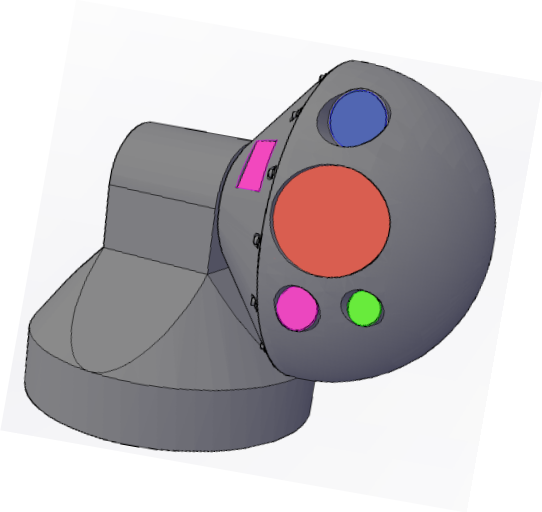
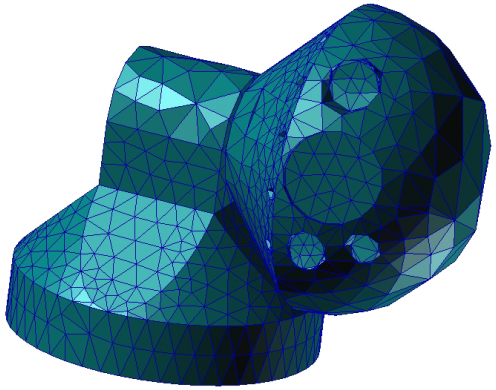
Controlling lines of sight and lines of propagation in stable systems



Alson E. Hatheway

Alson E. Hatheway Inc.
e: teale@aehinc.com



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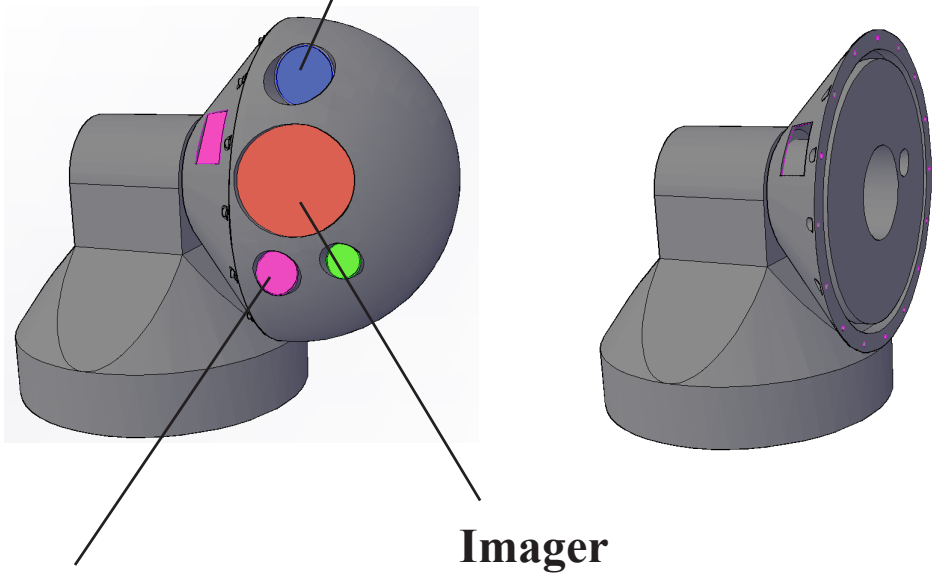
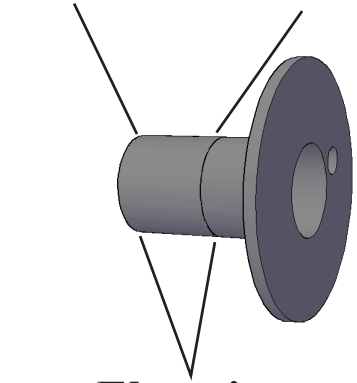
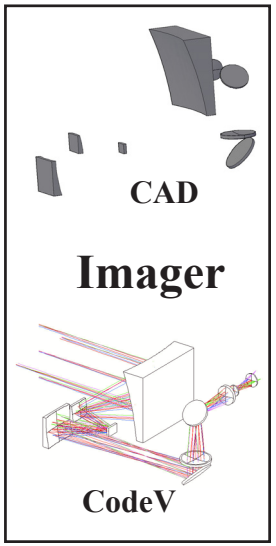
Optomechanics

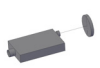
A Sensor Suite on a Stabilized Gimbal Set



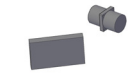


Laser Rcvr





Laser Xmtr

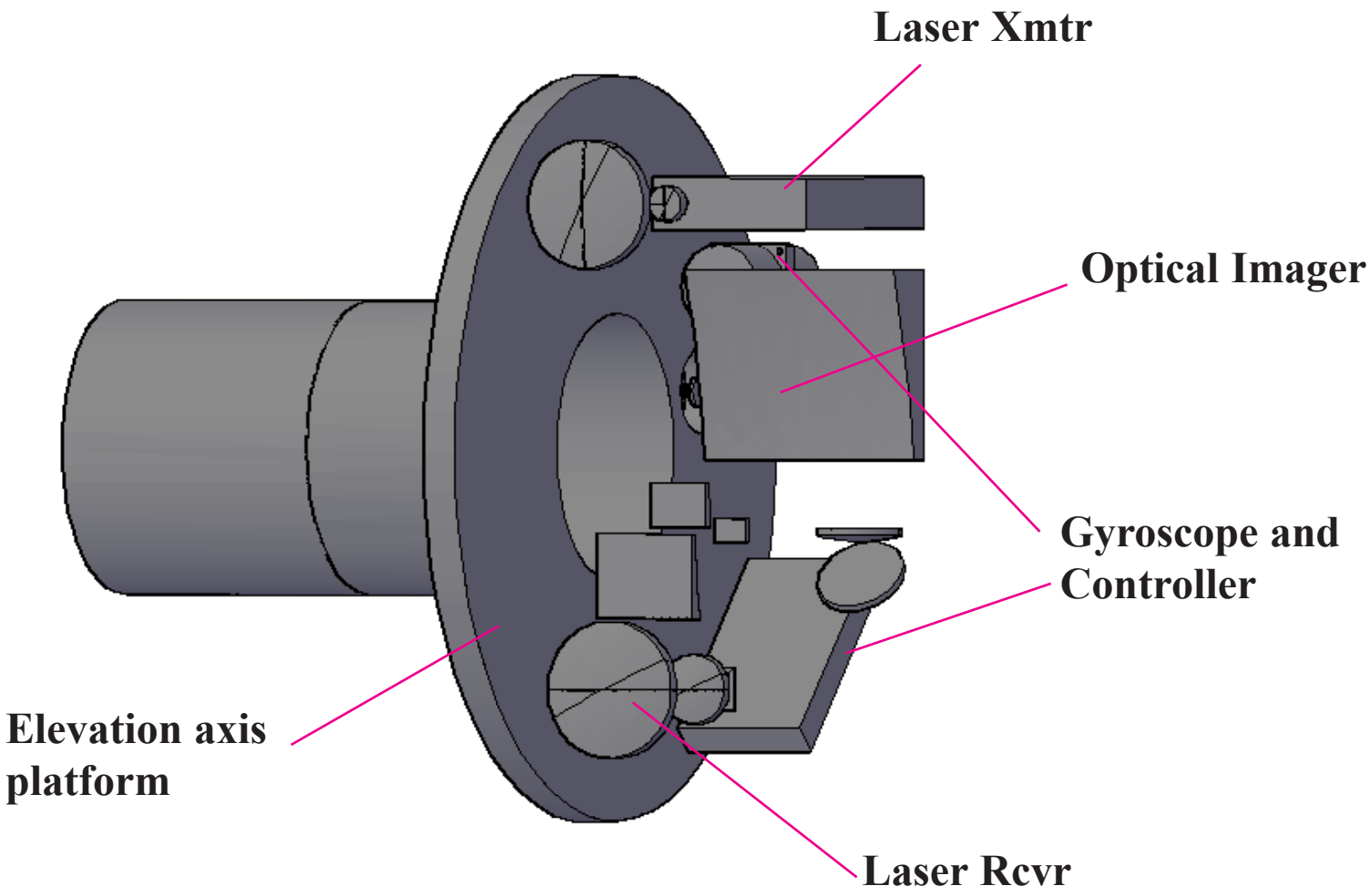


Gyroscope

AEH.

Optomechanics

Proposed Arrangement of Inner (Elevation) Axis



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Optomechanics

Normal Optomechanical Engineering Development Process

Optics:

Initial Design → Initial Tolerances → Optical Element Specs. → Vendor Contacts → Final Design → Vendor Contracts

IGS, STP and Prescription Files

Revised Tolerances ← Test Plating

Optical Design Influence Coefficients

~4 months

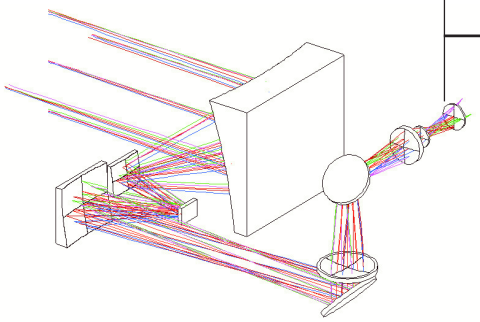
~1 month

Mechanics:

Geometric Packaging (CAD)
Thermal Analysis
Stress Analysis
Mass and Power Budgets
Error Budgets

Departmental Budgeting
Interface Definitions
System and Subsystem Specifications
Major Subcontracts

Optomechanical Engineering



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Optomechanics

Ivory's Optomechanical Engineering Development Process

Optics:

Initial Design → Initial Tolerances → Optical Element Specs. → Vendor Contacts → Final Design → Vendor Contracts

IGS, STP and Prescription Files

Revised Tolerances ← Test Plating

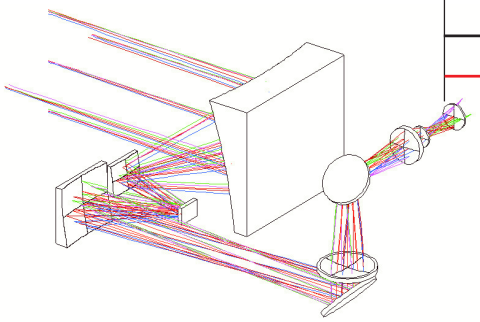
Optical Design Influence Coefficients

~4 months

~1 month

Mechanics: *Ivory's* Influence Coefficients

- Geometric Packaging (CAD)
- Thermal Analysis
- Stress Analysis
- Mass and Power Budgets
- Error Budgets
- Optomechanical Engineering



Departmental Budgeting
Interface Definitions
System and Subsystem Specifications
Major Subcontracts

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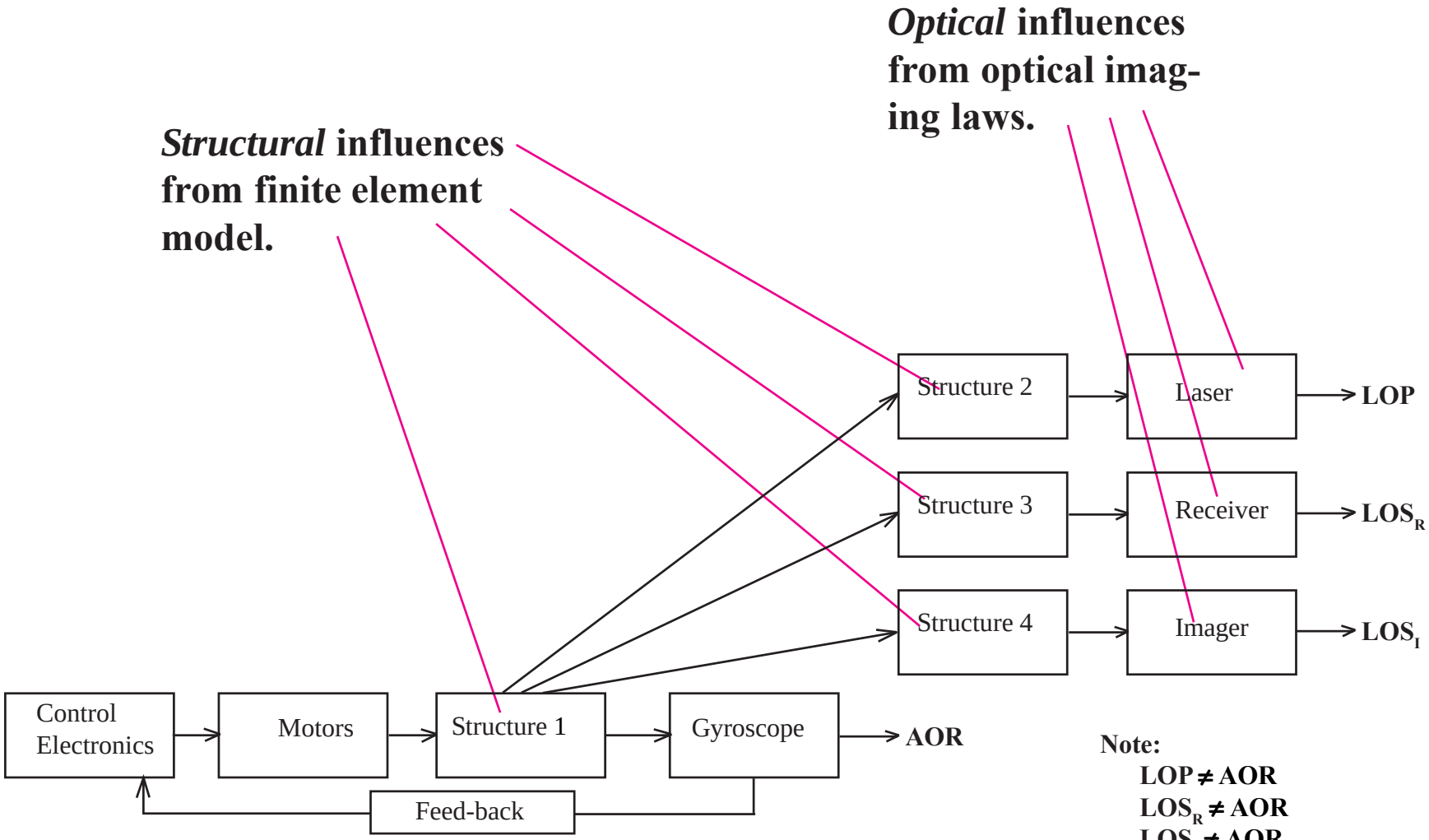
Optomechanics

