Desensitization of optical systems
Paul Fuller

22/01/2014

Methods to ensure that a final optical design not only meets its optical specification, but is easily manufacturable.

- Design inputs
- Compensation verses tight tolerances
- Determining sensitivity of tolerances
- Tolerancing methods
- Desensitization by opto-mechanical design choice
- Desensitization by analysis (MTF, aberrations…)
- Desensitization by optimization
- Conclusion/ Further prospects

Design inputs

- **System specification**
- **Choose the 'type' of optical design for the problem**
  - Use of proven data bases
  - Use of complex surface types (aspheric, diffractive, free form….)?
- **Cost target for the system**
  - Price acceptable for individual lenses and mechanical parts
  - Integration time
- **Industrial constraints**
  - General manufacturing tolerances / capabilities
  - Special manufacturing technologies available
  - Supply chain accessibility and Make/Buy scenario

Determining Sensitivities

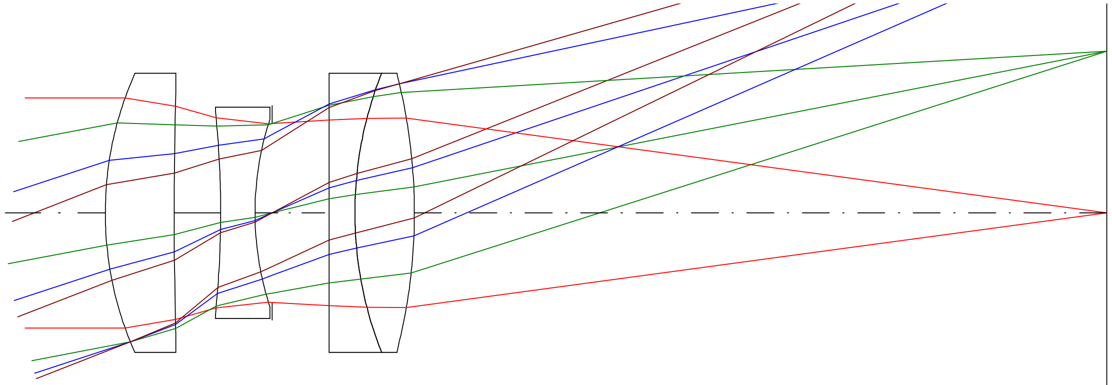
Early in the design phase, the following CodeV® functions enable us to determine the most senstive tolerances / surfaces in the system

- **Third Order aberration analysis *(THO SA ; GO)***
  - **This enables us to determine the surfaces with the largest aberration transfer, which are likely to be the most sensitive (rough estimate).**
- **Optimization analysis *(AUT ; SNS Sk ; WTC 0 ; go)***
  - **Running the SNS option in AUT for each surface can highlight surfaces which are sensitive to tilt tolerances.**
- **Wavefront Differential tolerancing *(TOR)***
  - **This is the most complete 'rapid' method to evaluate the sensitivity of the the different tolerances but can be inaccurate (MTF drops are approximations).**
  - **Requires the user to create a full set of tolerances and to set up the TOR function**
  - **Either:**
    - (SNS) The same tolerance value is assigned to each surface and the TOR is run to establish where the largest losses occur. OR
    - (INV) A loss of X points of MTF (typically 1 or 2) – the value for each tolerance is calculated

We are not interested in the final MTF value at this point!!

Relationships between aberrations and sensitivity

- **The more powerful an optical surface and the larger the pupil on this surface => the more sensitive the optical surface is likely to be to manufacturing errors.**
- **The larger the aberration produced (or compensated) by a surface, the more sensitive it is likely to be.**
- **Use third order aberration analysis 'THO SA' to establish early in the design phase where the large aberration transfers occur.**



	SA	TCO	TAS	SAS	PTB	DST	AX	LAT	PTZ
1	-0.578171	-0.743585	-1.332084	-1.119567	-1.013309	-0.479958	-0.344887	-0.147853	-0.012322
2	**-0.303926**	**2.145623**	**-4.941633**	**-1.575534**	**0.107516**	**3.707596**	**-0.179436**	**0.422254**	**0.001307**
3	**0.807140**	**-3.821298**	**6.339923**	**2.319605**	**0.309445**	**-3.660621**	**0.391991**	**-0.618610**	**0.003763**
4	0.507304	1.889186	3.462894	1.899499	1.117802	2.357894	0.400703	0.497402	0.013593
STO	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
6	-0.004343	-0.103773	-0.867542	-0.316471	-0.040935	-2.520870	-0.042743	-0.340476	-0.000498
7	-0.126395	-0.540875	-0.894330	-0.379989	-0.122818	-0.542021	-0.018079	-0.025788	-0.001494
8	-0.410482	1.226398	-1.793949	-0.979703	-0.572579	0.975686	-0.219828	0.218927	-0.006963

