantly reduced after athermalization. The transverse aberrations started at more than 0.02 mm before athermalization and were reduced to less than 0.007 mm after athermalization.

Figure 10 shows the MTF vs. frequency with a maximum spatial frequency of 42 cycles/mm in the nominal (left), cold (middle), and hot (right) environments. MTF is consistently close to the diffraction limit MTF (black dashed line) across temperatures after athermalization. Figure 11 shows the MTF at 42 cycles/mm vs. temperature before and after athermalization. We observe significant improvements and stable imaging performance across a 200-degree temperature range.

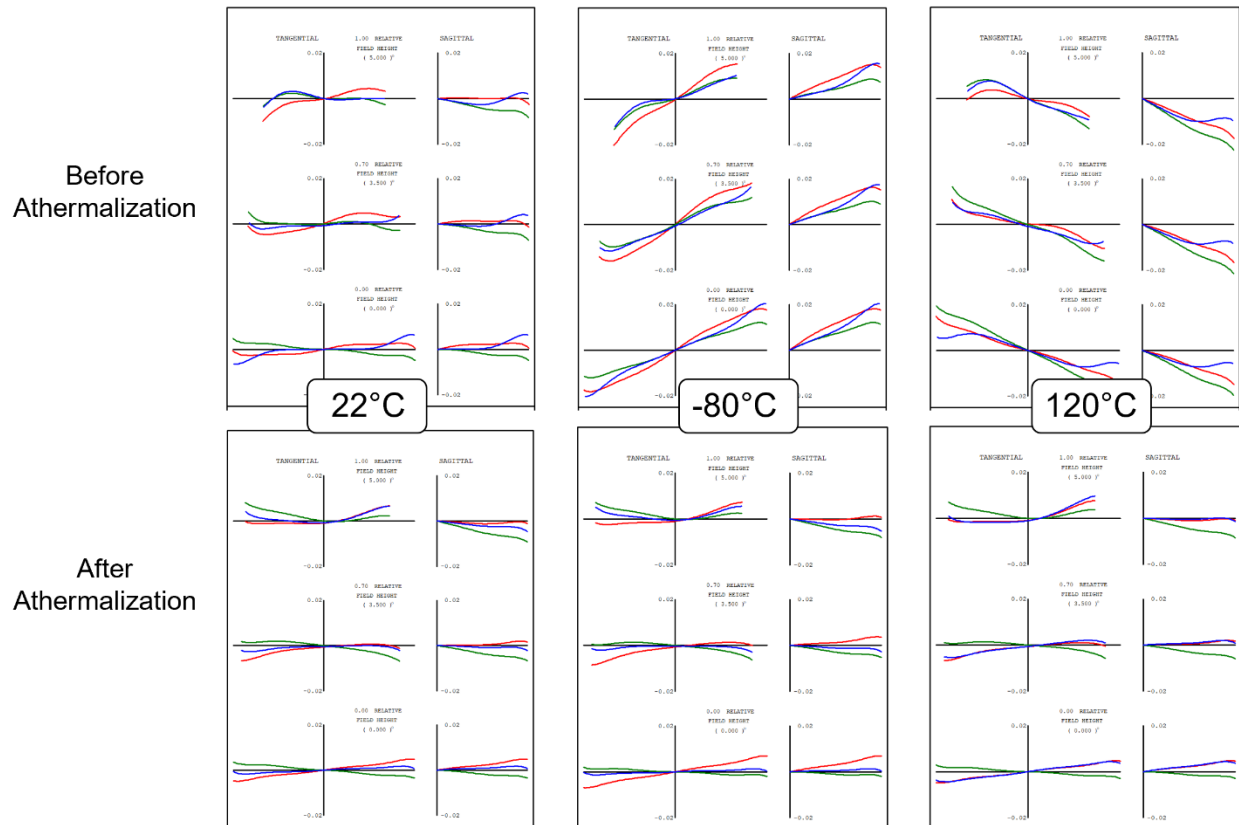


Figure 9. Transverse aberration plot up to 0.02 mm

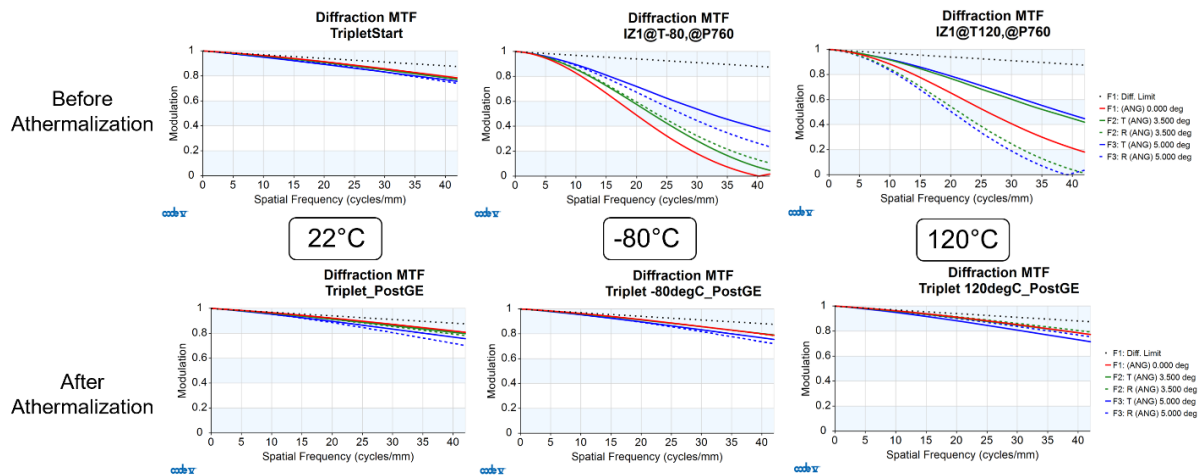


Figure 10. MTF vs. frequency with a maximum spatial frequency of 42 cycles/mm in the nominal (left), cold (middle), and hot (right) environments

