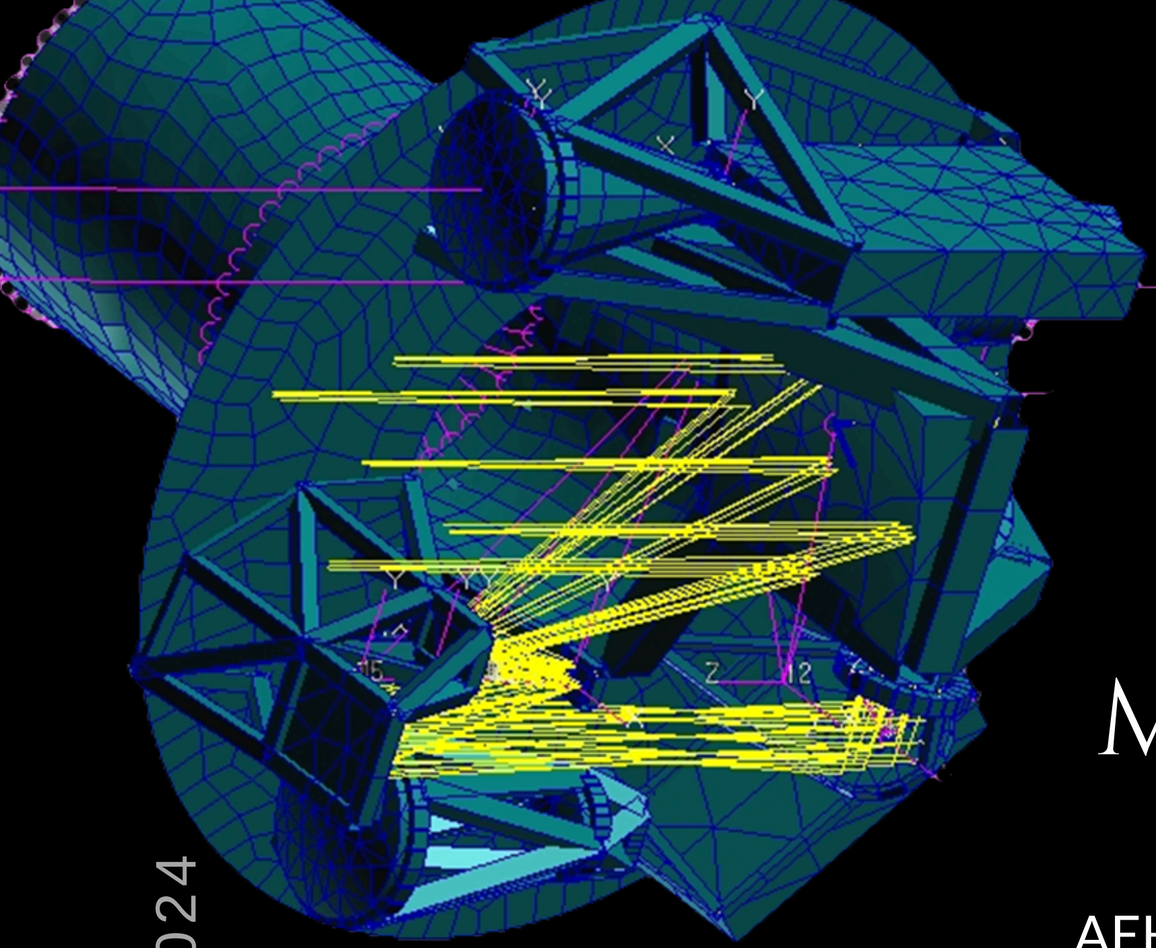


Ivory

Managing the Mechanics of Images

AEH's Optomechanical Modeling Tools save time and money in the design of optical systems.

2024

AEH.

Engineered Solutions

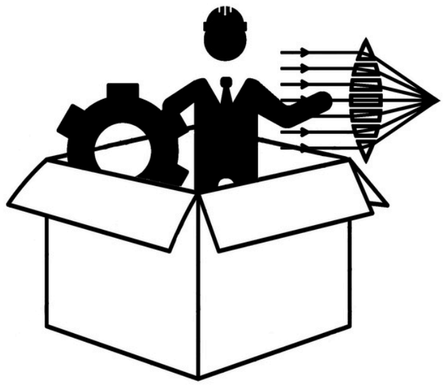
Ivory is like having a world-class optomechanical engineer in a box...

Ivory's job:

Evaluate the image's mechanical alignment and stability

Static, Dynamic, Thermal

Ivory is a tool for engineering thermally and structurally reliable optical systems. It is a lightweight and fast application, developed for engineers, designers and analysts who work with optical instruments. It reads the physical prescription data for the optical design and automatically produces the complete array of coefficients of all the influences of all of the optical elements on all of the image motions on the detector. It also produces the imaging properties (focal length and principal points) of all the optical elements and the locations of all the intermediate images (real or virtual) in the system.



