Tutorial 4

Optomechanical Static Analysis

In this tutorial we shall:

- Prepare an ***Ivory*** optomechanical model from a telescope's optical prescription
- Evaluate the optical faithfulness of the model in ***Ivory's*** output file
- Import the ***Ivory*** optomechanical model into Patran
- Import the CAD models of the optical elements into Patran
- Attach the optomechanical model to the meshed optical elements in Patran
- Construct lens cells in Patran
- Construct a structural truss in Patran to support the lens cells
- Checkout the full model's optical quality with 6 DOF rigid body checks in Nastran
- Analyze the static gravity stability of the image on the detector in Nastran

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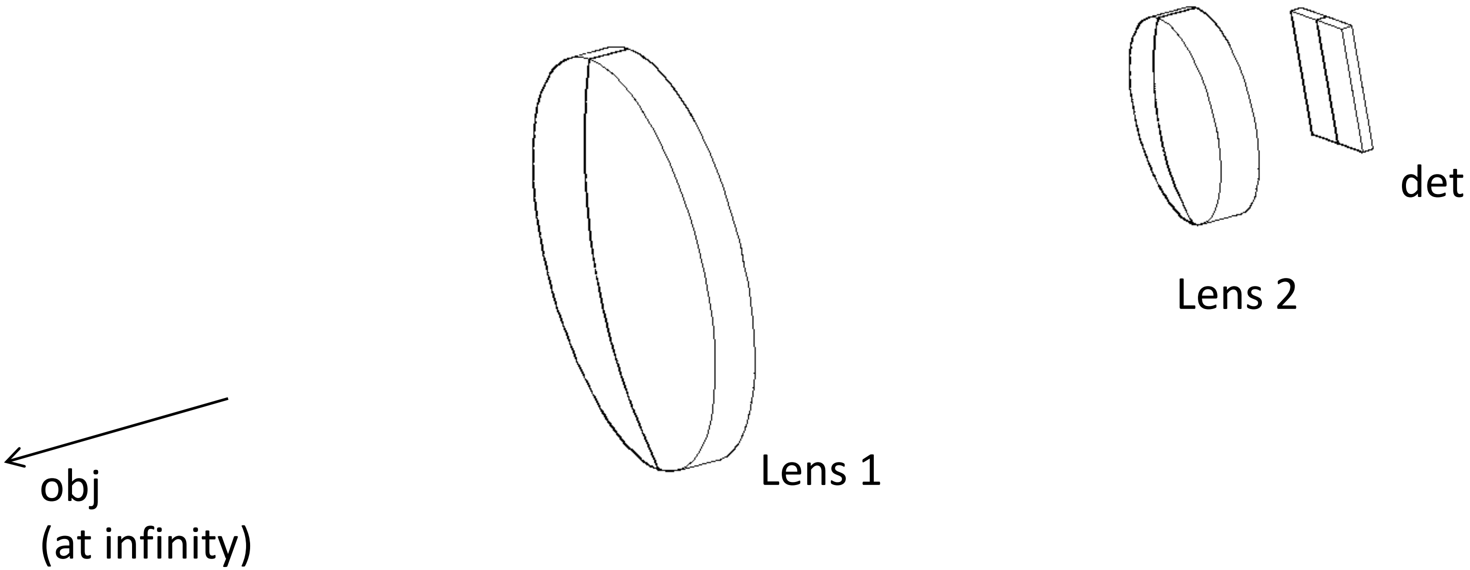
The Telescope's Optical Geometry Data



Surf	Elem	Radius	Index	Thickness
1	obj	inf	AIR	inf
2	1	3.5	ge	.25
3	1	5.	AIR	2.67
4	2	1.5	ge	.2
5	2	1	AIR	.674
6	det	inf	AIR	0.0

We shall call this file "tele.dat"

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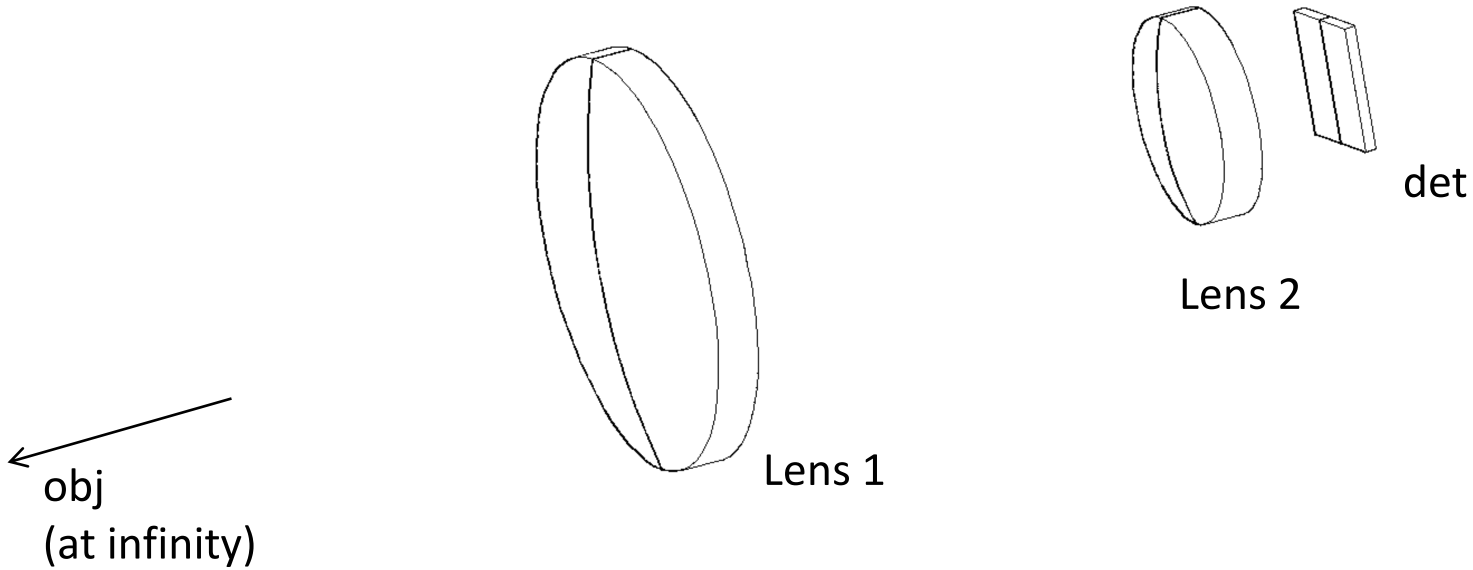
The Telescope's Index of Refraction Data



MATERIAL	INDEX
AIR	1.0
ge	4.00024

We shall call this file "tele.ind"