Optomechanical Influences



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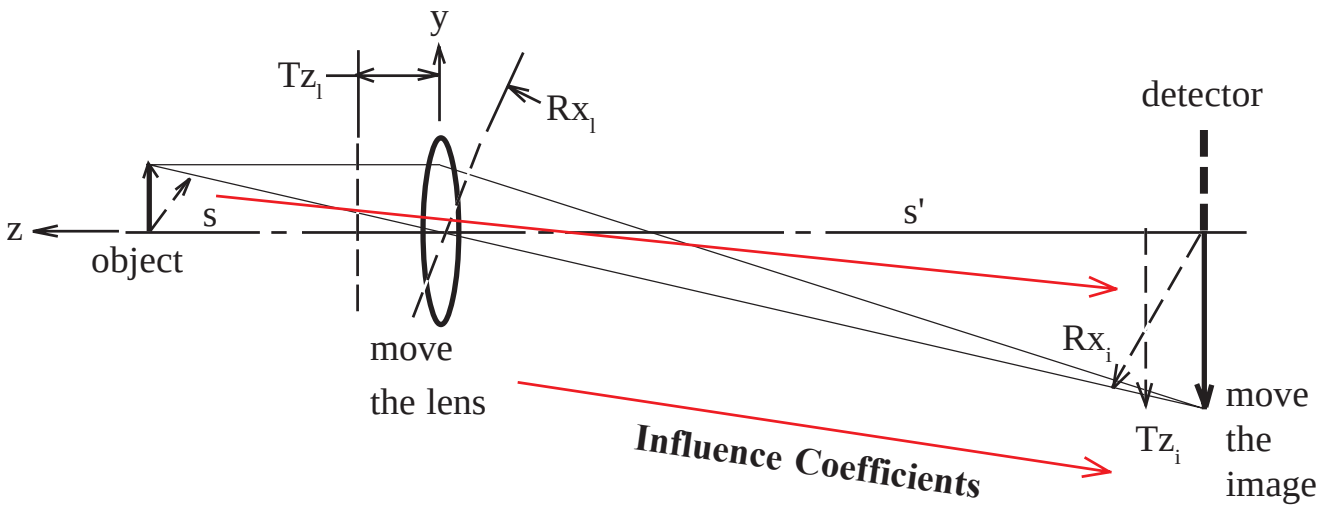
Optomechanics

Ivory's Optomechanical Constraint Equations[tm]



Seven equations determine the magnitude of the registration variables:

$$Tx_i = Tx_1(\partial x_i/\partial x_1) + Ty_1(\partial x_i/\partial y_1) + Tz_1(\partial x_i/\partial z_1) + \ldots \quad \text{(extends to all the elements)}$$

$$Ty_i = Tx_1(\partial y_i/\partial x_1) + Ty_1(\partial y_i/\partial y_1) + Tz_1(\partial y_i/\partial z_1) + \ldots$$

$$Tz_i = Tx_1(\partial z_i/\partial x_1) + Ty_1(\partial z_i/\partial y_1) + Tz_1(\partial z_i/\partial z_1) + \ldots$$

$$Rx_i = Tx_1(\partial \alpha_i/\partial x_1) + Ty_1(\partial \alpha_i/\partial y_1) + Tz_1(\partial \alpha_i/\partial z_1) + \ldots$$

$$Ry_i = Tx_1(\partial \beta_i/\partial x_1) + Ty_1(\partial \beta_i/\partial y_1) + Tz_1(\partial \beta_i/\partial z_1) + \ldots$$

$$Rz_i = Tx_1(\partial \gamma_i/\partial x_1) + Ty_1(\partial \gamma_i/\partial y_1) + Tz_1(\partial \gamma_i/\partial z_1) + \ldots$$

$$\Delta M_i/M_i = Tx_1(\partial M_i/M_i/\partial x_1) + Ty_1(\partial M_i/M_i/\partial y_1) + Tz_1(\partial M_i/M_i/\partial z_1) + \ldots$$

The partial derivatives are called "influence coefficients."

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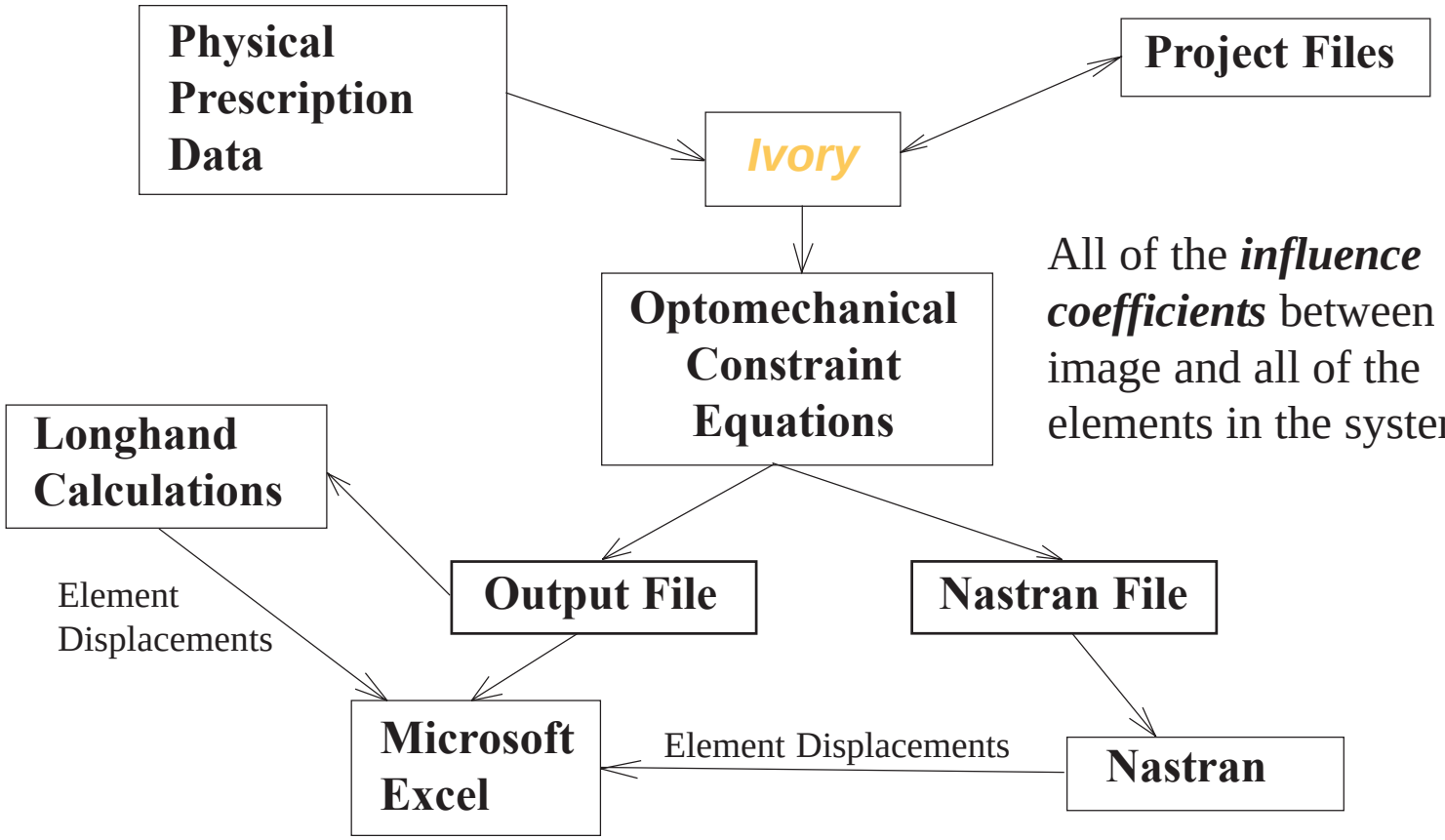
Optomechanics

Ivory Optomechanical Modeling Tools



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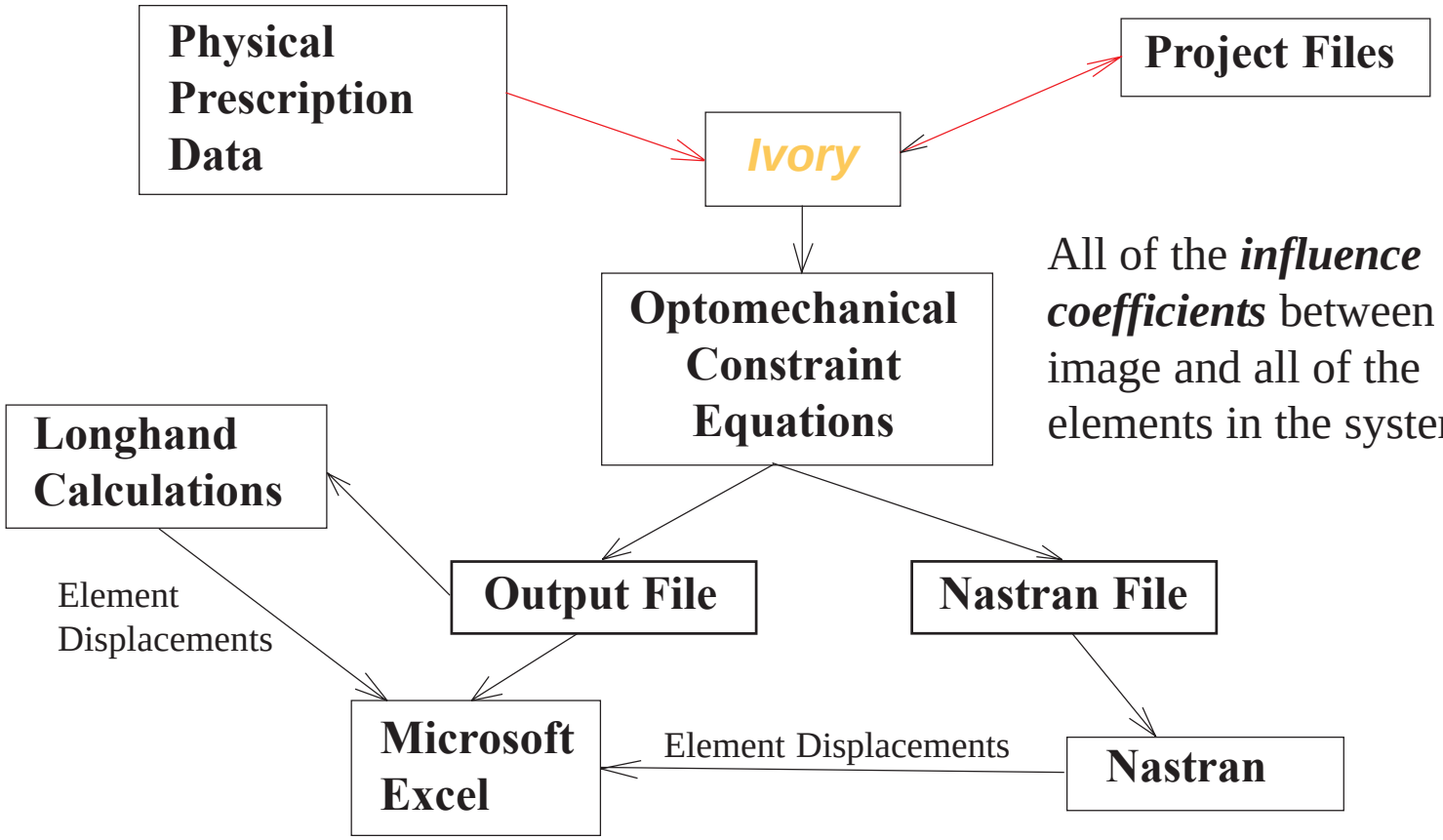
Optomechanics

Preparing *Ivory's* Project Files



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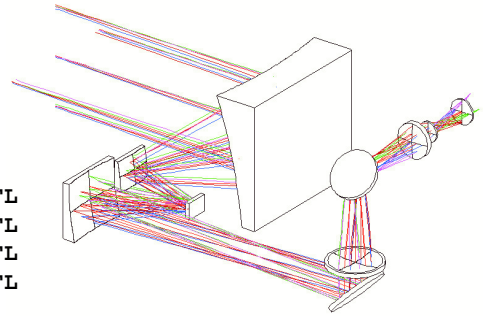
Ivory's Project Files for the Imager

ELT NO.	SUR NO.	SURFACE DESCRIPTION RADIUS X	RADIUS Y	SHAPE	THICKNESS OR SEPARATION	APERTURE DESCRIPTION DIMENSION X	DIMENSION Y	SHAPE	MATERIAL
OBJECT		INF		FLT	INFINITY				
					1.3000	7.405		CIR	
					0.0000	7.417		CIR	
					0.0000	7.417		CIR	
					4.4564	7.417		CIR	
1	1	-10.6445		A-1	-4.4555	3.400	2.798	C-1	REFL
2	2	-3.4340		A-2	1.5854	0.900	0.634	C-2	REFL
3	3	INF		FLT	-2.8516	0.500	0.338	C-3	REFL
4	4	5.3737		A-3	7.3000	1.540	1.240	C-4	REFL
		DECENTER(1)							
5	5	INF		FLT	0.0000	1.316		CIR	REFL
		BEND(1)							
					-0.5020	1.161		CIR	
6	6	-2.7639	CX	SPH	-0.1351	1.241		CIR	GERMMW
		HOLOGRAM(1)							
6	7	-3.9269		A-4	-2.0528	1.206		CIR	
		DECENTER(2)							
7	8								
8	9								
8	10								
9	11								
9	12								
	13								
10	14								
10	15								
IMAGE									