Ivory's data provide engineers and designers with tools for working out favorable solutions for many of their trickiest design problems:

- Balancing the tolerances in the instrument assembly
- Minimizing temperature and pressure sensitivity of focus
- Designing alignment mechanisms and procedures
- Locating and sizing fold mirrors
- Minimizing boresight errors
- Minimizing image motions on the detector and many, many more.

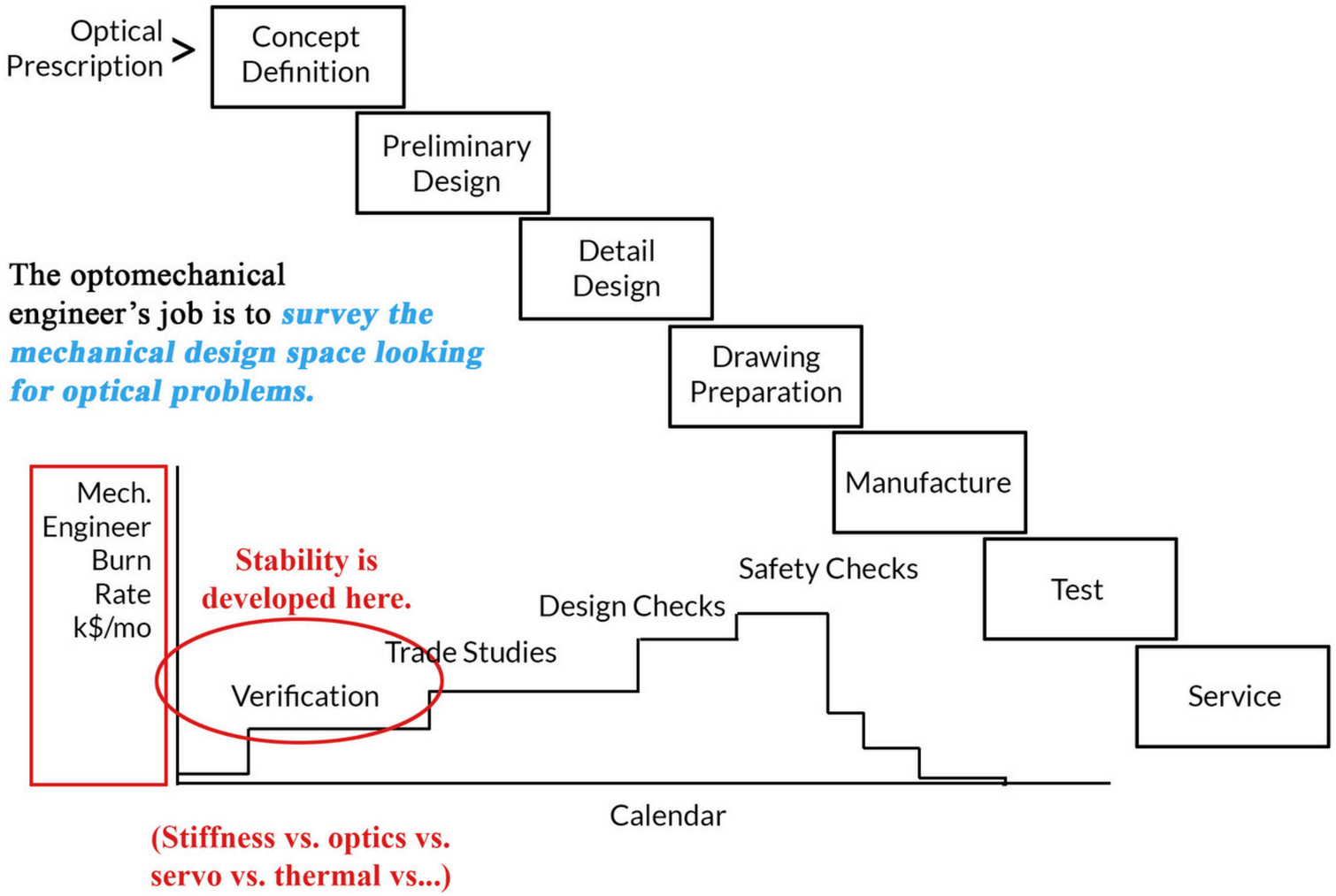
The premise:

AEH worked under the principle that optics are a perfect science and all optical system failures are a result of mechanical deficiencies.