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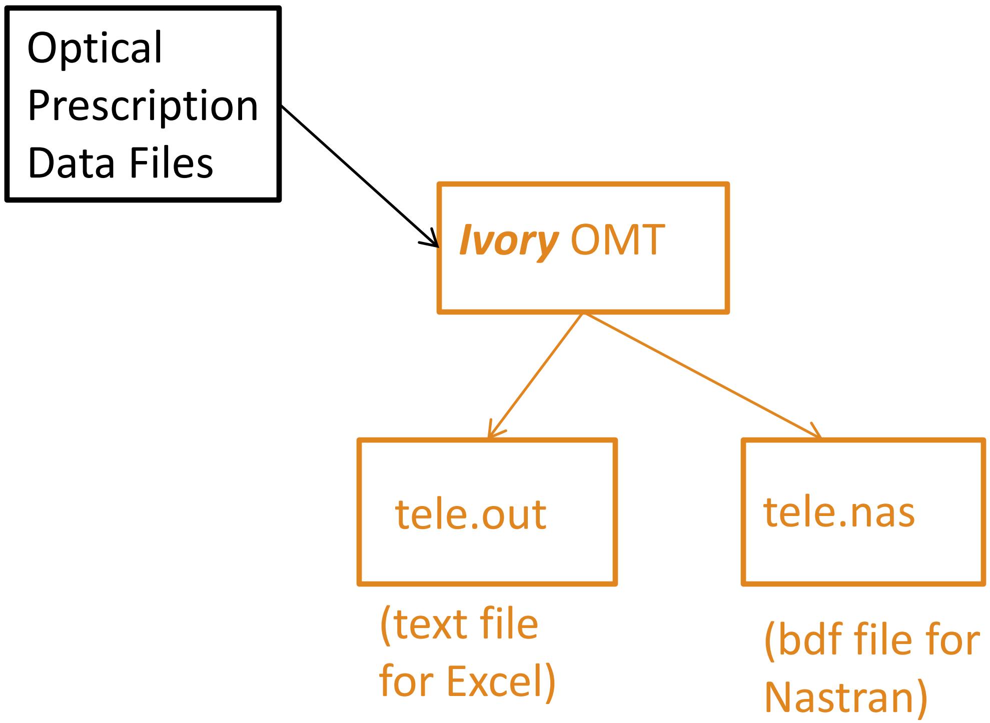
Ivory Generates the *Unified* Models' Data Files



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At the Top of the tele.out File for Excel:

Check the optical properties reported by *Ivory*

Output from -
IVORY Optomechanical Modeling Tools
Version 3.0

This Product has been licensed to Alson E. Hatheway Inc. for one user(s).

PROJECT NAME: 'TELE'   TIME AND DATE: 11:29:55 11-20-2014

PHYSICAL PRESCRIPTION INPUT ECHO IN OPTICAL CONVENTIONS

Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4
1	obj	inf	1.0	inf	obj	1	1	0	0
2	1	3.5	4.00024	.25	LENS	0	0	0	0
3	1	5	1.0	2.67	LENS	0	0	0	0
4	2	1.5	4.00024	.2	LENS	0	0	0	0
5	2	1	1.0	.674	LENS	0	0	0	0
6	det	inf	1.0	0	det				

INDEXES OF REFRACTION ARE RELATIVE TO THE VALUE OF 1.000292.

Check the data echos.

PHYSICAL PRESCRIPTION INPUT ECHO IN MECHANICAL CONVENTIONS

Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4
1	obj	inf	1.0	inf	obj	1	0	0	0
2	1	-3.5	4.00024	.25	LENS	0	0	0	0
3	1	-5	1.0	2.67	LENS	0	0	0	0
4	2	-1.5	4.00024	.2	LENS	0	0	0	0
5	2	-1	1.0	.674	LENS	0	0	0	0
6	det	inf	1.0	0	det				

INDEXES OF REFRACTION ARE RELATIVE TO THE VALUE OF 1.000292.

Focal length agrees with optical design.

GAUSSIAN PRESCRIPTION

ELE	F	H1	H2	P	P/AIR	PHI	THETA	TYPE	PHI'
obj	inf	0	0	0	inf	0	0	obj	
1	3.4565059	.12962156	.18517366	.1944479	3.0694484	0	0	LENS	
2	-1.4284694	-.21427469	-.1428498	.1285751	.5311502	0	0	LENS	
det	inf	0	0	0	0	0	0	det	
SYSTEM	4.741172	10.317298	4.0674085	9.3698891	4.7414085				

Focus error is very small.

OBJECTS, IMAGES AND MAGNIFICATIONS

ELE	F	S	S'	M	PHI	THETA	TYPE	e/Tzo	PHI'
obj	inf	0	0	1.0	0	0	obj	0	0
1	3.456506	0	-3.456506	0	0	0	LENS	0	0
2	-1.428469	-.3870576	.5309138	1.371666	0	0	LENS	-.9602	0
det	inf	2.36431E-4	2.36431E-4	+1.0	0	0	det	0	0

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At the Bottom of the tele.out File for Excel:

Check the Influence coefficients with “validation sums.”

```
OPTOMECHANICAL CONSTRAINT EQUATIONS       (ABSOLUTE VALUES SMALLER THAN  0  ARE PRINTED AS 0.0)

                                                        REGISTRATION VARIABLES

               TX            TY            TZ            RX            RY            RZ            DM/M          Df,p,G     LDesVar

Tx             0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0          Dt
Ty             0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0          DR1
Tz             0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0          DR2
Rx             0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0          Dn
Ry             0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
Rz             0.0           0.0           0.0           0.0           0.0          1              0.0           0.0
Df,p,G         0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
SYSTEM-OBJECT

Tx            1.371666       0.0           0.0           0.0           0.0           0.0           0.0          -1.536252     Dt
Ty             0.0          1.371666       0.0           0.0           0.0           0.0           0.0          -3.035868     DR1
Tz             0.0           0.0          1.881468       0.0           0.0           0.0          -.9602349     1.356994     DR2
Rx             0.0          .2667176       0.0          1.371666       0.0           0.0           0.0          -1.184077     Dn
Ry            -.2667176      0.0           0.0           0.0          1.371666       0.0           0.0           0.0
Rz             0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
Df,p,G         0.0           0.0          -1.881468      0.0           0.0           0.0          1.249544       0.0
ELEMENT-1

Tx            -.3716662      0.0           0.0           0.0           0.0           0.0           0.0          -3.061093     Dt
Ty             0.0          -.3716662      0.0           0.0           0.0           0.0           0.0          -3.129063     DR1
Tz             0.0           0.0          -.8814681      0.0           0.0           0.0          .9602349      5.509846     DR2
Rx             0.0          .1285751       0.0          -.3716662      0.0           0.0           0.0          .4251073     Dn
Ry            -.1285751      0.0           0.0           0.0          -.3716662      0.0           0.0           0.0
Rz             0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
Df,p,G         0.0           0.0          -.1381358      0.0           0.0           0.0          .2601849       0.0
ELEMENT-2

Tx            -1             0.0           0.0           0.0           0.0           0.0           0.0           0.0          Dt
Ty             0.0          -1             0.0           0.0           0.0           0.0           0.0           0.0          DR1
Tz             0.0           0.0          -1             0.0           0.0           0.0           0.0           0.0          DR2
Rx             0.0           0.0           0.0          -1             0.0           0.0           0.0           0.0          Dn
Ry             0.0           0.0           0.0           0.0          -1             0.0           0.0           0.0
Rz             0.0           0.0           0.0           0.0           0.0          -1             0.0           0.0
Df,p,G         0.0           0.0           0.0           0.0           0.0           0.0           0.0           0.0
DETECTOR

Thank you for using IVORY(tm) to prepare the Optomechanical Constraint Equations for 'TELE'.
```

```
   Sums =     -0.0000002    -0.0000002    -0.0000001    -0.0000002    -0.0000002     0.0
```

The sums of the diagonal terms should be computational zeros. OK.