5h.DAT - WordPad

File Edit View Insert Format Help

Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4
1	obj	inf	AIR	inf	obj	1.0000000	0.0000000	0.0000000	0.000(
2	1	10.6445	AIR	4.4555	MIRR	0.0000000	0.0000000	0.0000000	0.000(
3	2	-3.434	AIR	1.5854	MIRR	0.0000000	0.0000000	0.0000000	0.000(
4	3	inf	AIR	2.8516	MIRR	0.0000000	0.0000000	0.0000000	0.000(
5	4	5.3737	AIR	7.3	MIRR	0.0000000	0.0000000	0.0000000	0.000(
6	5	inf	AIR	.502	MIRR	45.	0.0000000	0.0000000	0.000(
7	6	-2.7639	GERM	.1351	LENS	0.0000000	0.0000000	0.0000000	0.000(
8	6	-3.9269	AIR	2.0528	LENS	0.0000000	0.0000000	0.0000000	0.000(
9	7	inf	AIR	2.0528	MIRR	45.	90.	0.0000000	0.000(
10	8	-1.829	GERM	.1621	LENS	0.0000000	0.0000000	0.0000000	0.000(
11	8	-6.8715	AIR	.4369	LENS	0.0000000	0.0000000	0.0000000	0.000(
12	9	inf	SAPH	.04	WIND	0.0000000	0.0000000	0.0000000	0.000(
13	9	inf	AIR	1.195	WIND	0.0000000	0.0000000	0.0000000	0.000(
14	10	inf	GERM	.04	WIND	0.0000000	0.0000000	0.0000000	0.0000000
15	10	inf	AIR	.2922	WIND	0.0000000	0.0000000	0.0000000	0.0000000
16	det	inf	AIR	0.0	det				

For Help, press F1 NUM

5h.IND - WordPad

File Edit View Insert Format Help

MATERIAL	INDEX
AIR	1.0
GERM	4.021147
SAPH	1.661519
nul	1.0

For Help, press F1

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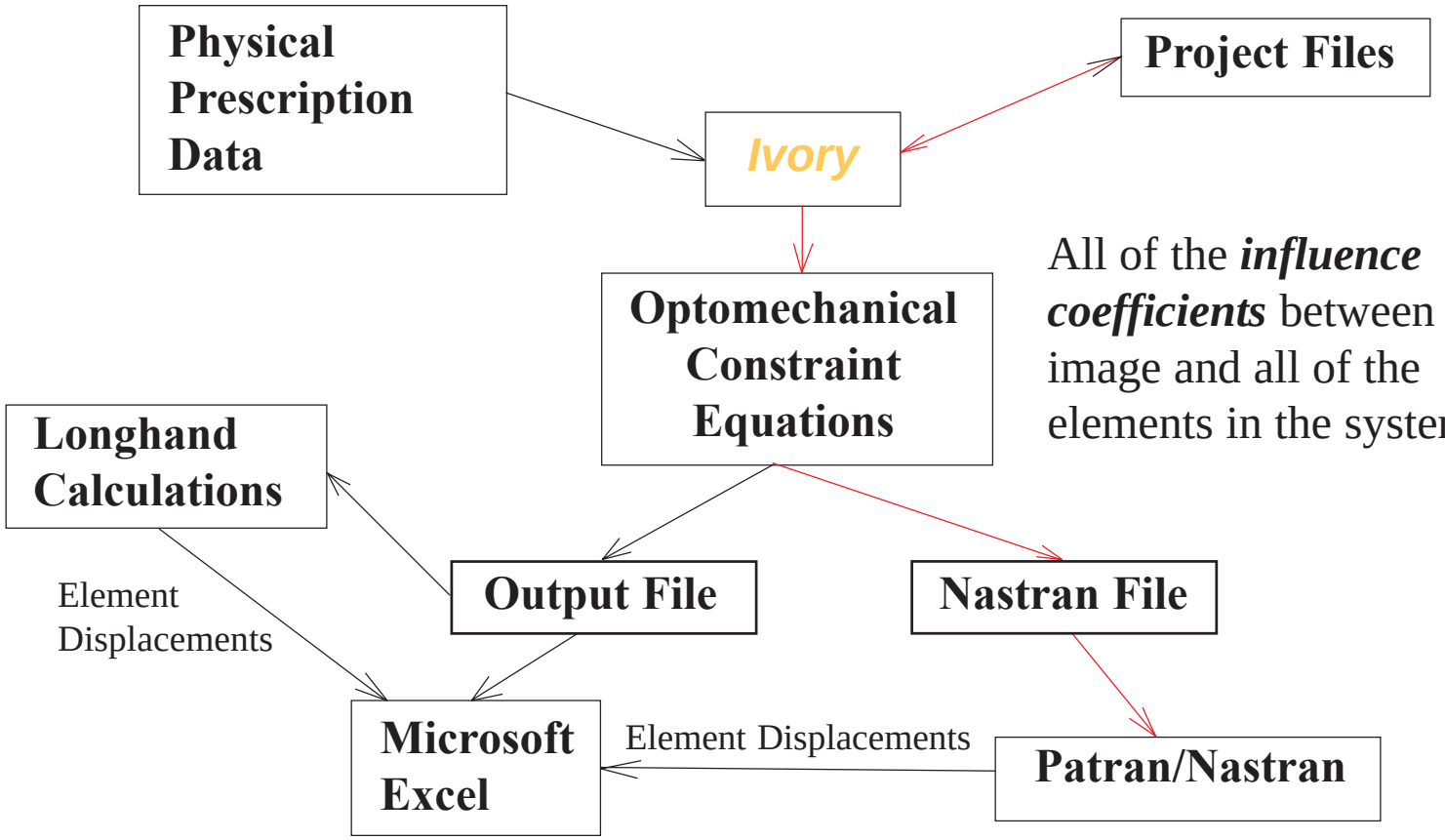
Optomechanics

Generating *Ivory's* Nastran Model



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Optomechanics

Ivory's Nastran File for the Imager (1)

```
NASTRAN MESH
CEND
TITLE=5H'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  10 /123456 ARE ASSIGNED TO THE OPTICAL ELEMENTS IN ASCENDING ORDER.
$  11 /123456 ARE ASSIGNED TO THE SYSTEM DETECTOR.
$  12 /123456 ARE ASSIGNED TO THE SYSTEM OBJECT.
$  13 /123456 ARE ASSIGNED TO THE REGISTRATION VARIABLES TX, TY, TZ, RX, RY, RZ.
$  14 /1 IS ASSIGNED TO THE REGISTRATION VARIABLE DM/M.

GRID    13              0.      0.      0.
GRID    14              0.      0.      0.

GRID,17,,10.,10.,10.
MAT1,1,10.+6,,.3,.098,23.-6,20.,.05
PBAR,1,1,1.,1.,1.,1.
CBAR,1,1,1,2,1.,1.,1.
=,*1,=,*1,*1,==
=10
CBAR,13,1,17,1,1.,-1.,1.


MPC     1000    13      1       -1.     1       1       +1.36-16
                1       2       -3.133631       4        33.3559
                1       5       +1.45-152       1       +6.89-17
                2       2        1.581872       4        5.43215
                2       5       -2.36-163       4         .51183
                3       5       +2.23-174       1       +6.76-17
                4       2        1.551664       4       -8.33817
                4       5       +3.63-165       3       +1.38-04
                5       4       -8.3396 5       5       -2.57-16
                6       1       +6.39-176       2        1.46771
                6       4        .15292 6       5       -6.66-18
                7       5        1.419898       1        2.46761
                8       5       -.12274 9       5       -.01593
                10      5       -.03005 11      1       -1.


MPC     1000    13      2       -1.     1       1       -3.13363
                1       2       +1.36-161       4       -1.45-15
                1       5       -33.35592       1       -1.58187
                2       2       -6.89-172       4       -2.36-16
                2       5        5.432153       4       -2.23-17
                3       5       -.51183 4       1       -1.55166
                4       2       -6.76-174       4       +3.63-16
                4       5       -8.338175       3       -6.05-21
                5       4       +3.63-165       5        5.89699
                6       1       -1.467716       2       -6.39-17
                6       4       -6.66-186       5        .15292
                7       3        2.075517       4        2.00803
                8       2        2.467618       4        .12274
                9       4       -.01593 10      4       -.03005
                11      2       -1.


MPC     1000    13      3       -1.     1       3       -9.81966
                2       3       -12.22763       3       -4.81592
                4       3       -2.407965       3       -1.36-08
                6       3        2.153877       3       -3.04603
                8       3       -1.1538711      3       -1.


MPC     1000    13      4       -1.     1       4       +1.36-16
                1       5       -3.133632       4       -2.04-16
                2       5       -4.685393       4       +1.35-16
                3       5       -3.103524       4       -6.76-17
                4       5       -1.551865       4       +8.55-21
                5       5       -1.38-046       4       +6.39-17
                6       5        1.467717       4        2.93521
                8       4        2.4676111      4       -1.


MPC     1000    13      5       -1.     1       4       -3.13363
                1       5       +1.36-162       4        4.68539
                2       5       +2.04-163       4       -3.10352
                3       5       +1.35-164       4        1.55186
                4       5       +6.76-175       4       -1.96-04
                5       5       +6.05-216       4       -1.46771
                6       5       -6.39-177       5       -2.07551
                8       5        2.4676111      5       -1.


MPC     1000    13      6       -1.     5       5        1.41421
                7       5       -1.4142111      6       -1.


MPC     1000    14      1       -1.     1       3        8.23626
                2       3        9.969513       3        3.46289
                4       3        1.731545       3       +3.33-05
                6       3       -1.821897       3        2.57657
                8       3        1.82191

SPC     1000    14      23456

$ DETECTOR
$ PRINCIPAL POINT
GRID    11      11      0.      0.      0.      11
$ DETECTOR COORDINATE SYSTEM
CORD2R  11      0       0.      0.      0.      0.      0.      1.
        1.      0.      0.
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  22      0       0.      0.      0.      0.      0.      1.
        1.      0.      0.

$ ELEMENT 10
$ FIRST PRINCIPAL POINT
GRID    10      22       0.      0.      .327   10
$ ELEMENT COORDINATE SYSTEM
CORD2R  10      22       0.      0.      .327    0.      0.      1.327
         1.      0.      .327
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  21      22       0.      0.      .327    0.      0.      1.327
         1.      0.      .327
```

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Optomechanics

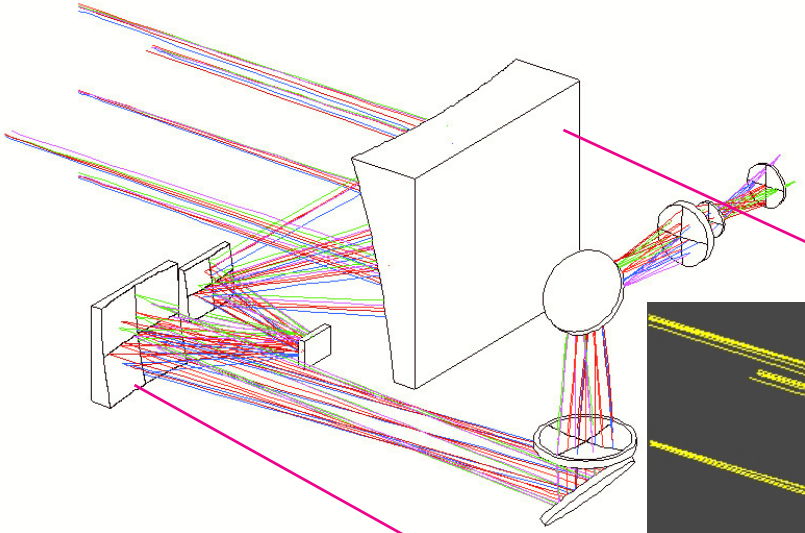
Ivory's Nastran File for the Imager (2)

```
$ ELEMENT 9
$ FIRST PRINCIPAL POINT
GRID    9       21      0.      0.      1.227  9
$ ELEMENT COORDINATE SYSTEM
CORD2R  9       21      0.      0.      1.227   0.      0.      2.227
         1.      0.      1.227
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  20      21      0.      0.      1.227   0.      0.      2.227
         1.      0.      1.227

$ ELEMENT 8
$ FIRST PRINCIPAL POINT
GRID    8       20      0.      0.       .625   8
$ ELEMENT COORDINATE SYSTEM
CORD2R  8       20      0.      0.       .625    0.      0.      1.625
         1.      0.       .625
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  19      20      0.      0.       .625    0.      0.      1.625
         1.      0.       .625

$ ELEMENT 7
$ FIRST PRINCIPAL POINT
GRID    7       19      0.      0.       2.038  7
$ ELEMENT COORDINATE SYSTEM
CORD2R  7       19      0.      0.       2.038   0.     -.707    1.331
        -1.      0.      2.038
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  18      19      0.      0.       2.038   0.     -1.      2.038
        -1.      0.      2.038

$ ELEMENT 6
$ FIRST PRINCIPAL POINT
GRID    6       18      0.      0.       2.261  6
$ ELEMENT COORDINATE SYSTEM
CORD2R  6       18      0.      0.       2.261   0.      0.      3.261
       +4.36-17 1.      2.261
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  17      18      0.      0.       2.261   0.      0.      3.261
       +4.36-17 1.      2.261

$ ELEMENT 5
$ FIRST PRINCIPAL POINT
GRID    5       17      0.      0.       .428   5
$ ELEMENT COORDINATE SYSTEM
CORD2R  5       17      0.      0.       .428    0.     -.707   -.278
        -1.      0.      .428
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  16      17      0.      0.       .428    0.     -1.      .428
        -1.      0.      .428

$ ELEMENT 4
$ FIRST PRINCIPAL POINT
GRID    4       16      0.      0.       7.3    4
$ ELEMENT COORDINATE SYSTEM
CORD2R  4       16      0.      0.       7.3     0.      0.      6.3
        -1.      0.      7.3
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  15      16      0.      0.       7.3     0.      0.      6.3
        -1.      0.      7.3
```