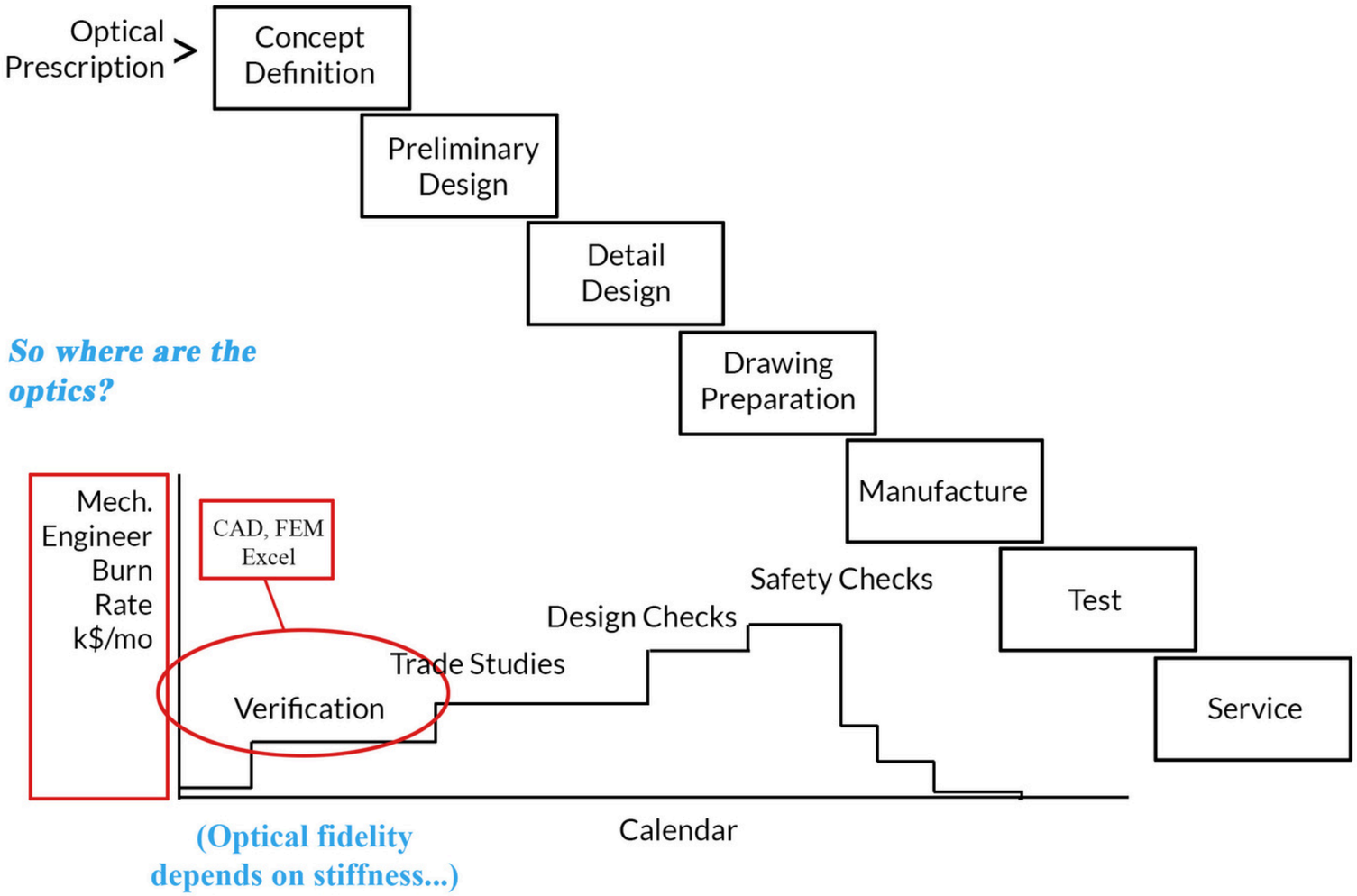
Therefore, a mechanical engineer can prevent optical failures by engineering the mechanical structure from the optical prescription.

Relying on his Optomechanical Constraints Equations, AEH wrote ***Ivory*** as a highly accurate, lightweight and fast utility to use at the outset of pre-development, ***saving an average of 2/3 time and money.***