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Optomechanics

The tele.nas Bulk Data File (in Two Columns) for Nastran is:

Compare these values to tele.out

```
NASTRAN MESH
CEND
TITLE=TELE'S IVORY(TM) UNIFIED OPTOMECHANICAL MODEL
$ SINGLE POINT CONSTRAINT SETS MUST BE CALLED OUT IN THE CASE CONTROL DECK.
SPC=1000
$ MULTIPOINT CONSTRAINT SETS MUST BE CALLED OUT IN THE CASE CONTROL DECK.
MPC=1000
BEGIN BULK

$ THE FOLLOWING GRID POINTS/DOFS HAVE BEEN ASSIGNED:
$  1  THRU  2 /123456 ARE ASSIGNED TO THE OPTICAL ELEMENTS IN ASCENDING ORDER.
$  3 /123456 ARE ASSIGNED TO THE SYSTEM DETECTOR.
$  4 /123456 ARE ASSIGNED TO THE SYSTEM OBJECT.
$  5 /123456 ARE ASSIGNED TO THE REGISTRATION VARIABLES TX, TY, TZ, RX, RY, RZ.
$  6 /1 IS ASSIGNED TO THE REGISTRATION VARIABLE DM/M.

GRID    5               0.      0.      0.
GRID    6               0.      0.      0.

MPC     1000    5       1       -1.     1       1       1.371666
                1       5       -.2667182       1       -.371666
                2       5       -.1285753       1       -1.


MPC     1000    5       2       -1.     1       2       1.371666
                1       4       .26671762       2       -.371666
                2       4       .12857513       2       -1.


MPC     1000    5       3       -1.     1       3       1.881468
                2       3       -.8814683       3       -1.


MPC     1000    5       4       -1.     1       4       1.371666
                2       4       -.3716663       4       -1.


MPC     1000    5       5       -1.     1       5       1.371666
                2       5       -.3716663       5       -1.


MPC     1000    5       6       -1.     3       6       -1.


MPC     1000    6       1       -1.     1       3       -.960235
                2       3       .9602349

SPC     1000    6       23456
```

MPCs use the influence coefficients to define the image motions.

```
$ DETECTOR
$ PRINCIPAL POINT
GRID    3       3       0.      0.      0.      3
$ DETECTOR COORDINATE SYSTEM
CORD2R  3       0       0.      0.      0.      0.      0.      1.
        1.      0.      0.
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  6       0       0.      0.      0.      0.      0.      1.
        1.      0.      0.

$ ELEMENT 2
$ FIRST PRINCIPAL POINT
GRID    2       6       0.      0.      .65972532
$ ELEMENT COORDINATE SYSTEM
CORD2R  2       6       0.      0.      .65972530.      0.      1.659725
        1.      0.      .6597253
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  5       6       0.      0.      .65972530.      0.      1.659725
        1.      0.      .6597253

$ ELEMENT 1
$ FIRST PRINCIPAL POINT
GRID    1       5       0.      0.      3.2638961
$ ELEMENT COORDINATE SYSTEM
CORD2R  1       5       0.      0.      3.2638960.      0.      4.263896
        1.      0.      3.263896
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  4       5       0.      0.      3.2638960.      0.      4.263896
        1.      0.      3.263896

$ OBJECT AT INFINITY AND NOT MODELED

$                  MODEL PREPARED BY IVORY(TM) OPTOMECHANICAL MODELING TOOLS
$                                   Version 3.0
$                             FOR Alson E. Hatheway Inc.
$                               PROJECT NAME:  'TELE'
$                             11-20-2014  11:29:56
$                         ALSON E. HATHEWAY INC., http://www.aehinc.com

ENDDATA
```

GRIDs and CORDs define the elements' positions and orientations.

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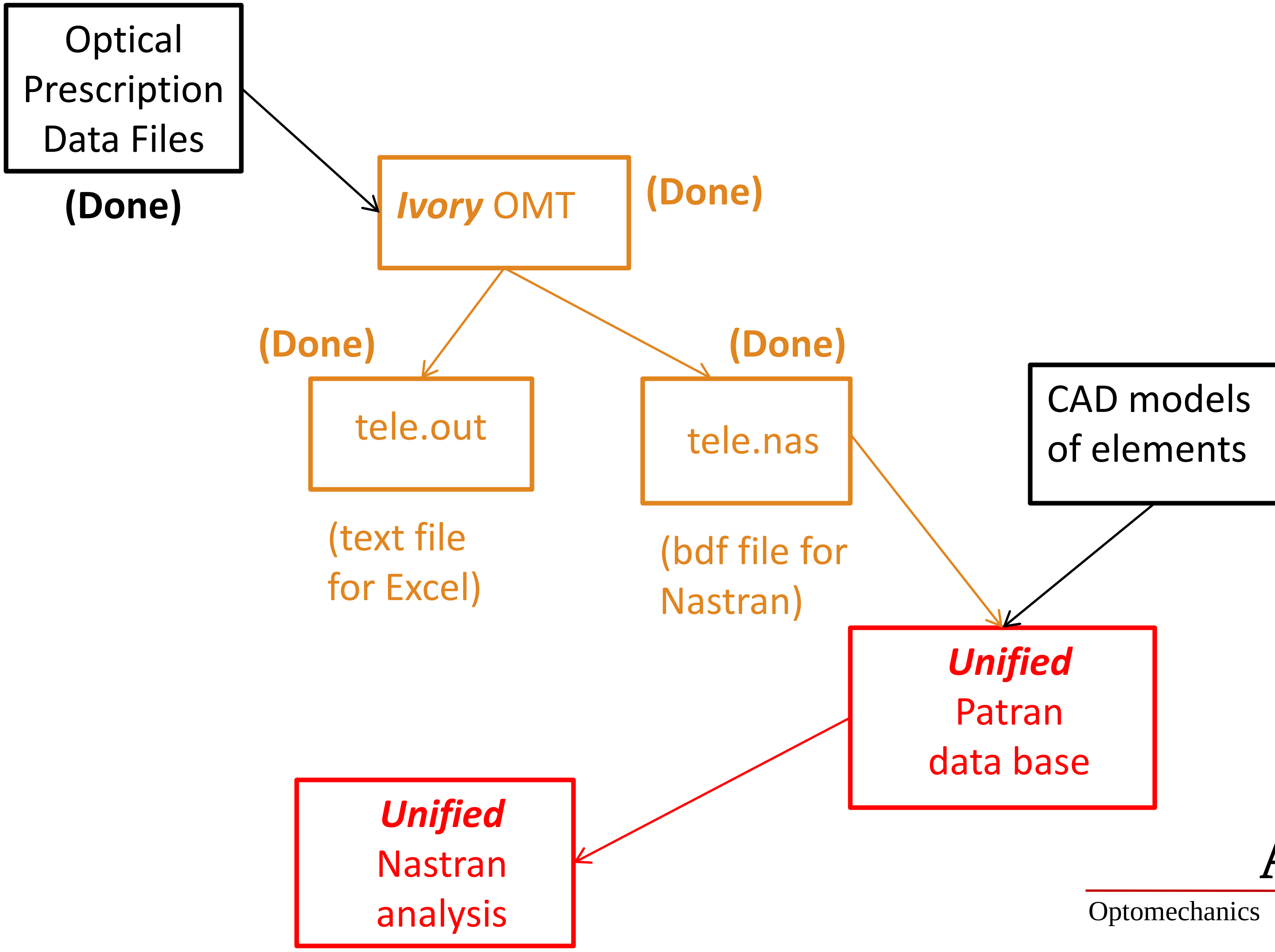
They agree with the tele.out data file.