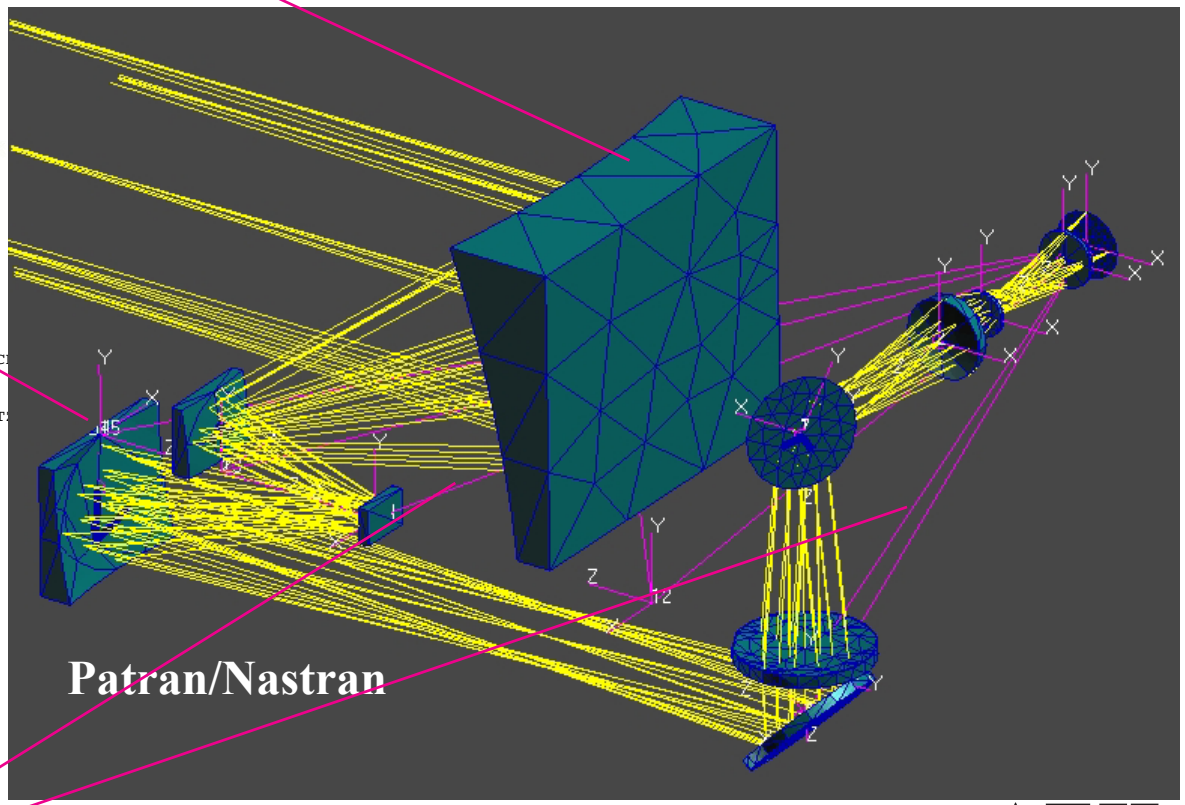
```
$ ELEMENT 3
$ FIRST PRINCIPAL POINT
GRID    3       15      0.      0.       2.851  3
$ ELEMENT COORDINATE SYSTEM
CORD2R  3       15      0.      0.       2.851   0.      0.      1.851
        -1.      0.      2.851
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  14      15      0.      0.       2.851   0.      0.      1.851
        -1.      0.      2.851

$ ELEMENT 2
$ FIRST PRINCIPAL POINT
GRID    2       14      0.      0.       1.585  2
$ ELEMENT COORDINATE SYSTEM
CORD2R  2       14      0.      0.       1.585   0.      0.      .585
        -1.      0.      1.585
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  13      14      0.      0.       1.585   0.      0.      .585
        -1.      0.      1.585

$ ELEMENT 1
$ FIRST PRINCIPAL POINT
GRID    1       13      0.      0.       4.455  1
$ ELEMENT COORDINATE SYSTEM
CORD2R  1       13      0.      0.       4.455   0.      0.      3.455
        -1.      0.      4.455
$ INCIDENT OPTICAL AXIS COORDINATE SYSTEM
CORD2R  12      13      0.      0.       4.455   0.      0.      3.455
        -1.      0.      4.455

$ OBJECT AT INFINITY AND NOT MODELED

$                MODEL PREPARED BY IVORY(TM) OPTOMECHANICAL MODELING TOOLS
$                                    Version I25B
$                                FOR Alson E. Hatheway Inc.
$                             PROJECT NAME:  '5H'
$                                 07-16-2010  15:28:10
$                        ALSON E. HATHEWAY INC., http://www.aehinc.com

ENDDATA
```

AEH.
Optomechanics

Ivory/Nastran Model of the Imager



CodeV's ***.stp* file**




```
MPC=1000
BEGIN BULK

$ THE FOLLOWING GRID POINTS/DOFS HAVE BEEN ASSIGNED:
$  1  THRU  10 /123456 ARE ASSIGNED TO THE OPTICAL ELEMENTS IN ASC
$  11 /123456 ARE ASSIGNED TO THE SYSTEM DETECTOR.
$  12 /123456 ARE ASSIGNED TO THE SYSTEM OBJECT.
$  13 /123456 ARE ASSIGNED TO THE REGISTRATION VARIABLES TX, TY, T
$  14 /1 IS ASSIGNED TO THE REGISTRATION VARIABLE DM/M.

GRID    13               0.      0.      0.
GRID    14               0.      0.      0.

GRID,17,,10.,10.,10.
MAT1,1,10.+6,,.3,.098,23.-6,20.,.05
PBAR,1,1,1.,1.,1.,1.
CBAR,1,1,1,2,1.,1.,1.
=,*1,=,*1,*1,==
=10
CBAR,13,1,17,1,1.,-1.,1.


MPC     1000    13      1       -1.     1       1       +1.36-16
                1       2       -3.133631       4        33.3559
                1       5       +1.45-152       1       +6.89-17
                2       2        1.581872       4        5.43215
                2       5       -2.36-163       4         .51183
                3       5       +2.23-174       1       +6.76-17
                4       2        1.551664       4       -8.33817
                4       5       +3.63-165       3       +1.38-04
                5       4       -8.3396 5       5       -2.57-16
                6       1       +6.39-176       2        1.46771
                6       4         .15292 6      5       -6.66-18
                7       5        1.419898       1        2.46761
```

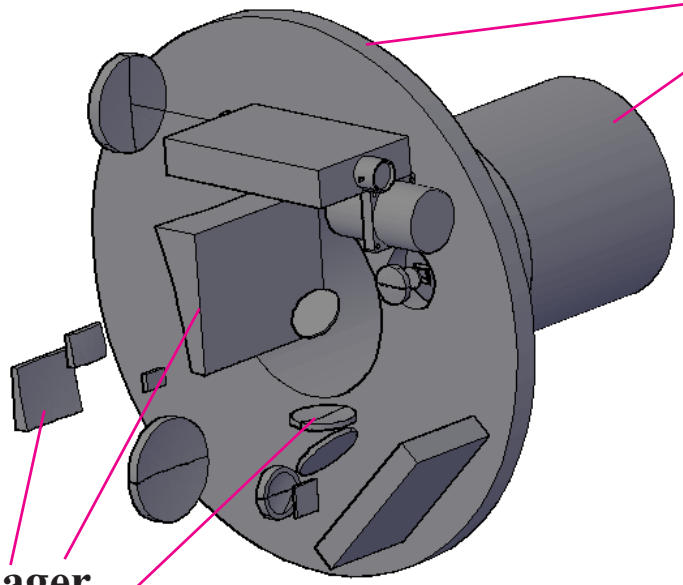
Ivory's ***.nas* file**

AEH.

Optomechanics

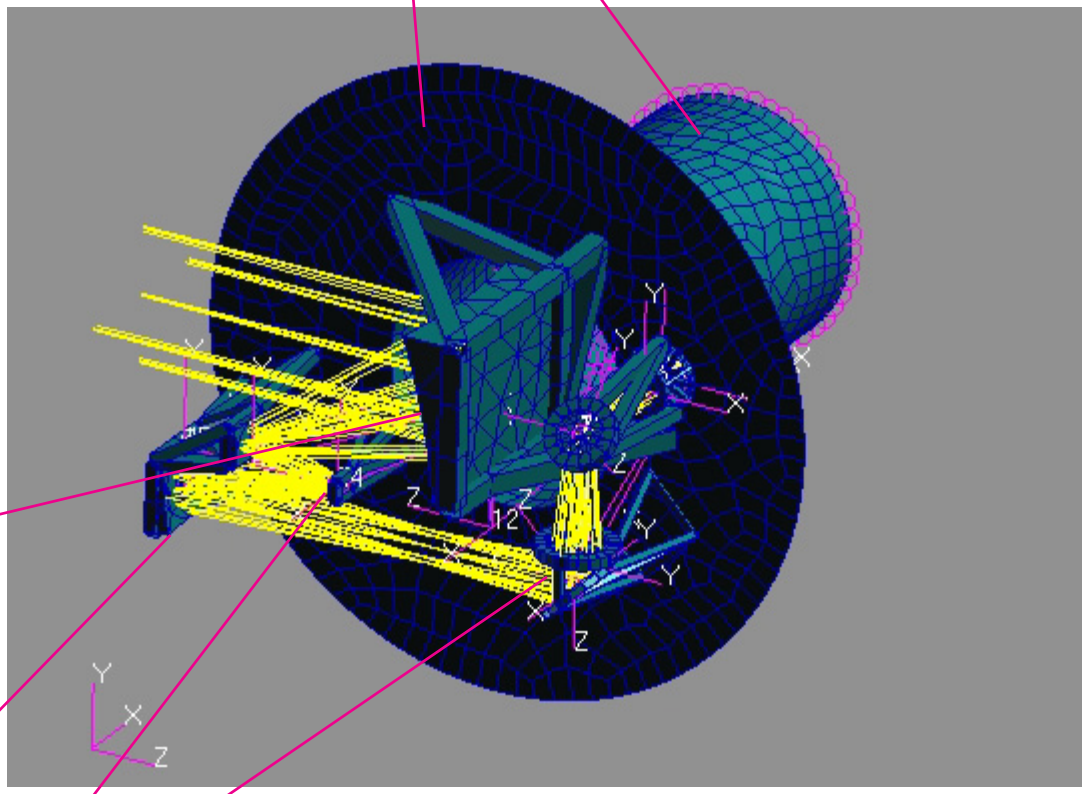
*Ivory/*Nastran Initial Model of the Elevation Axis

Shell element model of the elevation axis



Imager optical components

Imager Ivory/ Nastran model

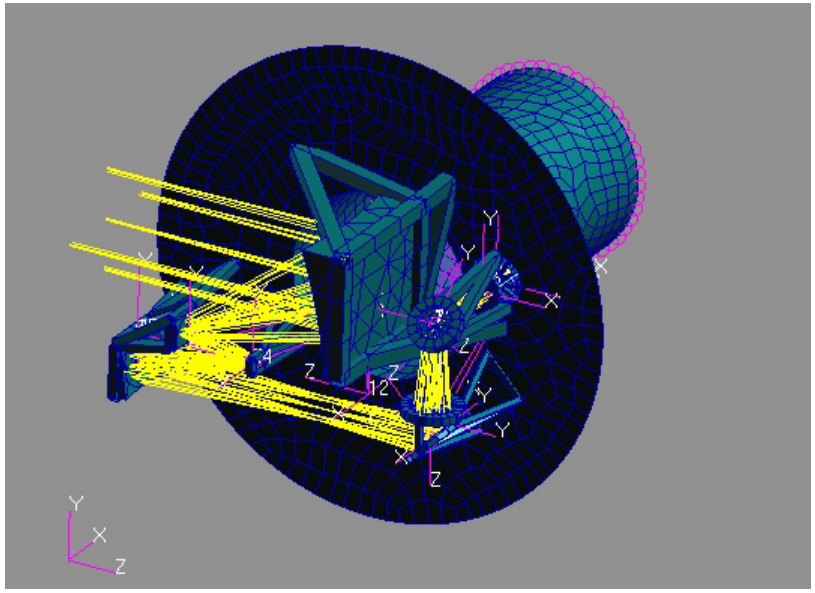


Structural cells for mounting Imager optical components

AEH.

Optomechanics

*Ivory/*Nastran Model of the Elevation Axis



Initial Trial

	LOS Errors (μr)		
	Rx	Ry	Net
X Gravity	-13.4053	2.993431	13.73547
Y Gravity	19.19801	-14.0298	23.77812
Z Gravity	20.78545	-19.5949	28.56559
El Axis Mass=		5.2	lb

Note: Focal length=16.68 inches

D I S P L A C E M E N T V E C T O R (Z G R A V I T Y)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2111	G	1.999586E-05	1.997723E-05	-5.321686E-05	5.066319E-06	1.063996E-05	7.893610E-06
2112	G	-6.852039E-06	-1.462925E-05	5.646881E-05	6.828990E-06	2.014371E-05	4.197356E-06
2113	G	1.812071E-06	6.913396E-06	-2.545205E-05	-1.394247E-06	7.730068E-06	2.295344E-06
2114	G	-3.135259E-05	-6.071180E-06	5.655266E-05	7.109179E-06	1.950236E-05	1.312777E-06
2115	G	-1.257047E-05	3.416554E-05	-2.684318E-05	-1.871679E-05	1.127948E-05	7.440939E-06
2116	G	1.157377E-05	5.342189E-05	-5.637081E-06	2.072088E-05	2.674286E-06	-1.306870E-05
2117	G	-6.071787E-05	1.641206E-05	3.284741E-06	3.252225E-06	4.534236E-06	-1.896452E-05
2118	G	1.743217E-05	1.389057E-06	-1.296191E-05	-3.609602E-06	1.356123E-05	2.382732E-06
2119	G	8.558804E-06	-4.574464E-07	-1.154363E-05	-4.478087E-06	1.625861E-05	4.497225E-08
2120	G	6.815590E-06	-2.064045E-06	-9.110042E-06	-2.474577E-06	2.677201E-06	-1.898830E-05
2121	G	9.244200E-06	-2.150108E-06	4.340725E-06	9.420930E-06	5.247391E-06	-2.945216E-06
2123	G	3.268024E-04	3.839157E-04	-1.930393E-04	-8.001957E-05	-6.618082E-05	1.248440E-05
2124	G	1.295611E-04	0.0	0.0	0.0	0.0	0.0
3454	G	0.0	0.0	0.0	0.0	6.137461E-07	-2.179917E-10
3456	G	0.0	0.0	0.0	8.850597E-08	1.117723E-06	-3.177722E-10