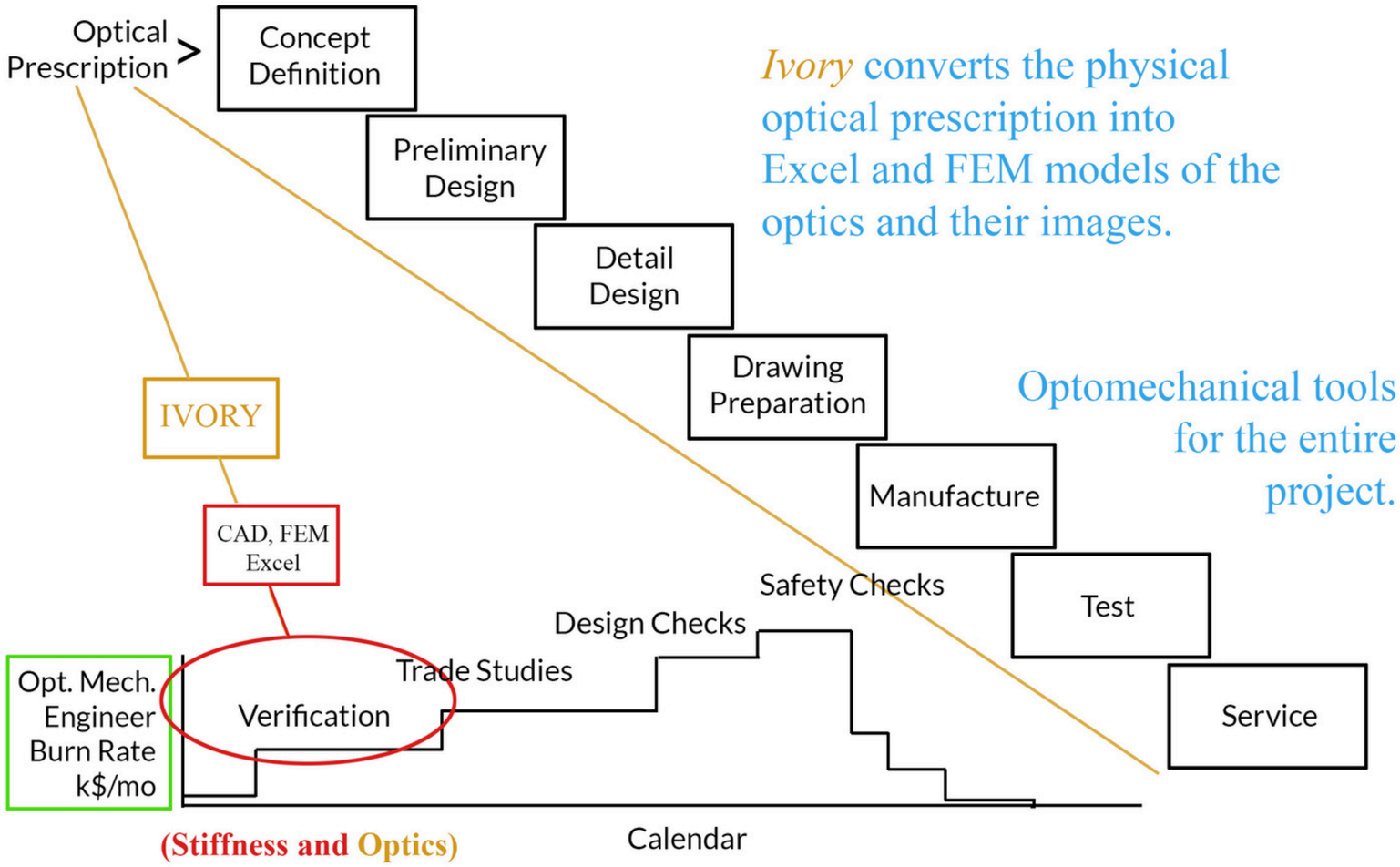
Phases of an optical development project