Generate the *Unified* Optomechanical Model



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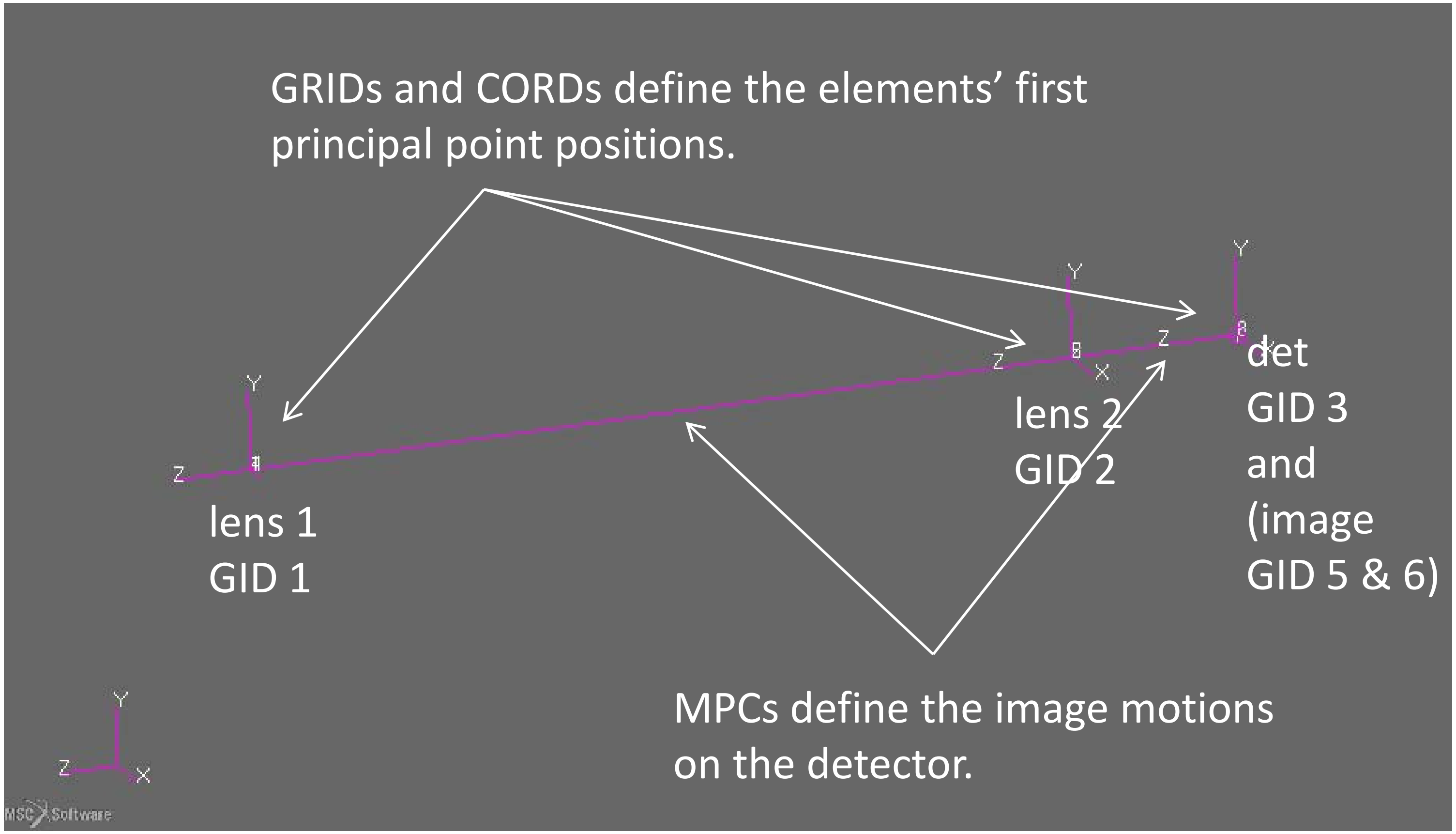
In Patran, Import the tele.nas File



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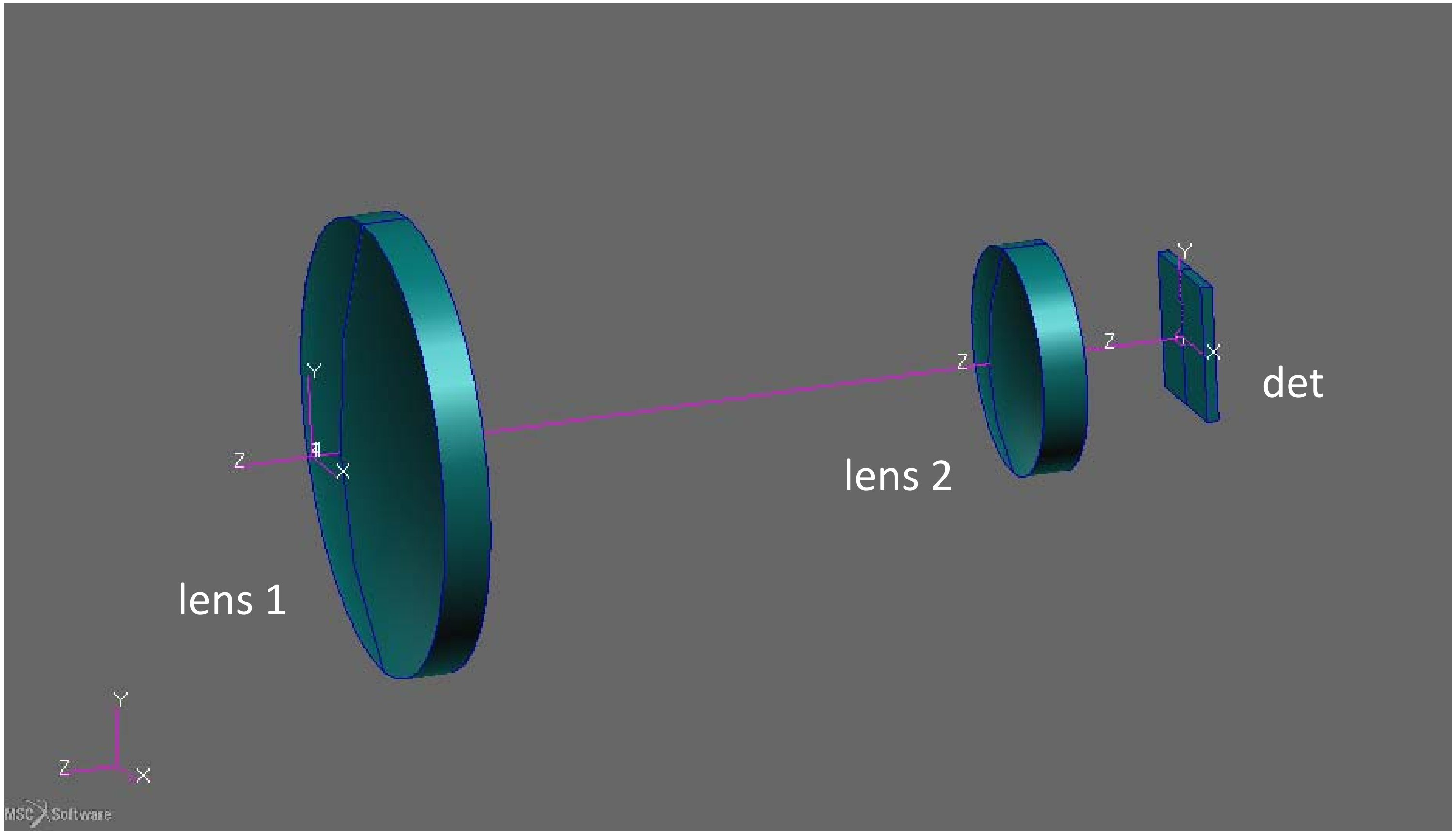
Then, Import the Lenses and Detector CAD Models into the Patran Model