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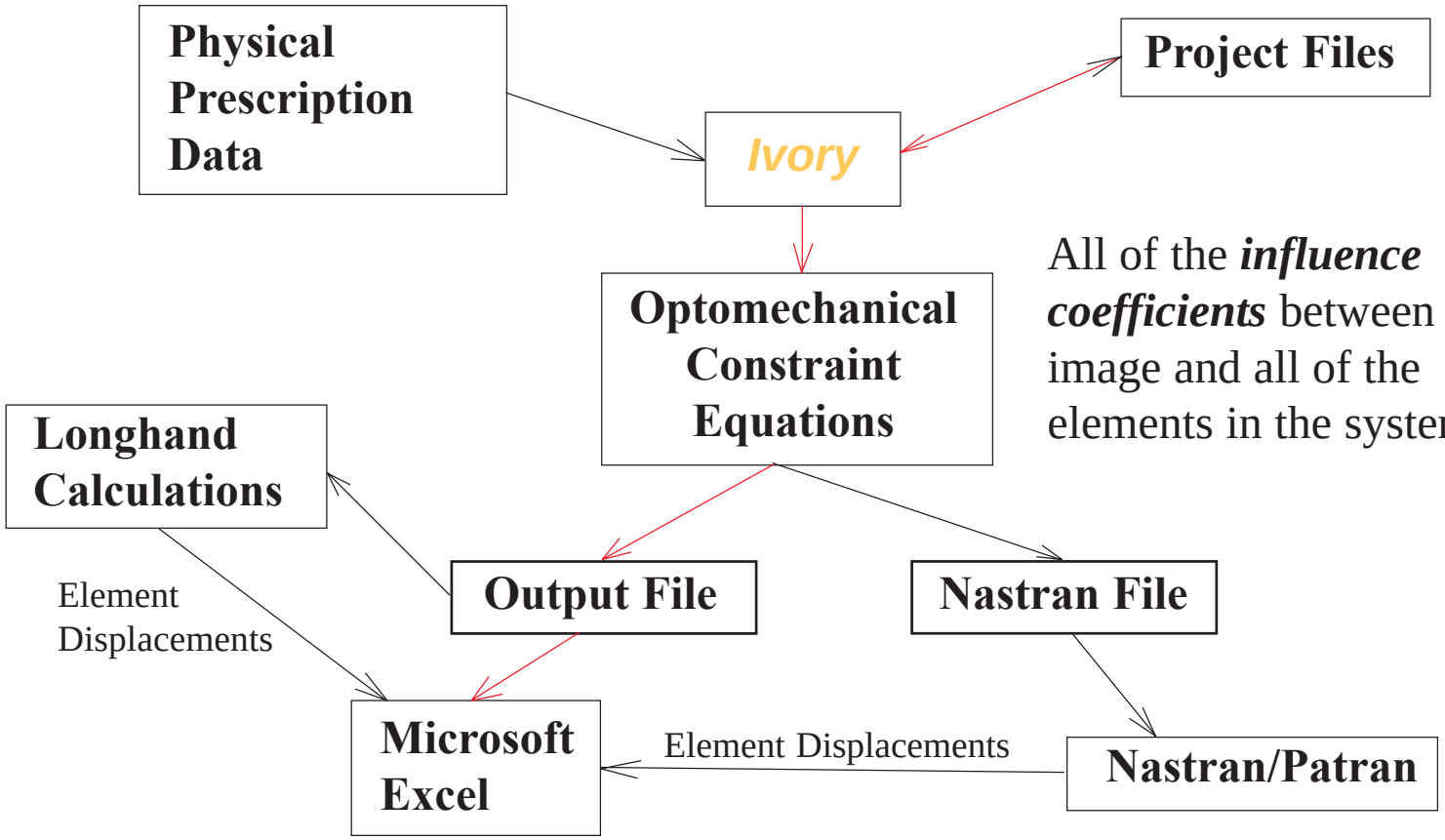
Generating *Ivory's* Excel Model



AEH.
Optomechanics

Ivory's Output File for the Imager (1)

Output from -
IVORY Optomechanical Modeling Tools
Version I25B

PROJECT NAME: '5H' TIME AND DATE: 15:28:06 07-16-2010

PHYSICAL PRESCRIPTION ECHO

Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4
1	obj	inf	1.0	inf	obj	1	0	0	0
2	1	10.6445	1.0	4.4555	MIRR	0	0	0	0
3	2	-3.434	1.0	1.5854	MIRR	0	0	0	0
4	3	inf	1.0	2.8516	MIRR	0	0	0	0
5	4	5.3737	1.0	7.3	MIRR	0	0	0	0
6	5	inf	1.0	.502	MIRR	45	0	0	0
7	6	-2.7639	4.021147	.1351	LENS	0	0	0	0
8	6	-3.9269	1.0	2.0528	LENS	0	0	0	0
9	7	inf	1.0	2.0528	MIRR	45	90	0	0
10	8	-1.829	4.021147	.1621	LENS	0	0	0	0
11	8	-6.8715	1.0	.4369	LENS	0	0	0	0
12	9	inf	1.661519	.04	WIND	0	0	0	0
13	9	inf	1.0	1.195	WIND	0	0	0	0
14	10	inf	4.021147	.04	WIND	0	0	0	0
15	10	inf	1.0	.2922	WIND	0	0	0	0
16	det	inf	1.0	0	det				

INDEXES OF REFRACTION ARE RELATIVE TO THE VALUE OF 1.000292

GAUSSIAN PRESCRIPTION

ELE	F	H1	H2	P	P/AIR	PHI	THETA	TYPE
obj	0	0	0	0	inf	0	0	obj
1	5.32225	0	0	0	4.4555	0	0	MIRR
2	-1.717	0	0	0	1.5854	0	0	MIRR
3	inf	0	0	0	2.8516	0	0	MIRR
4	2.68685	0	0	0	7.3	0	0	MIRR
5	inf	0	0	0	.4285642	45	0	MIRR
6	2.841062	7.343585E-02	.1043363	.1041995	2.157136	0	0	LENS
7	inf	0	0	0	2.038523	45	90	MIRR
8	.8055323	1.427698E-02	.0536382	.1227388	.5025754	0	0	LENS
9	inf	-1.203718E-02	1.203718E-02	1.592565E-02	1.212011	0	0	WIND
10	inf	-4.973705E-03	4.973705E-03	3.005259E-02	.2971737	0	0	WIND
det	0	0	0	0	0	0	0	det

SYSTEM 16.677988023 222.03352768 16.404836736 228.43291708 16.702010436

OBJECTS, IMAGES AND MAGNIFICATIONS

ELE	F	S	S'	M	PHI	THETA	TYPE	e/Tzo
obj	inf	0	0	+1.0000	0	0	obj	
1	5.32225	inf	-5.3223	0	0	0	MIRR	+0.00D+00
2	-1.717	-0.8668	-1.7503	+2.0194	0	0	MIRR	-1.18D+00
3	inf	-0.1649	-0.1649	+1.0000	0	0	MIRR	
4	2.68685	+2.6867	+4.25D+04	+1.58D+04	0	0	MIRR	+5.88D+03
5	inf	+4.25D+04	+4.25D+04	+1.0000	45	0	MIRR	
6	2.841062	+4.25D+04	-2.8413	-6.69D-05	0	0	LENS	-2.35D-05
7	inf	-0.6841	-0.6841	+1.0000	45	90	MIRR	
8	.8055323	+1.3544	-1.9877	-1.4676	0	0	LENS	-1.82D+00
9	inf	-1.4852	-1.4852	+1.0000	0	0	WIND	
10	inf	-0.2732	-0.2732	+1.0000	0	0	WIND	
det	inf	+2.40D-02	+2.40D-02	+1.0	0	0	det	

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Ivory's Output File for the Imager (2)

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	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	+1.00000	0.0	0.0	
Df,p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
SYSTEM-OBJECT									
Tx	+1.366E-16	-3.13363	0.0	0.0	0.0	0.0	0.0	0.0	Dt
Ty	-3.13363	+1.366E-16	0.0	0.0	0.0	0.0	0.0	+0.50000	DR1
Tz	0.0	0.0	-9.81966	0.0	0.0	0.0	+8.23626	0.0	DR2
Rx	+33.35596	-1.454E-15	0.0	+1.366E-16	-3.13363	0.0	0.0	0.0	Dn
Ry	+1.454E-15	-33.35596	0.0	-3.13363	+1.366E-16	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	0.0	0.0	-9.81966	0.0	0.0	0.0	+8.42415	0.0	
ELEMENT-1									
Tx	+6.897E-17	-1.58187	0.0	0.0	0.0	0.0	0.0	0.0	Dt
Ty	+1.58187	-6.897E-17	0.0	0.0	0.0	0.0	0.0	+0.50000	DR1
Tz	0.0	0.0	-12.22762	0.0	0.0	0.0	+9.96951	0.0	DR2
Rx	+5.43215	-2.368E-16	0.0	-2.043E-16	+4.68539	0.0	0.0	0.0	Dn
Ry	-2.368E-16	+5.43215	0.0	-4.68539	+2.043E-16	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	0.0	0.0	-2.50232	0.0	0.0	0.0	+2.39324	0.0	
ELEMENT-2									
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	-4.81592	0.0	0.0	0.0	+3.46289	0.0	DR2
Rx	+0.51183	-2.232E-17	0.0	+1.353E-16	-3.10352	0.0	0.0	0.0	Dn
Ry	+2.232E-17	-0.51183	0.0	-3.10352	+1.353E-16	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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ELEMENT-3									
Tx	+6.765E-17	-1.55166	0.0	0.0	0.0	0.0	0.0	0.0	Dt
Ty	+1.55166	-6.765E-17	0.0	0.0	0.0	0.0	0.0	+0.50000	DR1
Tz	0.0	0.0	-2.40796	0.0	0.0	0.0	+1.73154	0.0	DR2
Rx	-8.33817	+3.635E-16	0.0	-6.766E-17	+1.55186	0.0	0.0	0.0	Dn
Ry	+3.635E-16	-8.33817	0.0	-1.55186	+6.766E-17	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	0.0	0.0	-2.40765	0.0	0.0	0.0	+1.35908	0.0	
ELEMENT-4									
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	+1.388E-04	-6.052E-21	-1.363E-08	0.0	0.0	0.0	+3.330E-05	0.0	DR2
Rx	-8.33960	+3.636E-16	0.0	+8.559E-21	-1.963E-04	0.0	0.0	0.0	Dn
Ry	-2.571E-16	+5.89699	0.0	-1.388E-04	+6.052E-21	+1.41421	0.0	0.0	
Rz	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Df,p	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
ELEMENT-5									

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Optomechanics

Ivory's Output File for the Imager (3)

```
Tx        +6.399E-17   -1.46771    0.0        0.0        0.0        0.0        0.0       -1.68804 Dt
Ty          +1.46771 -6.399E-17    0.0        0.0        0.0        0.0        0.0       -3.27470 DR1
Tz            0.0        0.0      +2.15387    0.0        0.0        0.0       -1.82189   +1.52330 DR2
Rx          +0.15292 -6.667E-18    0.0      +6.399E-17   -1.46771    0.0        0.0       -0.95916 Dn
Ry        -6.667E-18   +0.15292    0.0        +1.46771 -6.399E-17    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          0.0        0.0       -2.15416    0.0        0.0        0.0       +2.17416    0.0
ELEMENT-6

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       +2.07551   -3.04603    0.0        0.0        0.0       +2.57657    0.0      DR2
Rx            0.0       +2.00803    0.0       +2.93521    0.0        0.0        0.0        0.0      Dn
Ry          +1.41989     0.0        0.0        0.0       -2.07551   -1.41421    0.0        0.0
Rz            0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
Df,p          0.0        0.0        0.0        0.0        0.0        0.0        0.0        0.0
ELEMENT-7

Tx          +2.46761     0.0        0.0        0.0        0.0        0.0        0.0       -0.11719 Dt
Ty            0.0       +2.46761    0.0        0.0        0.0        0.0        0.0       -0.59640 DR1
Tz            0.0        0.0       -1.15387    0.0        0.0        0.0       +1.82191   +0.03875 DR2
Rx            0.0       +0.12274    0.0       +2.46761    0.0        0.0        0.0       -0.26820 Dn
Ry          -0.12274     0.0        0.0        0.0       +2.46761    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          0.0        0.0       -6.08908    0.0        0.0        0.0       +3.06332    0.0
ELEMENT-8

Tx            0.0        0.0        0.0        0.0        0.0        0.0        0.0       +0.39814 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       -0.01593    0.0        0.0        0.0        0.0        0.0       +0.01449 Dn
Ry          -0.01593     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        0.0        0.0        0.0
Df,p          0.0        0.0       -1.00000    0.0        0.0        0.0        0.0        0.0
ELEMENT-9

Tx            0.0        0.0        0.0        0.0        0.0        0.0        0.0       +0.75131 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       -0.03005    0.0        0.0        0.0        0.0        0.0     +2.474E-03 Dn
Ry          -0.03005     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        0.0        0.0        0.0
Df,p          0.0        0.0       -1.00000    0.0        0.0        0.0        0.0        0.0
ELEMENT-10

Tx          -1.00000     0.0        0.0        0.0        0.0        0.0        0.0        0.0      Dt
Ty            0.0       -1.00000    0.0        0.0        0.0        0.0        0.0        0.0      DR1
Tz            0.0        0.0       -1.00000    0.0        0.0        0.0        0.0        0.0      DR2
Rx            0.0        0.0        0.0       -1.00000    0.0        0.0        0.0        0.0      Dn
Ry            0.0        0.0        0.0        0.0       -1.00000    0.0        0.0        0.0
Rz            0.0        0.0        0.0        0.0        0.0       -1.00000    0.0        0.0
Df,p          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 '5H'.
```

AEH.