Phases of an optical development project

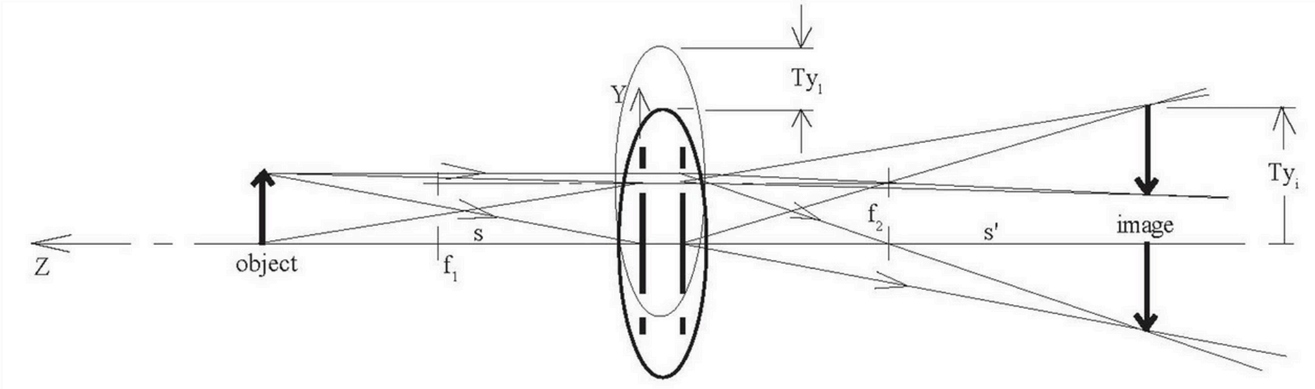


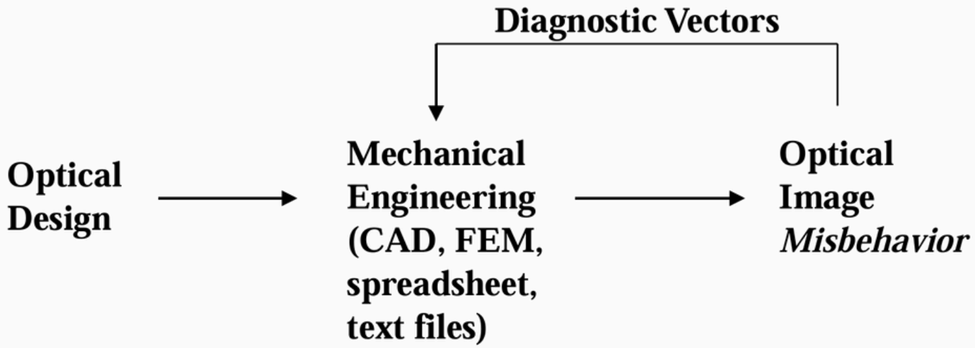
Phases of an optical development project



Ivory transforms optical modeling by predicting optical behavior at the earliest stages of pre-development.

Unified Optomechanical Modeling



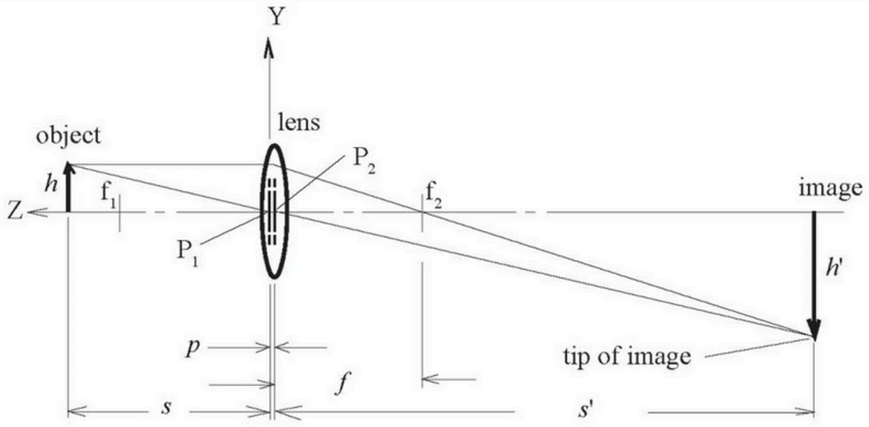


Optical and mechanical math functions are continuous:
The first partial derivatives are real.

Permissible deviations from the optical design are *very small*:
The deviations from linearity are correspondingly small.

AEH.
Optomechanical Engineering

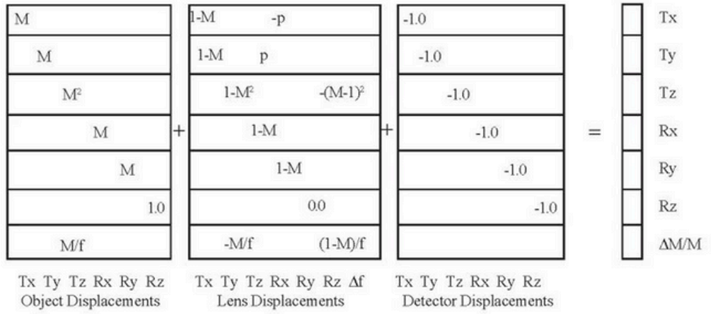
Optomechanical Constraints Equations, OCE (1)