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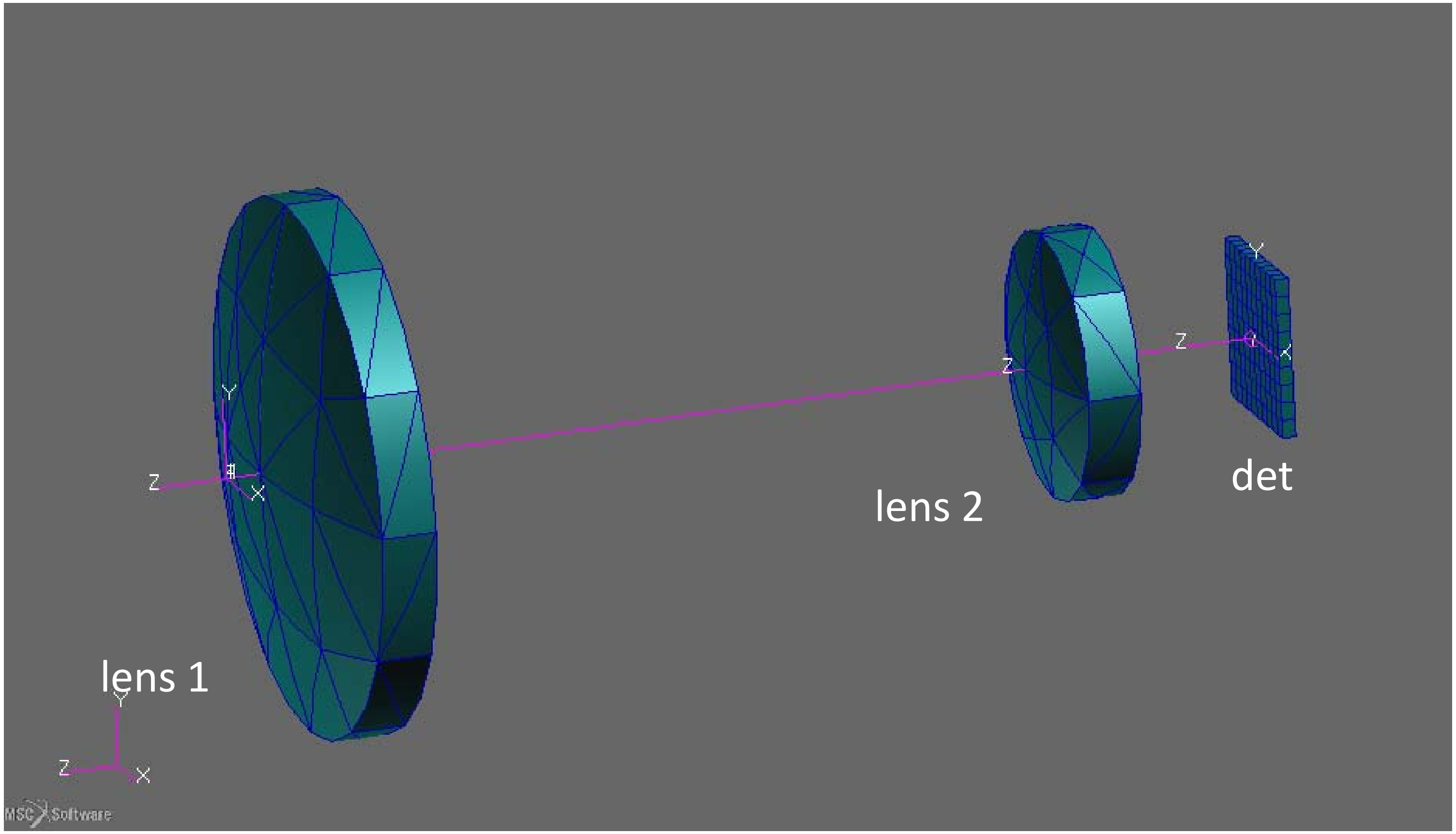
Mesh the CAD Models in Patran