Optomechanics

*Ivory/*Excel Model of the Imager (1)

Output	from	-										
	IVORY	Optomech	Modeling	Tools								
	Version	I25B										
	Copyright	2010,	Alson	E.	Hatheway	Inc.						
This	Product	has	been	licensed	to	Alson	E.	Hatheway	Inc.	for	one	user(s).
PROJECT	NAME:	'5H'	TIME	AND	DATE:	15:28:06	7/16/2010					
PHYSICAL	PRESCRII	ECHO										

	Surf	Elem	Radius	Index	Thickness	Type	f1	f2	f3	f4
	1	obj	inf	1	inf	obj	1	0	0	0
	2	1	10.6445	1	4.4555	MIRR	0	0	0	0
	3	2	-3.434	1	1.5854	MIRR	0	0	0	0
	4	3	inf	1	2.8516	MIRR	0	0	0	0
	5	4	5.3737	1	7.3	MIRR	0	0	0	0
	6	5	inf	1	0.502	MIRR	45	0	0	0
	7	6	-2.7639	4.021147	0.1351	LENS	0	0	0	0
	8	6	-3.9269	1	2.0528	LENS	0	0	0	0
	9	7	inf	1	2.0528	MIRR	45	90	0	0
	10	8	-1.829	4.021147	0.1621	LENS	0	0	0	0
	11	8	-6.8715	1	0.4369	LENS	0	0	0	0
	12	9	inf	1.661519	0.04	WIND	0	0	0	0
	13	9	inf	1	1.195	WIND	0	0	0	0
	14	10	inf	4.021147	0.04	WIND	0	0	0	0
	15	10	inf	1	0.2922	WIND	0	0	0	0
	16	det	inf	1	0	det				

INDEXES OF REFRACT ARE RELATIVE TO THE VALUE OF 1.000292

GAUSSIAN PRESCRIPTION

	ELE	F	H1	H2	P	P/AIR	PHI	THETA	TYPE
	obj	0	0	0	0	inf	0	0	obj
	1	5.32225	0	0	0	4.4555	0	0	MIRR
	2	-1.717	0	0	0	1.5854	0	0	MIRR
	3	inf	0	0	0	2.8516	0	0	MIRR
	4	2.68685	0	0	0	7.3	0	0	MIRR
	5	inf	0	0	0	0.428564	45	0	MIRR
	6	2.841062	7.34E-02	0.104336	0.1042	2.157136	0	0	LENS
	7	inf	0	0	0	2.038523	45	90	MIRR
	8	0.805532	1.43E-02	0.053638	0.122739	0.502575	0	0	LENS
	9	inf	-1.20E-02	1.20E-02	1.59E-02	1.212011	0	0	WIND
	10	inf	-4.97E-03	4.97E-03	3.01E-02	0.297174	0	0	WIND
	det	0	0	0	0	0	0	0	det
	SYSTEM	16.67799	222.0335	16.40484	228.4329	16.70201			

OBJECTS IMAGES AND MAGNIFICATIONS

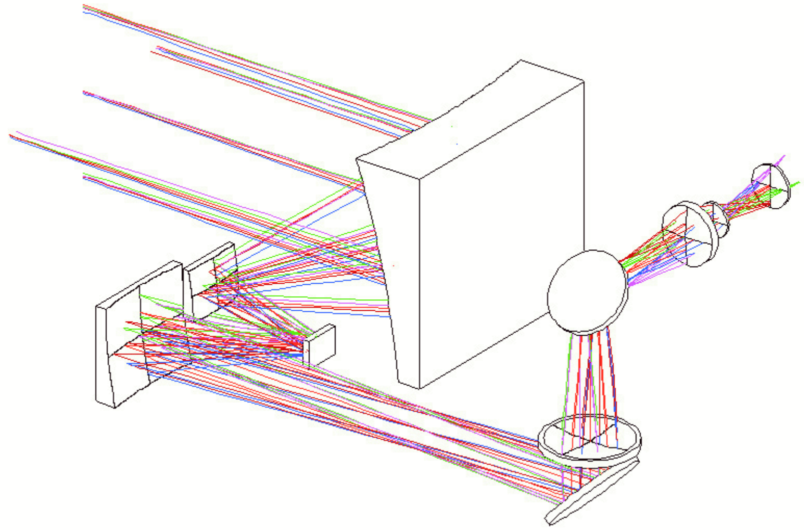
	ELE	F	S	S'	M	PHI	THETA	TYPE	e/Tzo
	obj	inf	0	0	1	0	0	obj	
	1	5.32225	inf	-5.3223	0	0	0	MIRR	+0.00D+00
	2	-1.717	-0.8668	-1.7503	2.0194	0	0	MIRR	-1.18D+00
	3	inf	-0.1649	-0.1649	1	0	0	MIRR	
	4	2.68685	2.6867	+4.25D+04	+1.58D+04	0	0	MIRR	+5.88D+03
	5	inf	+4.25D+04	+4.25D+04	1	45	0	MIRR	
	6	2.841062	+4.25D+04	-2.8413	-6.69D-05	0	0	LENS	-2.35D-05
	7	inf	-0.6841	-0.6841	1	45	90	MIRR	
	8	0.805532	1.3544	-1.9877	-1.4676	0	0	LENS	-1.82D+00
	9	inf	-1.4852	-1.4852	1	0	0	WIND	
	10	inf	-0.2732	-0.2732	1	0	0	WIND	
	det	inf	+2.40D-02	+2.40D-02	1	0	0	det	

OPTOME(CONSTRA EQUATIOI (ABSOLUT VALUES SMALLER THAN 0 ARE PRINTED AS 0.0)

REGISTRA VARIABLES

	TX	TY	TZ	RX	RY	RZ	DM/M	Df,p	LDesVar									
Tx	0	0	0	0	0	0	0	0	Dt			0	0	0	0	0	0	0
Ty	0	0	0	0	0	0	0	0	DR1			0	0	0	0	0	0	0
Tz	0	0	0	0	0	0	0	0	DR2			0	0	0	0	0	0	0
Rx	0	0	0	0	0	0	0	0	Dn			0	0	0	0	0	0	0
Ry	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0
Rz	0	0	0	0	0	1	0	0				0	0	0	0	0	0	0
Df,p	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0
SYSTEM-OBJECT												0	0	0	0	0	0	0
										1		0	0	0	0	0	0	0
Tx	1.37E-16	-3.13363	0	0	0	0	0	0	Dt	1.1	-4.33326E-06	-5.91924E-22	1.35788E-05	0	0	0	0	0
Ty	-3.13363	1.37E-16	0	0	0	0	0	0.5	DR1	1.2	5.67386E-07	-1.77798E-06	7.75049E-23	0	0	0	0	0
Tz	0	0	-9.81966	0	0	0	8.23626	0	DR2	1.3	1.4331E-06	0	0	-1.40725E-05	0	0	0	1.18033E-05
Rx	33.35596	-1.45E-15	0	1.37E-16	-3.13363	0	0	0	Dn	1.4	-8.206E-07	-2.73719E-05	1.19315E-21	0	-1.12094E-22	2.57146E-06	0	0
Ry	1.45E-15	-33.356	0	-3.13363	1.37E-16	0	0	0		1.5	1.92405E-07	2.79756E-22	-6.41784E-06	0	-6.02925E-07	2.62825E-23	0	0
Rz	0	0	0	0	0	0	0	0		1.6	-1.40635E-07	0	0	0	0	0	0	0
Df,p	0	0	-9.81966	0	0	0	8.42415	0				0	0	0	0	0	0	0
ELEMENT-1												0	0	0	0	0	0	0
										2		0	0	0	0	0	0	0
Tx	6.90E-17	-1.58187	0	0	0	0	0	0	Dt	2.1	1.8785E-06	1.2956E-22	-2.97154E-06	0	0	0	0	0
Ty	1.58187	-6.90E-17	0	0	0	0	0	0.5	DR1	2.2	1.26942E-06	2.00805E-06	-8.75517E-23	0	0	0	0	0
Tz	0	0	-12.2276	0	0	0	9.96951	0	DR2	2.3	-1.85196E-07	0	0	2.26451E-06	0	0	0	-1.84632E-06
Rx	5.43215	-2.37E-16	0	-2.04E-16	4.68539	0	0	0	Dn	2.4	-1.52734E-06	-8.29675E-06	3.61674E-22	0	3.12036E-22	-7.15619E-06	0	0
Ry	-2.37E-16	5.43215	0	-4.68539	2.04E-16	0	0	0		2.5	1.44986E-07	-3.43326E-23	7.87583E-07	0	-6.79314E-07	2.96205E-23	0	0
Rz	0	0	0	0	0	0	0	0		2.6	1.09079E-06	0	0	0	0	0	0	0
Df,p	0	0	-2.50232	0	0	0	2.39324	0				0	0	0	0	0	0	0
ELEMENT-2												0	0	0	0	0	0	0
										3		0	0	0	0	0	0	0
Tx	0	0	0	0	0	0	0	0	Dt	3.1	3.17789E-07	0	0	0	0	0	0	0
Ty	0	0	0	0	0	0	0	0	DR1	3.2	-2.2395E-06	0	0	0	0	0	0	0
Tz	0	0	-4.81592	0	0	0	3.46289	0	DR2	3.3	2.08011E-06	0	0	-1.00176E-05	0	0	0	7.2032E-06
Rx	0.51183	-2.23E-17	0	1.35E-16	-3.10352	0	0	0	Dn	3.4	-1.18147E-06	-6.0471E-07	2.63703E-23	0	-1.59852E-22	3.66671E-06	0	0
Ry	2.23E-17	-0.51183	0	-3.10352	1.35E-16	0	0	0		3.5	-1.04578E-06	-2.33417E-23	5.3526E-07	0	3.24559E-06	-1.41493E-22	0	0
Rz	0	0	0	0	0	0	0	0		3.6	-1.20858E-06	0	0	0	0	0	0	0
Df,p	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0
ELEMENT-3												0	0	0	0	0	0	0
										4		0	0	0	0	0	0	0
Tx	6.77E-17	-1.55166	0	0	0	0	0	0	Dt	4.1	1.83194E-06	1.23931E-22	-2.84255E-06	0	0	0	0	0
Ty	1.55166	-6.77E-17	0	0	0	0	0	0.5	DR1	4.2	-6.28229E-07	-9.74797E-07	4.24997E-23	0	0	0	0	0
Tz	0	0	-2.40796	0	0	0	1.73154	0	DR2	4.3	-1.72909E-07	0	0	4.16357E-07	0	0	0	-2.99398E-07
Rx	-8.33817	3.64E-16	0	-6.77E-17	1.55186	0	0	0	Dn	4.4	-1.7223E-06	1.43609E-05	-6.26057E-22	0	1.16531E-22	-2.67277E-06	0	0
Ry	3.64E-16	-8.33817	0	-1.55186	6.77E-17	0	0	0		4.5	8.13423E-08	2.95679E-23	-6.78246E-07	0	-1.26232E-07	5.50362E-24	0	0
Rz	0	0	0	0	0	0	0	0		4.6	7.13029E-07	0	0	0	0	0	0	0
Df,p	0	0	-2.40765	0	0	0	1.35908	0				0	0	0	0	0	0	0
ELEMENT-4												0	0	0	0	0	0	0
										5		0	0	0	0	0	0	0

TX SUM	TY SUM		RY SUM	RX SUM
INCHES	INCHES		mRAD	mRAD
0	0			
-2.91499E-05	7.16E-06	1	1.747805768	-0.429368118
-3.54386E-05	4.98E-06	2	2.124871199	-0.298419859
-3.60433E-05	5.51E-06	3	2.161129185	-0.33051363
-2.26572E-05	1.99E-06	4	1.358510917	-0.119409511
-6.12973E-05	1.03E-05	5	3.675342921	-0.615305428
-5.94531E-05	2.79E-06	6	3.564765291	-0.167565155
-5.61312E-05	4.27E-06	7	3.365588243	-0.256074126
-4.9701E-05	8.06E-06	8	2.980033916	-0.483172032
-4.99376E-05	8E-06	9	2.994222295	-0.479802288
-5.13975E-05	9.38E-06	10	3.081754253	-0.562499414
-8.29282E-05	1.32E-05	11	4.972312632	-0.791574408



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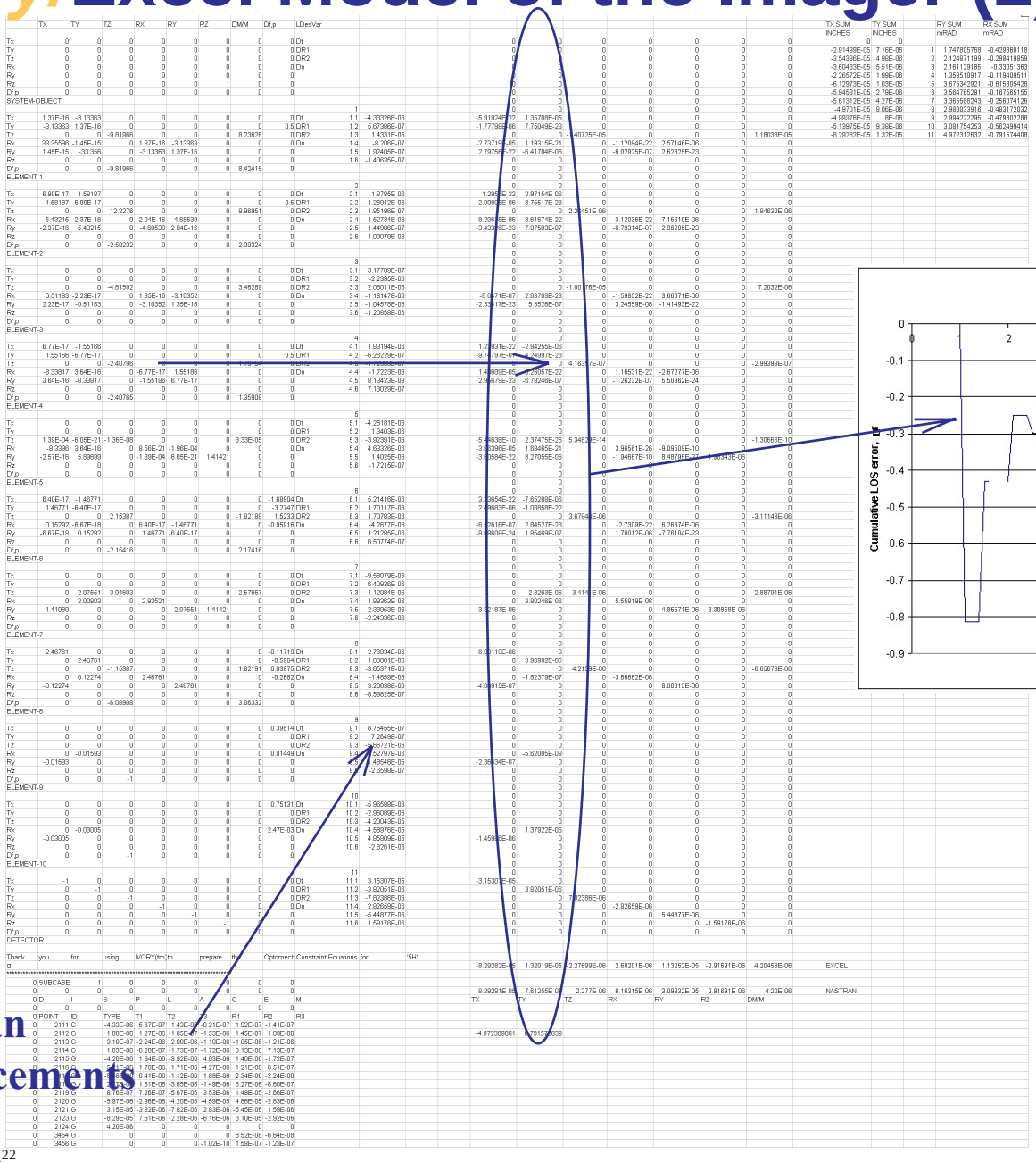
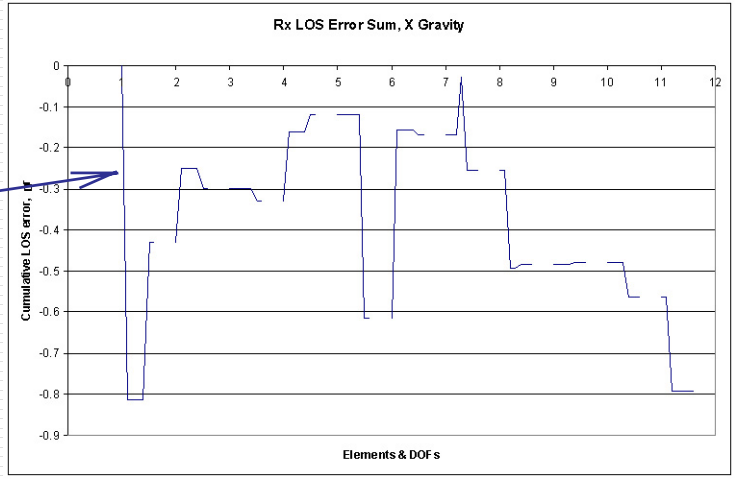
Ivory/Excel Model of the Imager (2)