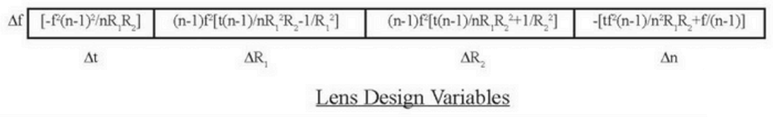


$$1/f = (n - 1)[1/R_2 - 1/R_1 + t(n - 1)/nR_1R_2]$$

$$s' = 1/(1/s - 1/f)$$

$$M = h'/h = s'/s$$





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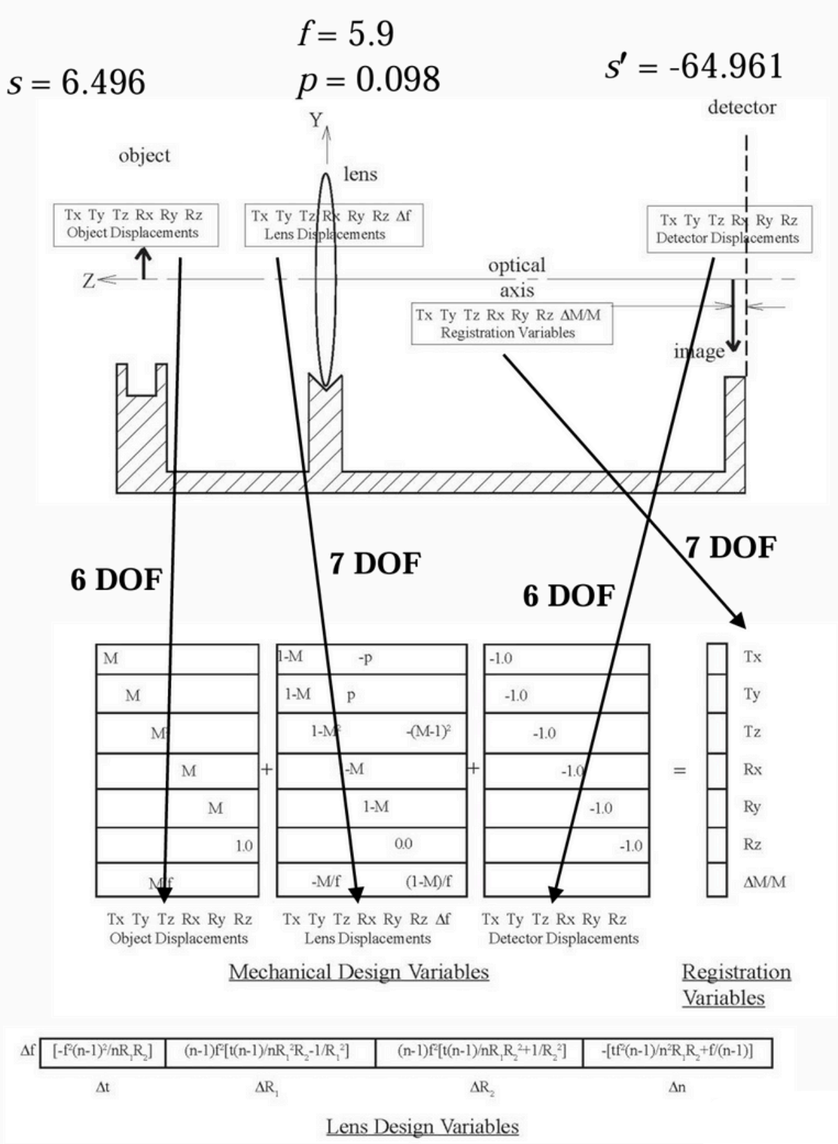
Optomechanical Engineering

Optomechanical Constraints Equations, OCE (2)



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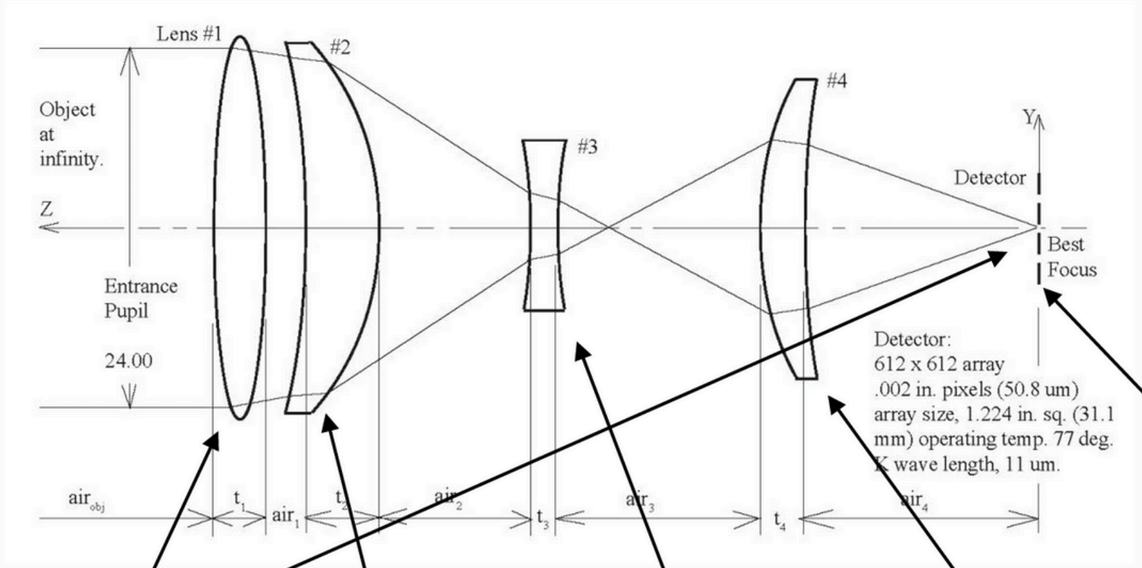
Optomechanical Engineering