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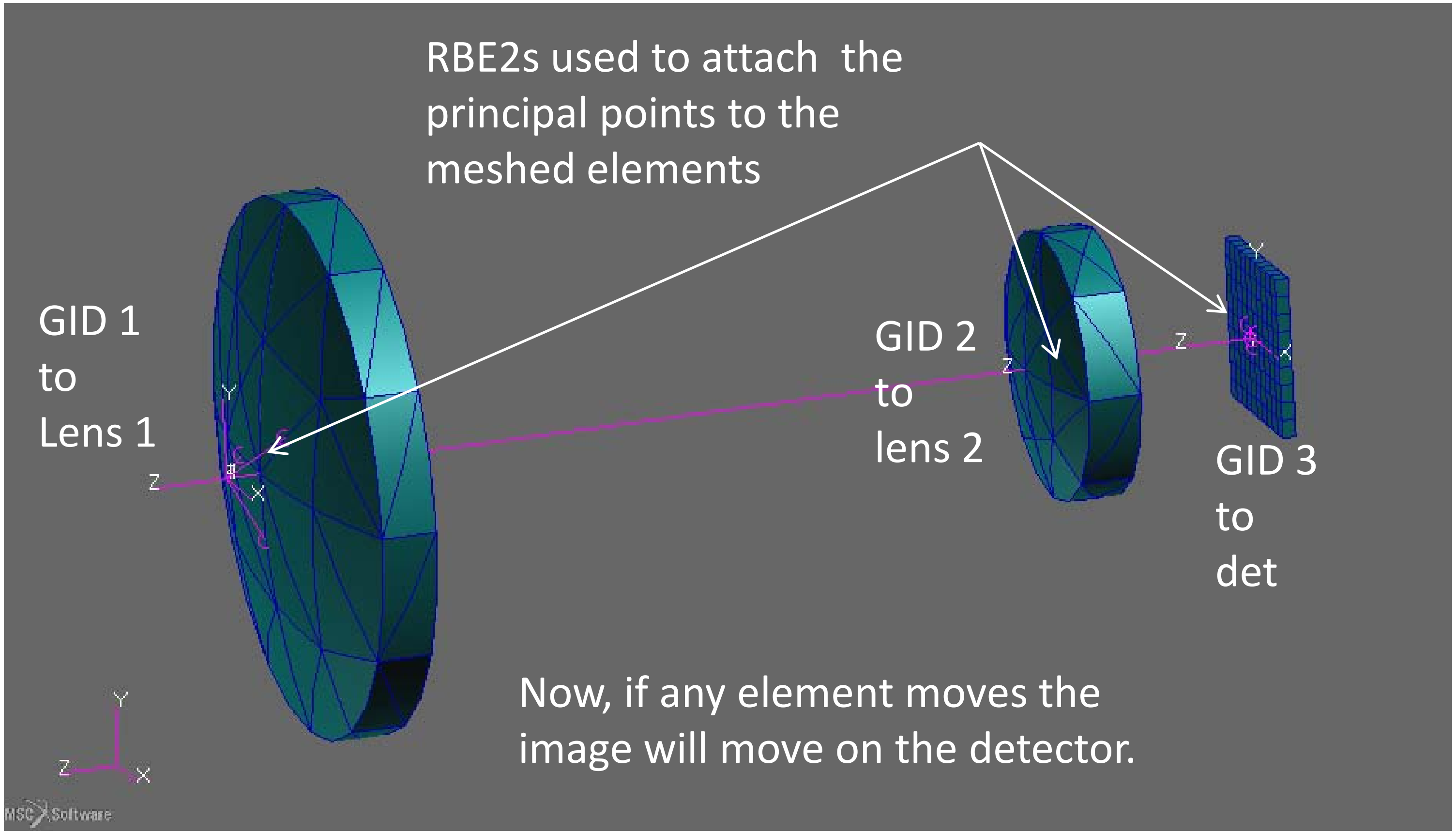
and Attach the Principal Points to the Meshed Elements in Patran



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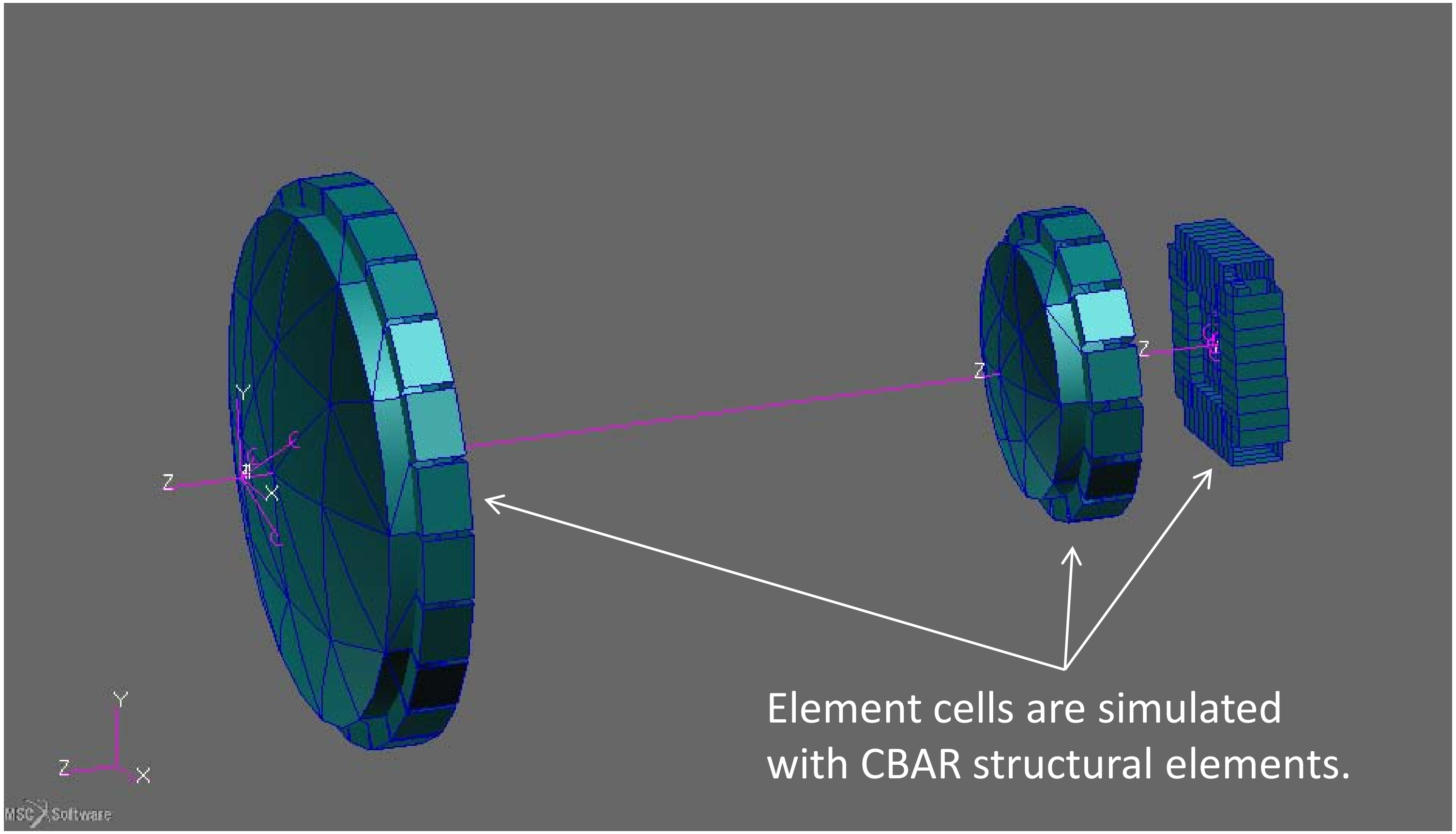
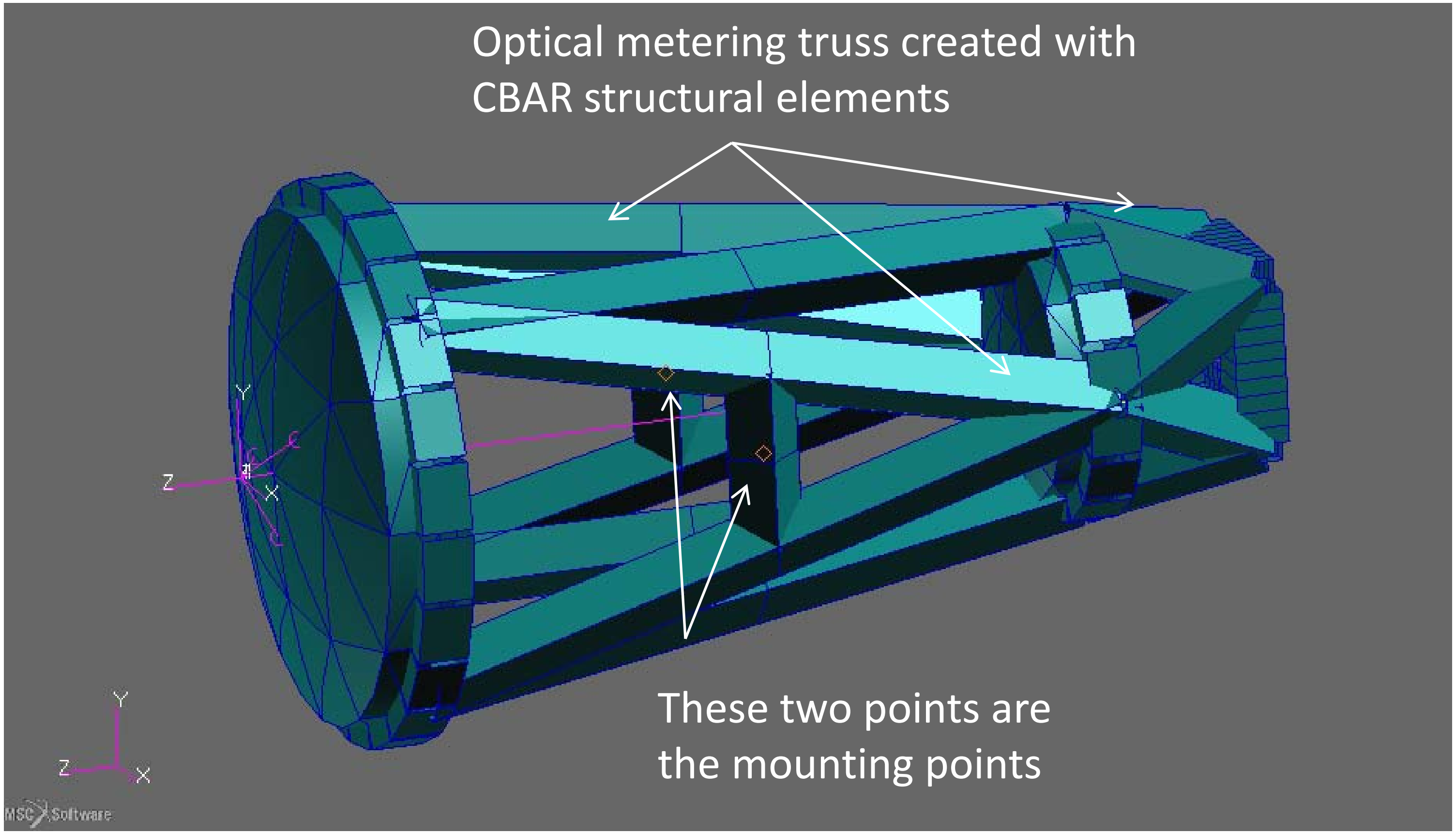
In Patran Create Cells for Each Element