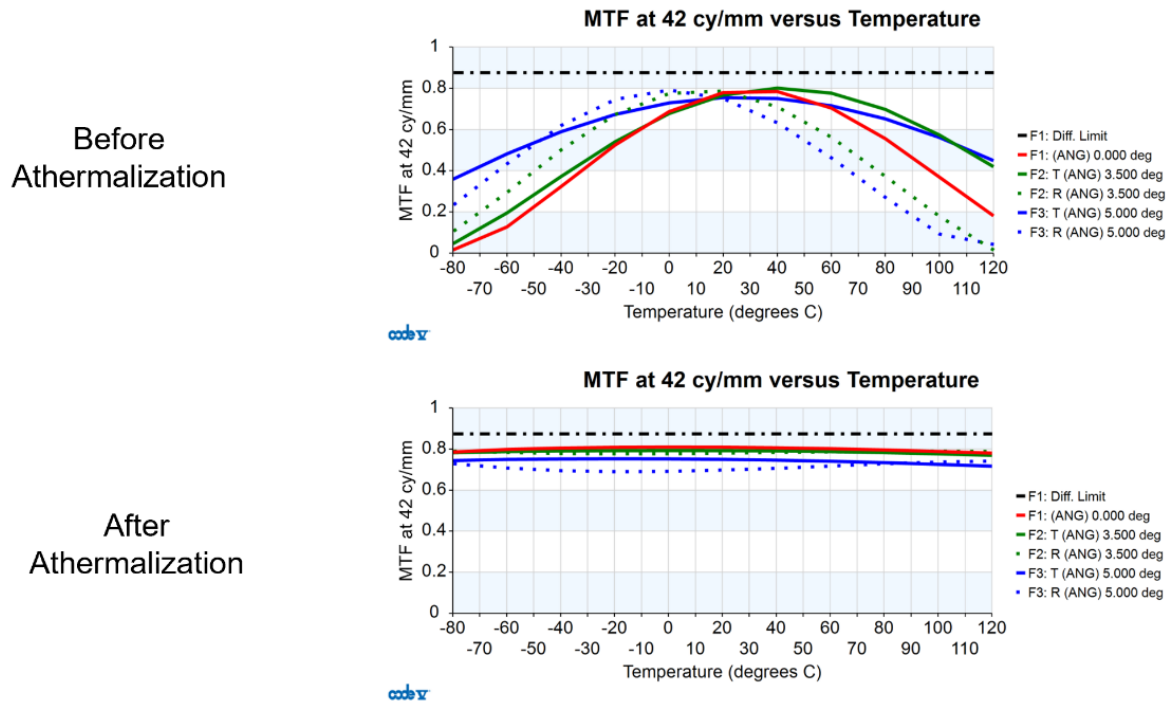


Figure 11. MTF at 42 cycles/mm vs. temperature before and after athermalization

Summary

CODE V's MECo feature provides a powerful, user-friendly platform for designers to create athermalized or environmentally compensated lenses. By considering environmental factors in the design from the start, MECo ensures that the lens design delivers exceptional image quality across extreme environments. This is particularly important for sectors that require high performance and reliability, such as automotive, aerospace, consumer electronics, and industrial applications. By leveraging MECo, optical designers can effectively overcome various environmental challenges and design superior optical products across temperature and pressure ranges.



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