- **For this Tessar lens, the airgap between L1 and L2 has a large transfer of aberrations and is likely to be sensitive.**

THALES

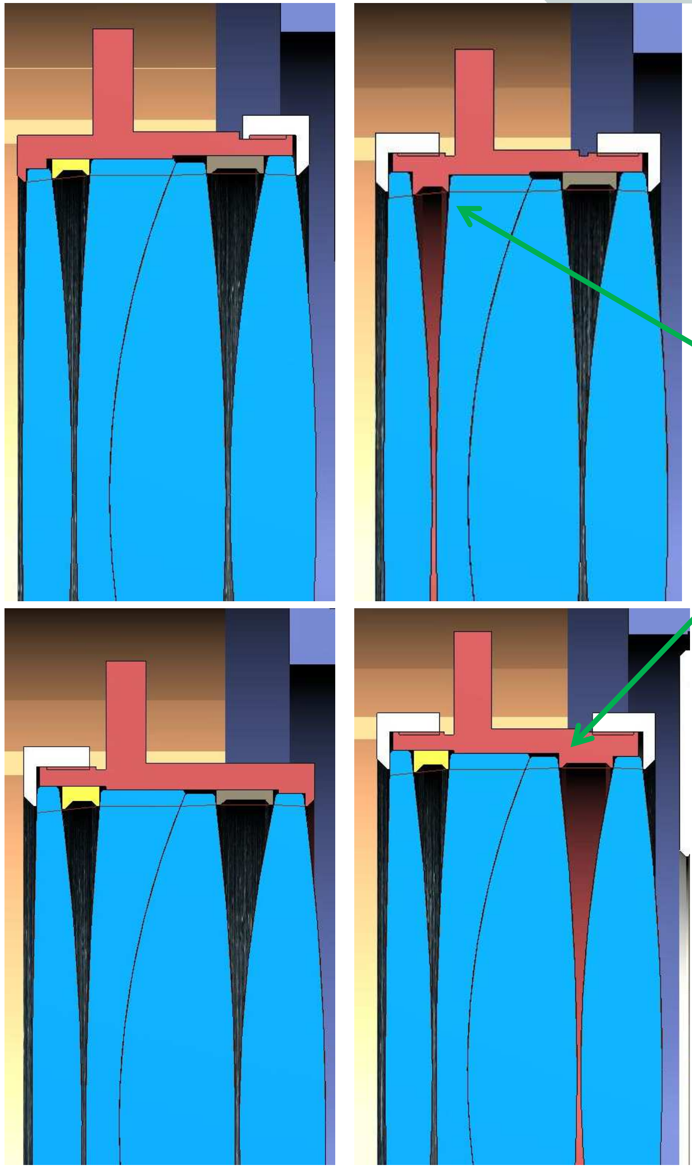
Compensators choice

Iterations using 'TOR' to find a good set of compensators:

CV code	Compensator type	Lens N°	Effect
CMP DSZ S1..2	Axial	L1	
CMP DSZ S3..4	Axial	L2	
CMP DSZ S6..8	Axial	D3/4	
CMP DIS S1..2	Radial	L1	
CMP DIS S3..4	Radial	L2	
CMP DIS S6..8	Radial	D3/4	
CMP DLZ Si	Axial	Image	

- Axial position and centering of L1 controls the airgap L1 -> L2
- Centering of D3/4 controls the dissymetrie in the system from the remaining tolerances
- Back focus recovers the remaining focus errors
- We are not surprised to find that the airgap between L1 and L2 needs to be controlled as we have already seen the results from the 3rd order aberration analysis