In Patran Create a Truss Structure for the Cells



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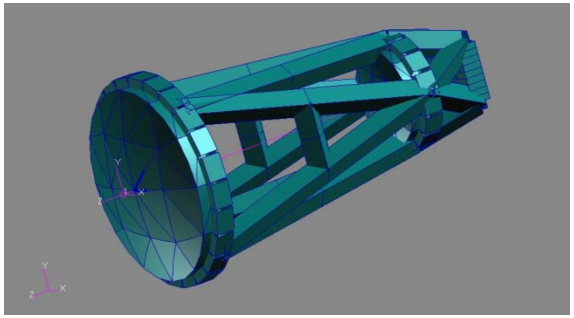
In Nastran Run a 6 DOF Rigid Body Check



For unit displacements with an object at infinity the image motions should be either computational zeros, the focal length of the system (4.741172, see page 4) or -1.0 in the "tele.f06" file.

D I S P L A C E M E N T   V E C T O R

	POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
BASE MOTION:								
1.0 Tx	5	G	-1.239011E-10	9.571148E-12	-1.010361E-13	-1.980658E-13	-3.283262E-13	-9.969587E-12
	6	G	3.545340E-14	0.0	0.0	0.0	0.0	0.0
1.0 Ty	5	G	4.249783E-11	-8.842371E-12	5.046801E-13	4.182508E-13	4.095761E-13	-5.423809E-12
	6	G	-2.176852E-13	0.0	0.0	0.0	0.0	0.0
1.0 Tz	5	G	4.585644E-11	1.080863E-11	-1.085557E-12	-2.709695E-13	-6.882338E-13	8.544233E-13
	6	G	4.827250E-13	0.0	0.0	0.0	0.0	0.0
1.0 Rx	5	G	-8.676349E-11	-4.739557E+00	1.405411E-12	3.416156E-13	-1.469747E-12	1.259602E-11
	6	G	7.719834E-13	0.0	0.0	0.0	0.0	0.0
1.0 Ry	5	G	4.739557E+00	3.172970E-11	-9.775003E-13	-1.338907E-13	-3.279599E-13	1.546279E-12
	6	G	4.457545E-13	0.0	0.0	0.0	0.0	0.0
1.0 Rz	5	G	2.361326E-12	2.262890E-11	-3.414756E-13	-3.825188E-13	-9.552226E-14	-1.000000E+00
	6	G	1.344123E-13	0.0	0.0	0.0	0.0	0.0
REGISTRATION VARIABLES			TX DM/M	TY	TZ	RX	RY	RZ

GIDs 5 and 6 show the image motions.