Nastran displacements

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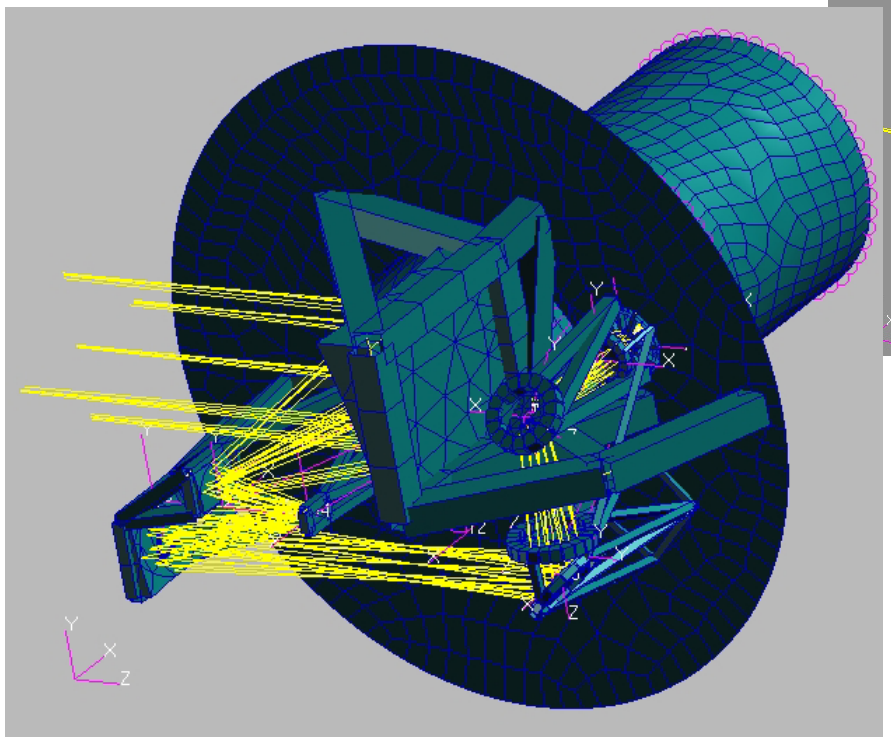
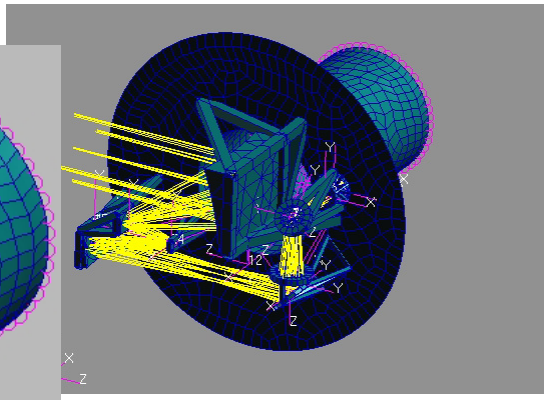
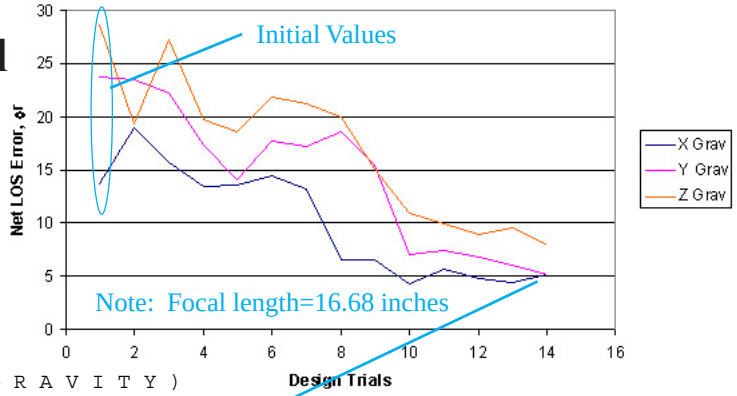
*Ivory/*Nastran Imager Stabilization Study





1st Trial Model

14th Trial Model



D I S P L A C E M E N T V E C T O R (X G R A V I T Y)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2111	G	-4.333262E-06	5.673855E-07	1.433095E-06	-8.206002E-07	1.924047E-07	-1.406347E-07
2112	G	1.878496E-06	1.269417E-06	-1.851963E-07	-1.527341E-06	1.449855E-07	1.090787E-06
2113	G	3.177888E-07	-2.239500E-06	2.080111E-06	-1.181467E-06	-1.045776E-06	-1.208584E-06
2114	G	1.831939E-06	-6.282287E-07	-1.729085E-07	-1.722303E-06	8.134225E-08	7.130288E-07
2115	G	-4.261809E-06	1.340301E-06	-3.923907E-06	4.633262E-06	1.402503E-06	-1.721496E-07
2116	G	5.214161E-06	1.701173E-06	1.707830E-06	-4.267697E-06	1.212852E-06	6.507744E-07
2117	G	-9.580793E-06	6.409356E-06	-1.120835E-06	1.893625E-06	2.339528E-06	-2.243364E-06
2118	G	2.768341E-06	1.608810E-06	-3.653708E-06	-1.485901E-06	3.266380E-06	-8.598251E-07
2119	G	8.764550E-07	7.264903E-07	-5.667206E-06	3.527969E-06	1.485459E-05	-2.659803E-07
2120	G	-5.965882E-06	-2.960889E-06	-4.200431E-05	-4.589756E-05	4.858093E-05	-2.826104E-06
2121	G	3.153071E-05	-3.820510E-06	-7.823855E-06	2.826585E-06	-5.448769E-06	1.591755E-06
2123	G	-8.292811E-05	7.612554E-06	-2.276996E-06	-6.163149E-06	3.098317E-05	-2.916905E-06
2124	G	4.204583E-06	0.0	0.0	0.0	0.0	0.0
3454	G	0.0	0.0	0.0	0.0	8.516471E-08	-6.636269E-08
3456	G	0.0	0.0	0.0	-1.020291E-10	1.580365E-07	-1.230489E-07

93975aCharts3.pmd(23

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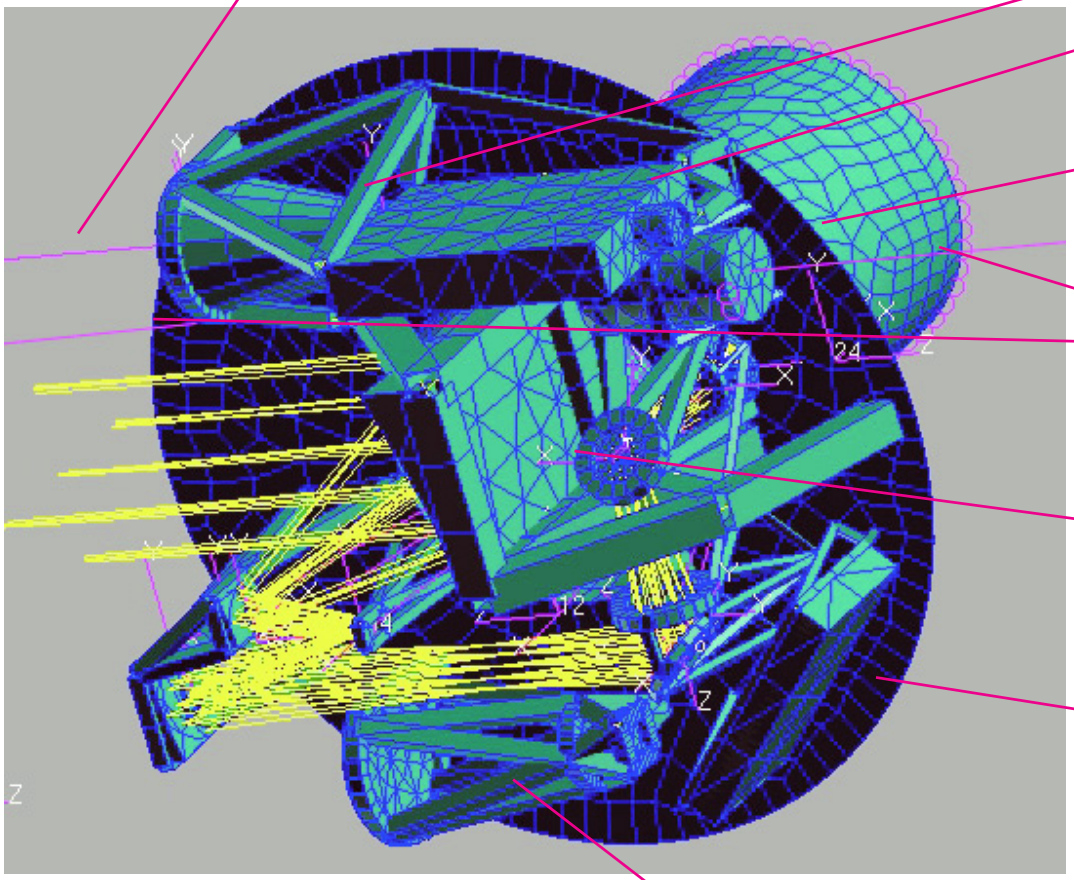
Optomechanics

*Ivory/*Nastran Complet Suite, Initial Model



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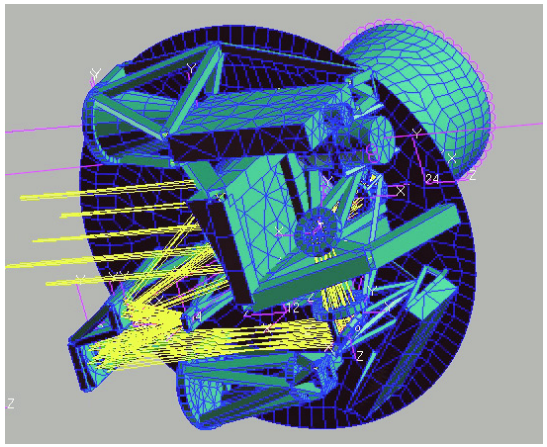
Optomechanics

*Ivory/*Nastran Suite Model Rigid Body Check



Point ID	Feature
2123, 2124	Imager
3454	El Axis Base
10286	Gyroscope
21663	Laser Xmtr

Base motions
Imager LOS motions
Target spot motions
Gyroscope motions
Image motions

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

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2123	G	-4.495383E-09	-2.804798E-06	1.535378E-06	-8.338841E-12	4.617249E-10	4.605635E-12
2124	G	1.157860E-07	0.0	0.0	-2.695207E-10	1.681897E-07	0.0
3454	G	1.000000E+00	0.0	0.0	0.0	0.0	0.0
10286	G	1.000000E+00	-5.218555E-13	2.939959E-12	9.166886E-14	1.907526E-12	-3.280729E-13
21663	G	9.978803E-01	7.512611E-08	-1.884684E-06	9.539138E-13	-1.267039E-05	0.0

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

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2123	G	2.489022E-06	2.804443E-06	-1.531967E-06	1.458557E-11	-7.180084E-11	6.401721E-12
2124	G	3.411351E-06	0.0	0.0	1.492293E-07	-1.681684E-07	0.0
3454	G	0.0	1.000000E+00	0.0	0.0	0.0	0.0
10286	G	-2.036865E-12	1.000000E+00	-2.744624E-13	-3.287505E-13	-3.137514E-13	6.276506E-13
21663	G	3.990776E-08	9.978800E-01	-2.557650E-06	1.267058E-05	-5.067208E-13	0.0

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

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2123	G	-2.348945E-06	-7.698533E-10	1.999892E-05	7.981358E-11	-1.151832E-10	-1.155364E-11
2124	G	1.876438E-03	0.0	0.0	-1.408310E-07	4.616426E-11	0.0
3454	G	0.0	0.0	1.000000E+00	0.0	0.0	0.0
10286	G	1.638512E-12	1.120773E-13	1.000000E+00	3.460578E-14	1.708762E-12	-4.397567E-14
21663	G	-2.340301E-08	1.000009E-08	-7.092953E-06	1.269761E-13	2.971550E-13	0.0

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

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2123	G	1.667934E+01	-7.940791E-06	-2.036467E-05	9.572198E-11	6.800884E-06	2.518961E-06
2124	G	-2.309178E-03	0.0	0.0	1.000010E+00	4.761695E-07	0.0
3454	G	0.0	0.0	0.0	1.000000E+00	0.0	0.0
10286	G	9.343575E-12	-4.202360E+00	2.381380E+00	1.000000E+00	5.768823E-12	-1.443130E-12
21663	G	-1.327908E-07	7.877207E+04	-3.290176E-05	1.000208E+00	1.686085E-12	0.0

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

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2123	G	2.328079E-02	-1.667689E+01	2.076247E-04	2.350952E-06	2.803869E-06	7.069737E-04
2124	G	1.907376E-02	0.0	0.0	1.395799E-03	1.000030E+00	0.0
3454	G	0.0	0.0	0.0	0.0	1.000000E+00	0.0
10286	G	4.202360E+00	8.033660E-14	8.866570E+00	9.443453E-13	1.000000E+00	-1.798773E-12
21663	G	-7.877207E+04	8.014755E-08	-6.198883E-05	1.017673E-12	1.000193E+00	0.0

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

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2123	G	-2.529502E-05	-1.178215E-01	1.429845E-05	1.248827E-05	2.497396E-10	9.992900E-01
2124	G	-3.477024E-05	0.0	0.0	-1.516563E-06	7.065168E-03	0.0
3454	G	0.0	0.0	0.0	0.0	0.0	1.000000E+00
10286	G	-2.381380E+00	-8.866570E+00	-3.332883E-12	2.541370E-12	-1.770245E-12	1.000000E+00
21663	G	-3.613265E+00	-8.621584E+00	2.843650E-05	-1.094726E-04	4.587871E-05	0.0

Note: Three and four place accuracy in the model's geometry and the largest dimension is 78,800.