OCE of a Multi-lens System by Linear Superposition (Ivory)



Reg. Var. | Object | Lens 1 | Lens 2 | Lens 3 | Lens 4 | Detector

	Tx	Ty	Tz	Rx	Ry	Rz	Df,p,(SYS	Tx	Ty	Tz	Rx	Ry	Rz	Df,p,(ELEM	Tx	Ty	Tz	Rx	Ry	Rz	Df,p,(ELEM	Tx	Ty	Tz	Rx	Ry	Rz	Df,p,(ELEM	Tx	Ty	Tz	Rx	Ry	Rz	Df,p,(ELEM	Tx	Ty	Tz	Rx	Ry	Rz	Df,p,(DETECTOR
TX								-1				1.54			-1.3				6.02			0.11				3.28			3.18				-1.2				-1							
TY									-1		-1.5					-1.3		-6					0.11		-3.3					3.18		1.16					-1						
TZ										1.06				-1.1			4.19				-1.6			-0.5				-0			-3.8				-10			-1					
RX											-1						-1.3							0.11							3.18							-1				
RY												-1						-1.3							0.11							3.18							-1			
RZ						1																																				-1		
DM/M										-0.1				0.09			-0.3				0.13			0.06				0			0.33				0.48								
Df,p,(								0.06	-0.1	0.08	-17				-0.5	-0.3	1.24	-12				0.06	-0.1	0.12	14.1				-0.4	-1.2	0.25	-2.3											
LDes		Dt	DR1	DR2	Dn			Dt	DR1	DR2	Dn				Dt	DR1	DR2	Dn				Dt	DR1	DR2	Dn				Dt	DR1	DR2	Dn					Dt	DR1	DR2	Dn			

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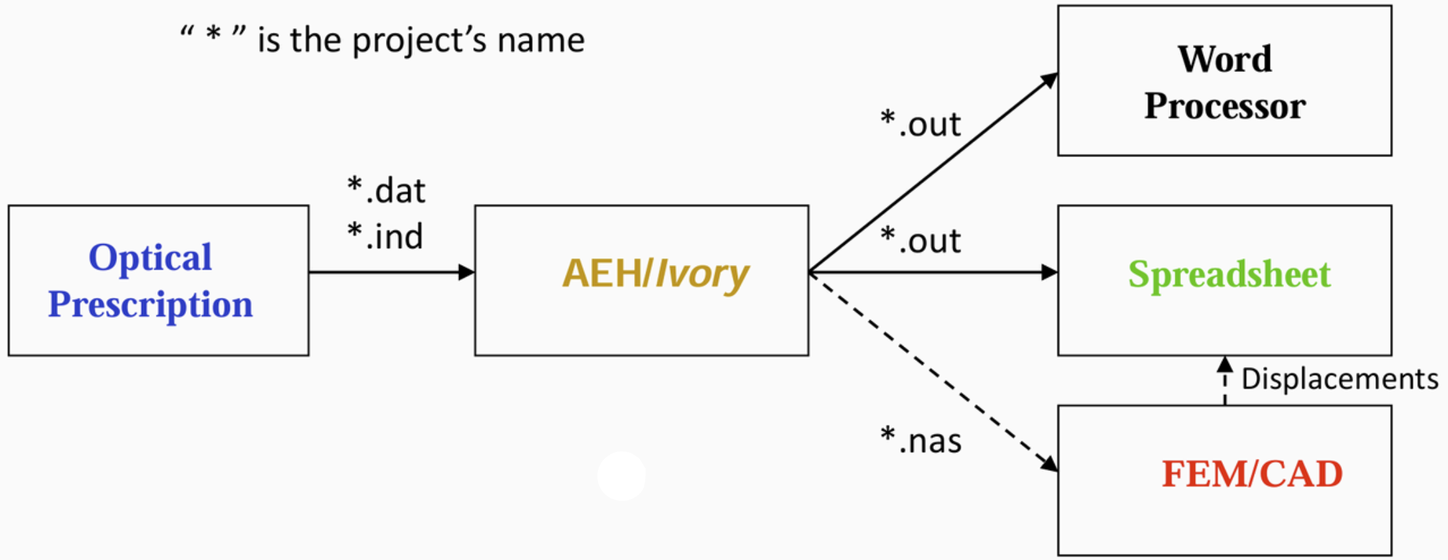
Optomechanical Engineering

Ivory Optomechanical Modeling Tools



AEH/*Ivory's* Files

***.dat**
Geometrical optical data

***.ind**
Index of refraction data

***.out**
Header
Optical prescription echo
Gaussian optical properties
Objects, images and magnifications
Optomechanical Constraint Equ.