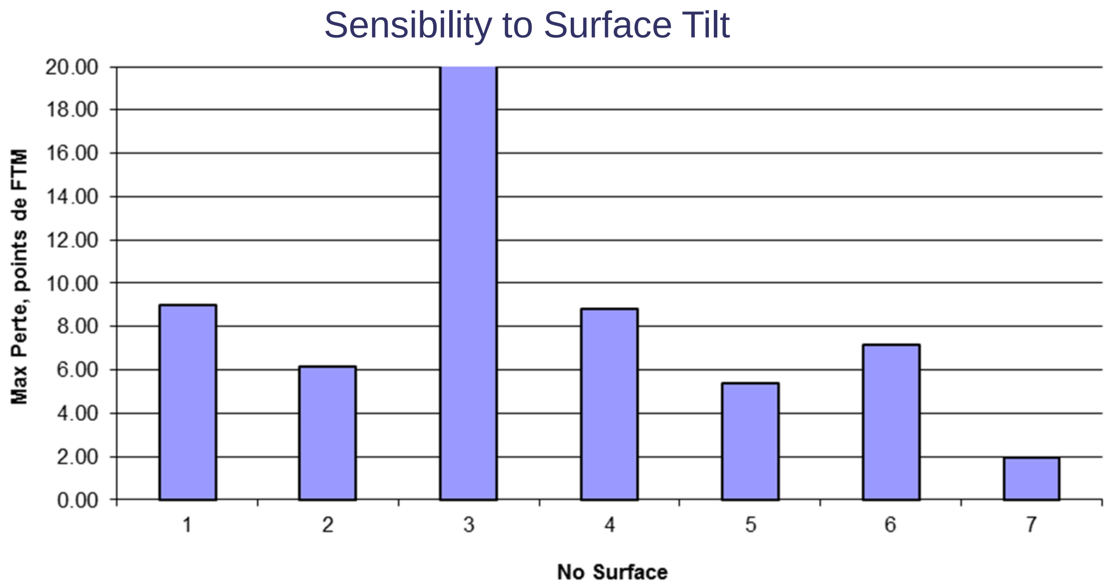
Mechanical design choice



1 2 3 4 5 6 7

Lens mount choice:
There can be several different solutions to choosing how to mount a lens system. Without knowing the sensitivities for each surface, it is difficult to choose!

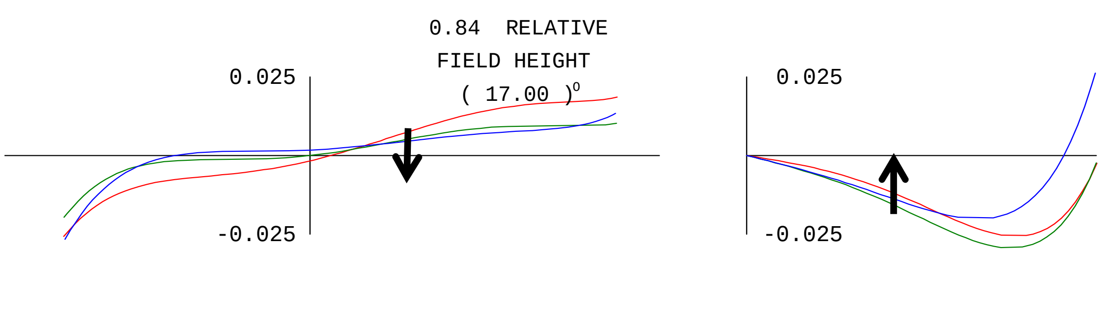
These solutions are more likely to accurately hold the surface 3 (L2R1) in position

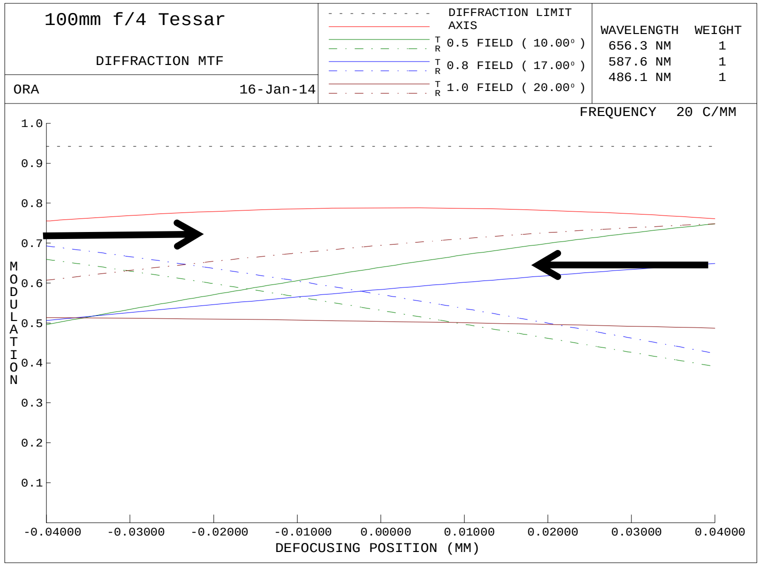


THALES

Desensitization by optimization

- **Zooming of sensitive parameters (with pertubated configurations)**
- **Minimize angle of incidence on critical surfaces *(AOI Sk < X°)***
- **Control and limit surface curvature, lens power and air gap power**
- **Careful use of weightings within the optimisation**
- **Ray targeting for specific aberration control**