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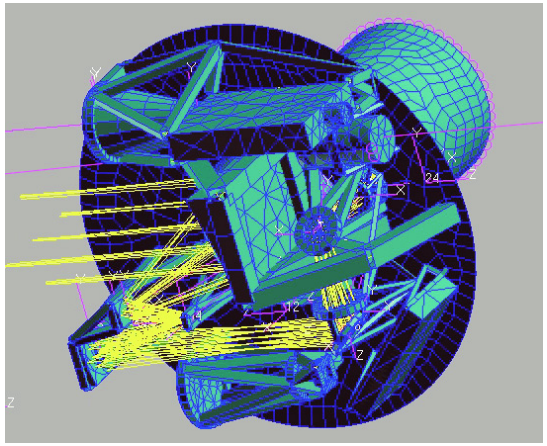
*Ivory/*Nastran Suite Initial Model Static Stability



D I S P L A C E M E N T V E C T O R (X G R A V I T Y)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2124	G	4.056844E-05	0.0	0.0	5.851008E-06	-1.103894E-06	0.0
3454	G	0.0	0.0	0.0	0.0	1.287777E-07	-1.336708E-07
10286	G	1.885340E-05	7.280877E-06	1.876988E-06	1.542009E-06	4.394471E-07	-5.254006E-06
21663	G	-5.920674E-01	-8.027378E-02	-3.915012E+00	-1.019276E-06	7.517657E-06	0.0
21665	G	0.0	0.0	0.0	-2.561285E-06	7.078210E-06	0.0
21666	G	0.0	0.0	0.0	4.308999E-06	-1.543341E-06	0.0
21667	G	0.0	0.0	0.0	6.870284E-06	-8.621551E-06	0.0

D I S P L A C E M E N T V E C T O R (Y G R A V I T Y)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2124	G	-6.381926E-05	0.0	0.0	-3.775492E-06	3.562594E-06	0.0
3454	G	0.0	0.0	0.0	0.0	-6.629356E-10	-1.057327E-06
10286	G	1.194491E-05	3.208232E-05	1.210022E-06	-1.602568E-06	1.213423E-06	-8.743267E-06
21663	G	-3.727667E-02	-7.611592E-02	-3.129728E+01	-9.664819E-07	4.733131E-07	0.0
21665	G	0.0	0.0	0.0	6.360858E-07	-7.401100E-07	0.0
21666	G	0.0	0.0	0.0	-2.172924E-06	2.349171E-06	0.0
21667	G	0.0	0.0	0.0	-2.809010E-06	3.089281E-06	0.0

D I S P L A C E M E N T V E C T O R (Z G R A V I T Y)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
2124	G	-2.886976E-05	0.0	0.0	-3.036141E-06	6.944848E-06	0.0
3454	G	0.0	0.0	0.0	0.0	1.057485E-06	-4.698557E-10
10286	G	2.854246E-05	4.238918E-06	3.694515E-05	-3.561562E-07	1.500905E-05	-4.810248E-06
21663	G	-4.362355E-01	6.051603E-03	-1.010807E+01	7.684023E-08	5.539012E-06	0.0
21665	G	0.0	0.0	0.0	4.329965E-07	-9.470039E-06	0.0
21666	G	0.0	0.0	0.0	-2.679984E-06	-8.064203E-06	0.0
21667	G	0.0	0.0	0.0	-3.112981E-06	1.405836E-06	0.0

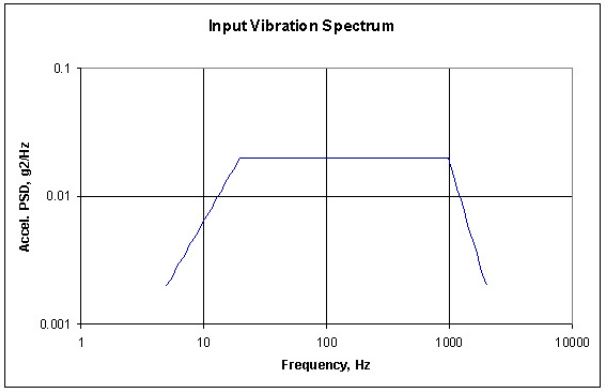
Point ID	Feature
(2123) 2124	Imager
3454	El Axis
10286	Gyroscope
21663	Laser Xmtr
21665	Laser-Gyro
21666	Imager-Gyro
21667	Imager-Laser

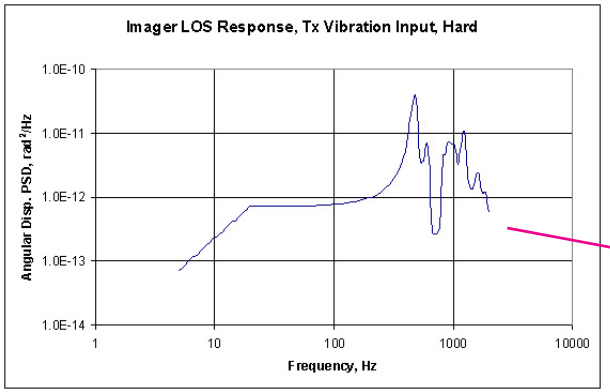
Gravity loading vector:	Tx	Ty	Tz
Net <u>pointing errors</u> (microradians):			
Imager (2124)	5.9	5.2	7.5
Laser (21663)	7.6	0.5	5.5
Gyroscope (10286)	1.6	2.0	15.0
Net <u>bore sight errors</u> (microradians):			
Laser minus Gyro (21665)	7.1	0.7	9.5
Imager minus Gyro (21666)	4.6	3.2	8.5
Imager minus Laser (21667)	11.0	4.2	3.4

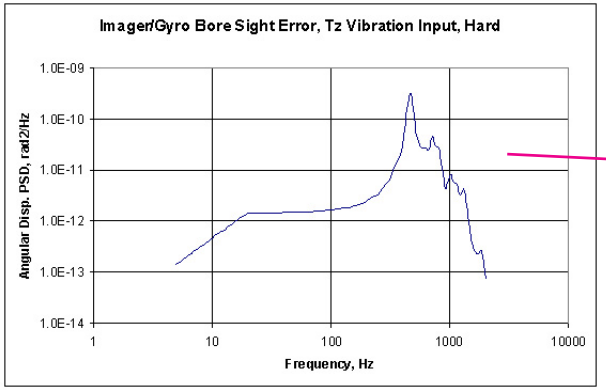
AEH.

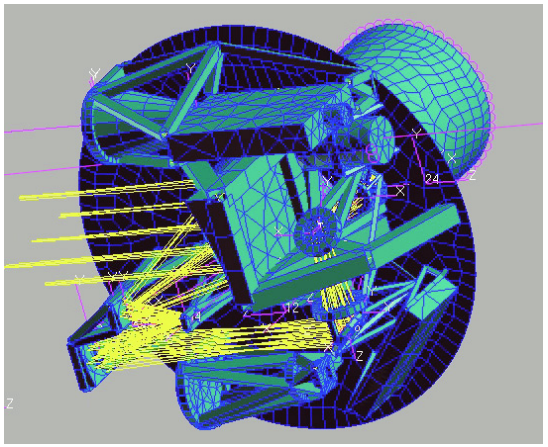
Optomechanics

*Ivory/*Nastran Model Dynamics, Hard Mounted







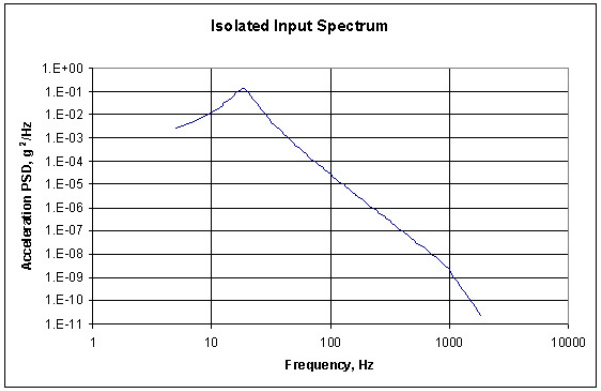


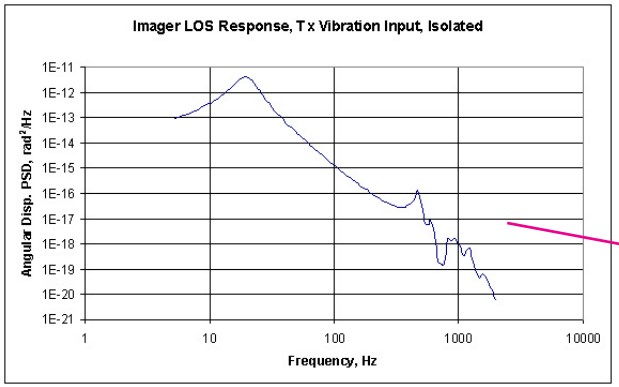
Vibration loading vector:	Tx	Ty	Tz
Net <u>pointing errors</u> (rms microradians):			
Imager (2124)	88.6	113.	130.
Laser (21663)	98.7	126.	136.
Gyroscope (10286)	111.	92.2	264.
Net <u>bore sight error</u> (rms microradians):			
Laser minus gyro (21665)	172.	102.	156.
Imager minus gyro (21666)	132.	130.	188.
Imager minus laser (21667)	141.	175.	121.

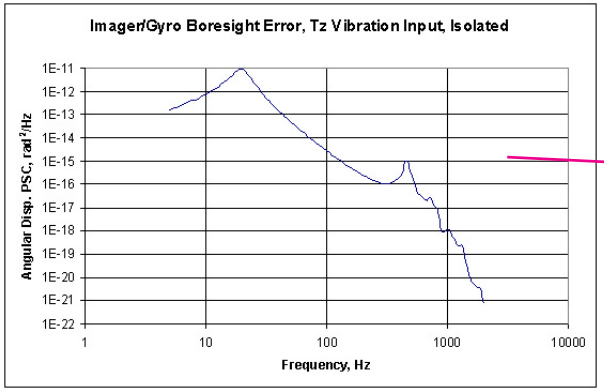
AEH.

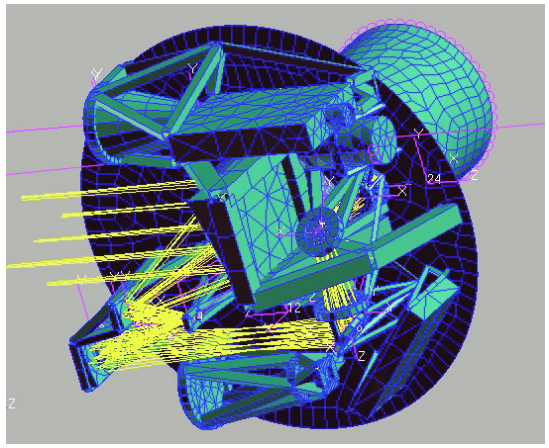
Optomechanics

*Ivory/*Nastran Model Dynamics, Isolated









Vibration loading vector:	Tx	Ty	Tz
Net <u>pointing errors</u> (rms microradians):			
Imager (2124)	6.4	5.5	8.9
Laser (21663)	7.5	0.9	6.8
Gyroscope (10286)	1.7	2.2	16.9
Net <u>bore sight error</u> (rms microradians):			
Laser minus gyro (21665)	7.7	1.4	10.1
Imager minus gyro (21666)	4.9	3.4	9.1
Imager minus laser (21667)	11.5	4.8	3.7

AEH.

Optomechanics

Accomplishments

1. We have *linked both the imager and the laser to the gyroscope* in an optomechanical model.

2. We have *debugged and validated the model* in both Nastran and Excel.

3. We have *stabilized the imager* to less than 10 microradians in static gravity loads.

4. We have *computed the dynamic stability* (rms microradians) of the imager, laser and gyro mounted in the initial structural configuration when excited by the required operating random vibration environment.

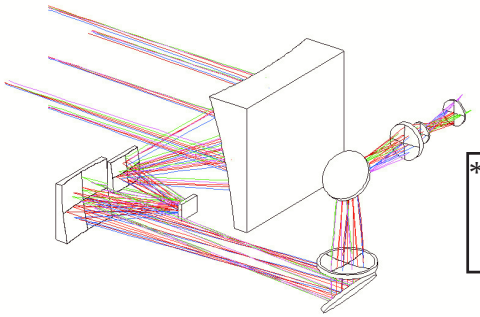
5. We have also *computed the dynamic bore sight errors* relative to the gyro under the same conditions.

AEH.

Optomechanics

The Optomechanical Constraint Equations Provide and Early Start...

Optics:



Initial Design → Initial Tolerances → Optical Element Specs. → Vendor Contacts → Final Design → Vendor Contracts →

*.igs, *.stp and Prescription Files

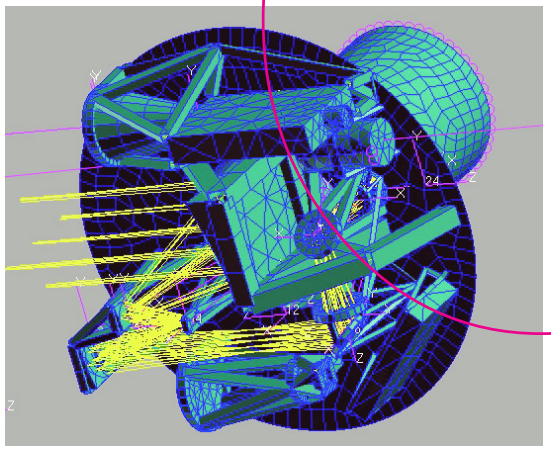
Revised Tolerances ← Test Plating

Optical Design Influence Coefficients

~4 months

~1 month

Mechanics: *Ivory's* Influence Coefficients



Geometric Packaging (CAD)
Thermal Analysis
Stress Analysis
Mass and Power Budgets
Error Budgets
Optomechanical Engineering

Departmental Budgeting
Interface Definitions
System and Subsystem Specifications
Major Subcontracts

AEH.
Optomechanics