***.nas**
Header
Optomechanical Constraint Equ.
Optical path geometry

AEH.
Optomechanical Engineering

What one of the nation's top optomechanical engineers has to say:

"Alson's greatest contribution to optomechanics was his ability to link computer aided design in mechanical engineering to computer assisted design in optical engineering: *something the rest of us have been unable to do*. His software is the bridge between those two disciplines."

- Daniel Vukobratovich

Senior Principle Multi-Disciplinary Engineer at Raytheon Missile Systems
Adjunct Professor at the Wyant College of Optical Sciences, University of Arizona
2020 SPIE President’s Award Recipient

"IVORY... can perform an independent sanity check of ZEMAX optical sensitivities... Furthermore IVORY is capable of writing the OSE in NASTRAN syntax code including all necessary coordinate systems that define both the optic rigid body displacement six degrees of freedom and the image motion relative to the focal plane directions. Implementing the OSE in a Finite Element Model is a difficult task because the optical sensitivities have different sign convention definitions in the following data sets: IVORY Optical Sensitivities, ZEMAX Optical Sensitivities and NASTRAN Finite Element Model OSE syntax code."

- Assessment of Optical Software Ivory.
Goodrich-Danbury Mechanical Engineering

"In addition to providing the mechanical engineer with a better understanding of the impact on optical performance, IVORY can generate input for use with mechanical FEA tools. At present ZEMAX/CODE V etc cannot do this. There are ways to generate a simplistic model but it is not easy to tie this to the optical design. IVORY provides this link."

- Douglas Osborne
Independent Ivory User

"IVORY focuses mainly on determining the effects of alignment errors on first order imaging properties while other optical design software focus mainly on properties associated with wavefront errors such as the RMS spot size."

- Esperza, M., Choi, H., & Kim, D.W. (2021). Cassegrain Telescope Sensitivity Analysis using Ivory Optomechanical Software. *College of Optical Sciences, University of Arizona*

About AEH

Founded in 1979 by Alson E. Hatheway, AEH Inc. had a reputation as one of the United State's preeminent optomechanical analysis and design companies.

Alson's unusual mastery of both optics and mechanics made him a highly sought after designer, advisor and consultant on hundreds of contracts over the course of his career. He developed the Optomechanical Constraints Equations, and subsequently wrote Ivory, to improve the efficacy of mechanical engineering for optical systems.

Alson is highly decorated within the ranks of the optical community (SPIE, OSSC, AIAA).

Alson E. Hatheway

Author: The Optomechanical Constraint Equations: Theory and Applications

Honors and Awards:
OSSC Lifetime Achievement Award
Life Member of ASME
Fellow of SPIE
Fellow of OSSC
Senior Member of AIAA

Service to Industry:
Board of Directors: SPIE
President: OSSC and Fellows Chair
Chairman: AIAA, San Gabrial Valley Section
Chair: SPIE's Optomechanical/Instrument Technical Group
Vice Chair: ANSI-ASME B46, Nanometer Metrology
Faculty: University of La Verne

Authored over seventy technical papers
Edited eleven conference proceedings

Alson E. Hatheway
President, Principal Engineer
AEH Inc.

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for writings, papers, presentations and more, please visit:

aehinc.com

Advisors

The process of re-homing the intellectual property of Alson E. Hatheway has been supported by industry leaders, including:

- Dan Vukobratovich - Senior Principle Multi-Disciplinary Engineer at Raytheon Missile Systems; Adjunct Professor at the Wyant College of Optical Sciences, University of Arizona
- Martin Seilonen - Program Manager | IPTL | Engineering Manager | Optical Systems | Opto-Mechanics, Northrop Grumman Space Systems
- Mark Kahan - Chief Electro-Optical Systems Engineer, Synopsys, Inc.
- Dae Wook Kim - Assistant Professor of Optical Sciences and Astronomy, University of Arizona
- Keith Doyle - Assistant Division Head, Engineering, MIT Lincoln Lab
- Krisztina (Z) Holly - scouting, advising, and investing in innovators at the frontier
- Joshua Tarbutton, Ph.D., P.E. - Associate Professor/Assistant Director, Energy Production & Infrastructure Center Mechanical Engineering and Engineering Science, UNC Charlotte
- Harvey M. Spencer - Director of Optical Engineering at Leonardo DRS