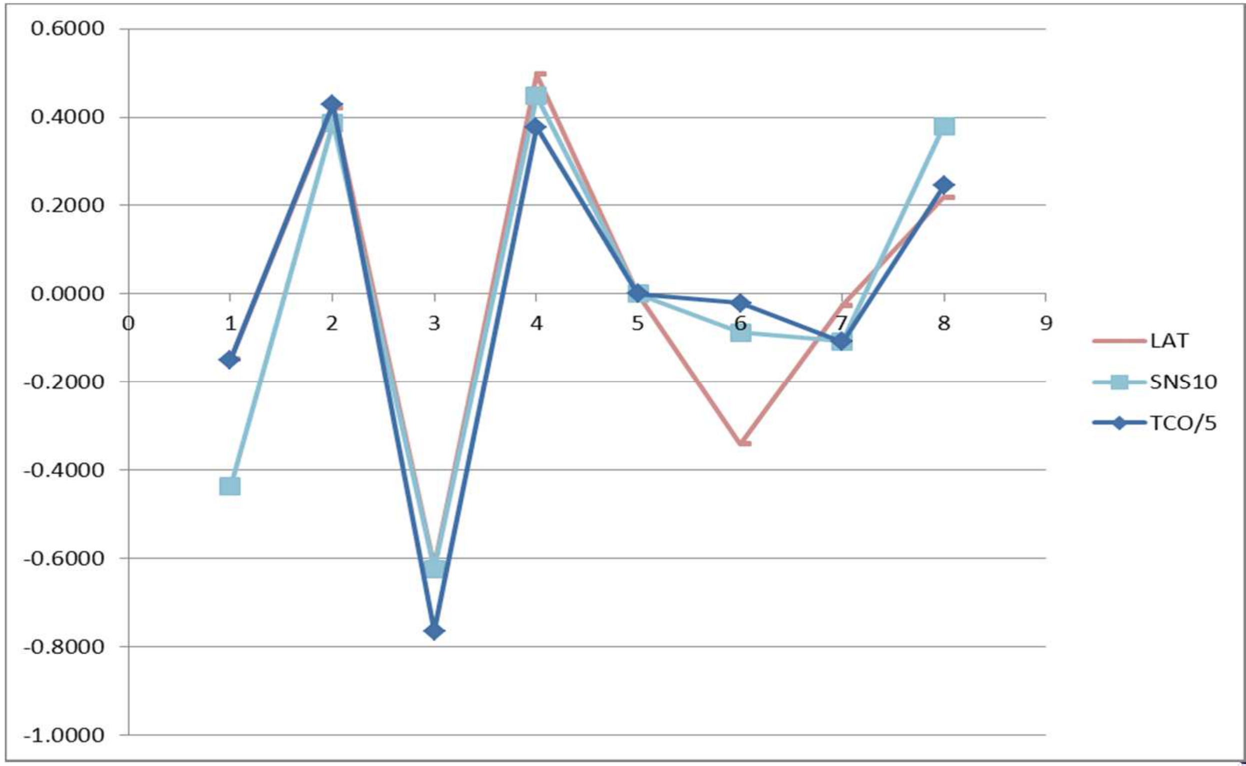


- **MTF optimization –*close to the finished, this can be used to balance the TFMTF curves (through focus MTF).***

THALES

CodeV® Specific optimisation routines (SNS)

- **Tilt Sensitivity *(SNS) (SNS Sk;WTC X)***
  - Used in 'aut' optimization to desensitize surfaces to tilt errors. Sensitivity to surface tilt can be linked to other manufacturing errors (lens tilt, lens decenters etc…)
  - Linked to Coma (and almost to Lateral Color), proportional to the output of THO SA;GO



THALES

CodeV® Specific optimisation routines (SAB)

- **Sensitivity As Built *(SAB)***
  - The SAB optimization routine should be used in a similar way to the MTF optimization routine. Once a locally optimized solution is found, SAB is used to increase 'as-built' performance at the cost of nominal performance
  - SAB option allows for compensators inputs.
  - Only the most critical tolerances should be included in the optimization to minimize calculation time.
  - The calculation is similar (or the same?) as the TOR Wavefront Differential calculation
  - Needs to be set up correctly to ensure good results

Conclusion

- **Importance to take into account the sensitivities at the earliest stages of the design.**
- **Knowledge of simple 'rule of thumb' methods for finding the most sensitive parts of a design**
- **Knowledge of the *'smart'* options (SAB, SNS…) with their limitations is necessary.**
- **Although helpful (time savings), tools never replace the need of experience in optical design.**