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In Nastran Analyze Optical Image Motions Due to X, Y and Z Axis Static Gravity Vectors in Nastran

```
1    DOUB'S IVORY(TM) UNIFIED OPTOMECHANICAL MODEL                        NOVEMBER  20, 2014  MSC.NASTRAN  1/26/09   PAGE    10
     X GRAVITY
0                                                                                                      SUBCASE 1

                                       D I S P L A C E M E N T   V E C T O R

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             1      G      1.608140E-05  -4.240751E-08  -4.555795E-08   2.931421E-07   2.206466E-06   9.189821E-10
             2      G      7.448824E-06   7.022216E-10   2.065525E-08  -1.122153E-07   1.105190E-06   2.692745E-08
             3      G      6.956108E-06   8.417413E-10  -1.196107E-08   4.716450E-07   1.627794E-06  -2.378198E-08
             5      G      1.160343E-05   4.476981E-09  -9.196381E-08  -2.783151E-08   9.880168E-07   2.378198E-08
             6      G      6.357791E-08   0.0            0.0            0.0            0.0            0.0
1    DOUB'S IVORY(TM) UNIFIED OPTOMECHANICAL MODEL                        NOVEMBER  20, 2014  MSC.NASTRAN  1/26/09   PAGE    11
     Y GRAVITY
0                                                                                                      SUBCASE 2

                                       D I S P L A C E M E N T   V E C T O R

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             1      G     -4.065706E-09   2.677417E-05   1.061671E-08  -9.334290E-06  -1.283125E-08  -1.461772E-08
             2      G      3.189777E-09  -3.738374E-06   6.650016E-10  -8.295156E-06   2.750977E-08   1.446298E-08
             3      G      1.190348E-09  -9.189099E-06  -1.882948E-09  -8.415510E-06   4.071022E-09  -2.324561E-08
             5      G     -8.068579E-09   4.374857E-05   2.127209E-08  -1.305026E-06  -3.189704E-08   2.324561E-08
             6      G     -9.555630E-09   0.0            0.0            0.0            0.0            0.0
1    DOUB'S IVORY(TM) UNIFIED OPTOMECHANICAL MODEL                        NOVEMBER  20, 2014  MSC.NASTRAN  1/26/09   PAGE    12
     Z GRAVITY
0                                                                                                      SUBCASE 3

                                       D I S P L A C E M E N T   V E C T O R

      POINT ID.   TYPE          T1             T2             T3             R1             R2             R3
             1      G     -1.975805E-08   3.548287E-08   1.006376E-06  -1.880925E-07  -5.978592E-09  -7.007633E-08
             2      G     -6.183997E-09  -5.286045E-10   8.377465E-07  -2.167514E-07   5.622505E-08  -1.054539E-08
             3      G     -3.091442E-09  -1.129015E-09   8.114725E-07  -7.394736E-08  -4.540797E-09   3.566945E-09
             5      G     -2.734813E-08  -2.804116E-08   3.435514E-07  -1.034927E-07  -2.455889E-08  -3.566945E-09
             6      G     -1.619185E-07   0.0            0.0            0.0            0.0            0.0
```

Optical element motions in black

Optical image motions in red

Image size changes

Displacement vectors from "tele.f06" Nastran output file.

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Optomechanics

Stability of the (On-Axis) Image for 3 Axis Static Gravity

	Image lateral motion (X-Y Plane) micro-inches	Image focus motion (Z Axis) micro-inches	Image Size change ($\Delta M/M$)
X Gravity	11.6	-0.092	6.4 E-8
Y Gravity	43.7	0.0213	-9.6 E-9
Z Gravity	0.0392	0.344	-1.6 E-7

From “tele.f06” Nastran output file.
(Only translation effects reported here.)

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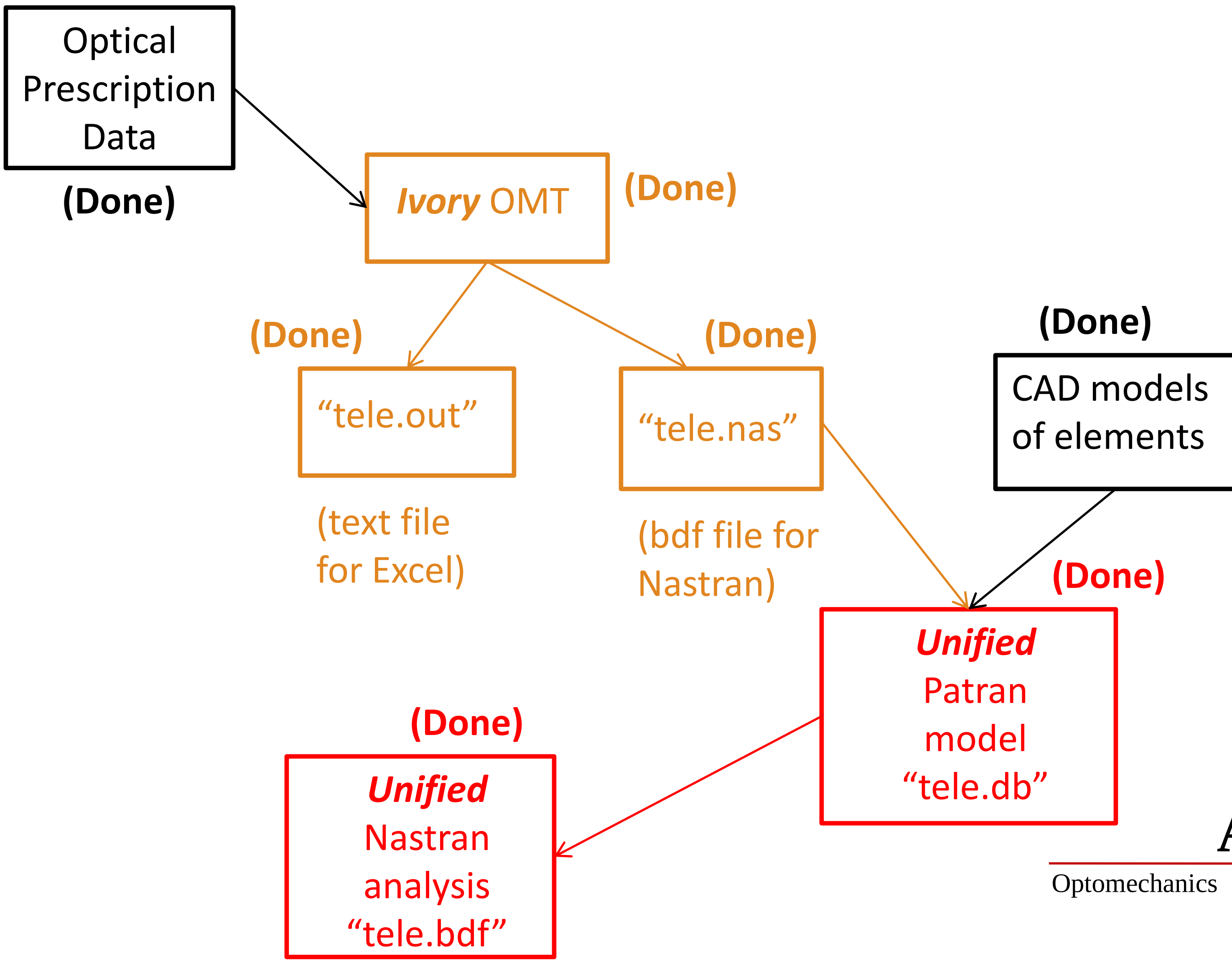
Analysis with the *Unified* Optomechanical Model



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Unified Optomechanical Static Analysis

In this tutorial we did:

- Prepare an ***Ivory*** optomechanical model from a telescope's optical prescription
- Evaluate the optical faithfulness of the model in ***Ivory's*** output file
- Import the ***Ivory*** optomechanical model into Patran
- Import the CAD models of the optical elements into Patran
- Attach the optomechanical model to the meshed optical elements in Patran
- Construct lens cells in Patran
- Construct a structural truss in Patran to support the lens cells
- Check out the full model's optical quality with 6 DOF rigid body checks in Nastran
- Analyze in Nastran the static gravity stability of the image on the detector

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Optomechanics